SRGS
Slip Resistance Group Spain

PROVISIONAL VERSION

"Slips, Trips & Falls"
Conference Madrid 2020

February 13th-14th, 2020

"A vision for the future"

PROCEEDINGS

Slip Resistance Group Spain

"Slips, Trips & Falls"

Conference Madrid 2020

February 13th-14th, 2020

"A vision for the future"

PROCEEDINGS

Proceedings “SLIPS, TRIPS & FALLS. Conference Madrid 2020”
Madrid, 2020.

Editor Fundación Gómez Pardo

ISBN 978-84-09-18516-0

Printed by DiScript preimpresión, S.L.

PART I. PRESENTATION

CONTENTS

INTRODUCTION

The *"Slips, Trips and Falls" Technical Committee* of the *International Ergonomics Association* (IEA STF TC) invited our association *Slip Resistance Group of Spain* (SRGS) in 2018 to organize the International Conference "Slips, Trips and Falls 2020" in Madrid.

The IEA STF TC has held conferences in Europe, America and Asia. Each past conference has been independently managed by the host body. The host organization has been able to choose its own theme and focus. This way, they can address important local problems. At the same time, there is an expectation that the diverse membership of the STF fraternity can respond to the call for documents with topics that are relevant to their specific interests.

The conference is open to scientific opinions about the study of the problem of slips, trips and falls in order to open a debate on this area of knowledge. This Conference will be a turning point at national and international level in the study, analysis, research, training and information for each of the topics addressed.

Slip Resistance Group of Spain. SRGS

The SRGS is the Spanish Association for the fall prevention in pedestrian transit. Similar to its counterpart the UK Slip Resistance Group (UKSRG), it is the leading independent authority for slip resistance in Spain. Our common goals include a greater understanding of causes and solutions related to slips, trips and falls.

The strategic focus is to promote actions for the prevention of falls, among which are the realization of courses and workshops, provision of advice and collaboration in the improvement of test methods, and the dissemination addressed to the agents involved, which results in the safety of our environments and the well-being of our citizens.

Slips, Trips and Falls Technical Committee. International Ergonomics Association

The International Ergonomics Association (IEA) is the global federation of national ergonomics and human factors societies. Its mission is to elaborate and advance ergonomics science and practice; and to expand its scope of application and contribution to society and to thereby improve the quality of life, working closely with its constituent societies and related international organizations.

the Slips, Trips and Falls Technical Committee (STF TC) was formed as a platform to discuss and exchange up-to-date information seeking to minimise if not prevent the occurrence of falls, either when walking on level surfaces, using stairways, or from heights. There is an extremely wide focus, where many topics that are of mutual interest to other IEA TCs.

The STF TC participates in major international conferences by organising symposia. It also delights in holding annual international conferences in countries where this will provide lasting benefits to the host organisation and the national participants, both from developing a better appreciation as to what is being done internationally, but also by sharing to enable international visitors to profit from a deeper understanding of local experience and practices.

Miguel Sánchez Fernández
President SRGS

Richard Bowman
Honorary President SRGS. Chair IEA STF TC

Organisers

Collaborators

Institutional Support

Sponsors

Scientific Committee

Chairs: *Richard Bowman. Miguel Sánchez Fernández*.

The members of the Scientific Committee belong to different Institutions, Universities and Countries, in alphabetical order:

Richard Bowman. Intertile Research, Australia
Daniel del Barrio Saiz. Laboratorio Oficial para ensayo de materiales de construcción - LOEMCO
Marcel Engels. Forschungsinstitut für Anorganische Werkstoffe-Glas-Keramik-GmbH. Germany
Elena Frías López. Eduardo Torroja Institute for Construction Sciences – CSIC. Spain.
Simon Hall. Lucideon Limited. United Kingdom
Jesús Hernández Hueros. Fundación Mapfre. Spain
Juan Manuel Iriarte Gil. WESSEX. Laboratorio de resbaladicidad SL. Spain
Raquel García Campillo. A NIVEL estudio de arquitectura. Spain
Yue (Sophia) Li. The Kite Research Institute, Toronto Rehabilitation Institute, University Health Network, Toronto, Canada
Domingo A. Martín Sánchez. ETSI de Minas y Energía. Universidad Politécnica de Madrid. Spain
Juan Queipo de Llano Moya. Eduardo Torroja Institute for Construction Sciences – CSIC. Spain
Miguel Sánchez Fernández. ETSI de Minas y Energía. Universidad Politécnica de Madrid. Spain
Isabella Tiziana Steffan. Studio Steffan- Design and Research. Italy
Carl Strautins. Safe Environments Pty Limited. Australia
Stephen C. Thorpe. Olver & Rawden, Consulting Forensic Engineers. United Kingdom

Venue

The "Slips, trips & Falls" Conference Madrid 2020 is held at the *Eduardo Torroja Institute for Construction Sciences*.

The *Eduardo Torroja Institute for Construction Sciences* (IETcc) of the *Spanish Research Council* (CSIC) engages in a scientific technical research and assistance, as well as knowledge transfer in the area of construction and its materials.

Founded by the internationally recognised engineer D. Eduardo Torroja Miret with the slogan “Technicae Plures Opera Unica”, the institute maintains a multidisciplinary spirit to face the development of scientific works through different ways of study.

Eduardo Torroja Institute for Construction Sciences (IETcc-CSIC).
Calle de Serrano Galvache, 4, 28033 Madrid. SPAIN

PROGRAMME

February 13th, Thursday

8:30 Registration

9:15 Opening Ceremony

Ángel Castillo Talavera. *Director. Instituto de Ciencias de la Construcción Eduardo Torroja. CSIC*
Luis Vega Catalán. *Subdirector. Dirección General de Arquitectura. Ministerio de Transportes, Mobilidad y Agenda Urbana*
Javier Pinilla García. *Director. Instituto Nacional de Seguridad y Salud en el Trabajo*
Jesús Ángel Celada Pérez. *Director general, Políticas de Apoyo a la Discapacidad. Director, Real Patronato sobre Discapacidad*
José Luis Parra y Alfaro. *Director. Escuela Técnica Superior de Ingenieros de Minas y Energía. Universidad Politécnica de Madrid*
Richard Bowman. *Chair. Slip, Trips and Falls Technical Committee. International Ergonomics Association*
Miguel Sánchez Fernández. *President. Slips Resistance Group of Spain. SRGS*

10:15 Conference Introduction

SLIPS, TRIPS & FALLS. A VISION FOR THE FUTURE
Miguel Sánchez, Juan Manuel Iriarte. *Slips Resistance Group of Spain. SRGS*

10:30 Keynote Lectures

10:30 **USE OF 'MAINTENANCE' VALUES TO IMPROVE SLIP RESISTANCE ARCHITECTURAL SPECIFICATIONS, MAXIMISE PRODUCTIVE LIFE CYCLES AND FURTHER ENABLE THE DEVELOPMENT OF BUILDING CODES**
Richard Bowman

11:00 **FOOTWEAR FOR THE PREVENTION OF HUMAN SLIPS: FROM FRICTION MECHANICS TO ERGONOMIC SOLUTIONS**
Kurt E. Beschorner, Sarah L. Hemler, Seyed Reza M. Moghaddam, Arian Iraqi, Mark Redfern

11:30 Coffee Break

12:00 Technical Sessions (I)

Safety Standards, Regulations and Design Criteria.
The role of Architectural Design

12:00 **PLAN EILA: SPANISH CONTRAST INTERLABORATORIES ESSAYS**
Victoria A. Viedma Peláez, Fernando Meseguer Peña, Emilio Meseguer Peña, Elvira Salazar

12:10 **REQUISITOS EXISTENTES Y EN DESARROLLO DE PAVIMENTOS EN LOS ESTADOS UNIDOS RELACIONADOS CON LA TRACCIÓN Y LAS ZONAS DE USO**
Grant Davidson, Eric Astrachan

12:20 **ERGONOMICS AND DESIGN FOR ALL IN THE BUILT ENVIRONMENT**
Isabella Tiziana Steffan, Carol Thomas

12:30 **THE WORK OF THE UK SLIP RESISTANCE GROUP**
Stephen C. Thorpe, Simon Hall

12:40 **FUNCTIONAL DIVERSITY AND DESIGN INDICATORS FOR THE IMPROVEMENT OF ACCESSIBILITY ON THE FLOOR OF URBAN PEATONAL ROUTES**
Delfín Jiménez, Jesús Hernández-Galán, José L. Borau

12:50 Lunch

14:30 Technical Sessions (II)

Measurement Principles and Technology

14:30 **LOOKING FOR A COMPREHENSIVE SCALE FOR SLIP RESISTANCE**
Gonzalo Silva, Adoración Muñoz, Rebeca Domínguez, Ana Torró, Cristina Llobell, Gloria Lillo

14:40 **THE IMPORTANCE OF SURFACE CHARACTERIZATION FOR SLIP RESISTANCE: AN OVERVIEW**
Marcel Engels

14:50 **HYDRODYNAMIC LUBRICATION AND THE MEASUREMENT OF PEDESTRIAN SLIP RESISTANCE**
Malcolm Bailey

15:00 **SLIPPERINESS: CONTRIBUTION OF TESTING MATERIALS LABORATORIES**
Joaquim Valente de Almeida

15:10 **FOOTWAY EVALUATION**
Tim Massart, Luc Goubert

15:20 **IDENTIFICATION OF APPROPRIATE TRIBOMETER VALIDATION SURFACES**
Russell J. Kendzior

15:30 **PENDULUM FRICTION TEST: IMPROVING THE METHOD IN DRY CONDITIONS**
Juan Queipo de Llano Moya, Elena Frías López

15:40 **PENDULUM CALIBRATION, METROLOGICAL TRACEABILITY AND REFERENCE MATERIAL**
Carl Strautins

15:50 **DETERMINATION OF THE SLIP RESISTANCE OF FLOORINGS FOR BAREFOOT AREAS**
Christoph Wetzel

16:00 Technical Sessions (III)

Ergonomics, rehabilitation and assistance products.
Research & development of innovative products. Footwear

16:00 **THE EFFECT OF GRAB BAR ORIENTATION AND USE STRATEGY ON FALL. PREVENTION DURING CHALLENGING BATHING TASKS**
Iris C. Levine, Konika Nirmalanathan, Rebecca M. Greene, Roger E. Montgomery, Alison C. Novak

16:10 **APPLICABILITY OF IOT TECHNOLOGIES AS A DIGITAL TOOL FOR THE EVALUATION OF THE USE OF SAFETY FOOTWEAR**
Alberto Villarino, Alberto Benito, Javier Caridad, Jose Ignacio Villarino, Miguel Ángel Casanova, Alejandro Alañon

16:20 **ANALYSIS OF TEST METHODS TO DETERMINE FOOTWEAR SLIP RESISTANCE ON MELTING AND COLD ICE SURFACES**
Chantal Gauvin, Yue (Sophia) Li, Atena Roshan Fekr, Tilak Dutta

16:30 **DOES SLIP RESISTANT WINTER FOOTWEAR REDUCE SLIPS AMONG OUTDOOR WORKERS ON SNOW AND ICE?**
Y. Li, K. Morrone, Z.S. Bagheri, N. Patel, I. Levine

16:40 **INFLUENCE OF INDIVIDUAL GAIT AND SHOE DESIGN FACTORS ON TREAD WEAR**
Sarah L. Hemler, Kurt E. Beschorner

16:50 Closing of the first day

February 14th, Friday

9:00 Technical Sessions (IV)

Analysing accidents and determining fall causes. Prevention measures. Risk management
Human & Behavioural Factors. Ageing.

9:00 **RISK ON ROOF WORKS: PRESERVE LIFES IS THE KEY**
Fernando Sanz Albert, Elena Limón García

9:10 **RISK OF FALLS OF OLDER PEOPLE DURING HOSPITALIZATION**
Izabela Witczak, Anna Kołcz, Joanna Rosińczuk, Piotr Karniej, Piotr Pobrotyn, Łukasz Rypicz

9:20 **THE RISK OF A WOKER'S FALL AND INJURY AT WORK IN THE CONTEXT OF EMPLOYER'S RESPONSABILITY AND OPERATING COSTS IN HEALTH CARE INSTITUTION**
Piotr Karniej, Izabela Witczak, Anna Kołcz, Joanna Rosińczuk, Łukasz Rypicz

9:30 **SAFE AND ACCESSIBLE SPACES**
Raquel García Campillo

9:40 **ACCIDENTABILITY STUDIES AND FALL PREVENTION ACTIONS IN ELDERLY PERSONS. MAPFRE FOUNDATION**
Jesús Hernández Hueros

9:50 Keynote Lectures

9:50 **PATIENT CHARACTERISTICS AND IMMEDIATE AND 6-MONTH OUTCOMES BY CAUSES AMONG OLDER ADULTS PRESENTING TO SPANISH EMERGENCY DEPARTMENTS AFTER A FALL**
Berenice N. Brizzi, Montserral Lázaro del Nogal, Sira Aguiló, Òscar Miró, Elena Fuentes, Javier Jacob, Adriana Gil, Pere Llorens, Raquel Cenjor, Pablo Herrero, Cristina Fernández, Francisco Javier Martín Sánchez

10:20 **QUALITY OF USER CENTERED DESING AND REENGINEERING IN URBANISM BASED IN BIOMECHANICS OF HUMAN MOVEMENT**
Kostas Gianikellis

10:50 Technical Sessions (V)
Ergonomics. Biomechanics.
Human & Behavioural Factors. Ageing.

10:50 **IT IS TIME FOR US TO BE THE FIRST**
Fernando Garcia-Monzon, Alfonso Oltra Pastor

11:00 **ASSESSMENT AND TRAINING OF FALL-RESISTING SKILLS FOR OCCUPATIONAL HEALTH CARE**
Matthias König , Gaspar Epro, Julian Werth, Christoph Wetzel, Wolfgang Potthast, Kiros Karamanidis

11:10 **ELECTROMECHANICAL TRAINING SYSTEM DEVELOPMENT FOR THE PREVENTION OF FALLS AND THE IMPROVE OF POSTURAL STABILITY**
Kostas Gianikellis, Rafael Gutierrez-Horrillo, Miguel Rodal

11:20 **STABILOMETRY APPLIED TO FALL PREVENTION**
Kostas Gianikellis , Miguel Rodal , Rafael Gutierrez-Horrillo

11:30 Coffee Break

12:00 Workshop Introduction

12:00 **THE FALLS PROBLEM AS GENERATOR OF REAL SOLUTIONS BY AGENTS INVOLVED TO PRESERVE THE HEALTH AND SAFETY FOR ALL: AN NATIONAL AND INTERNATIONAL OVERVIEW**
Juan Manuel Iriarte. *Laboratorio de resbaladicidad*

12:10 Workshop (I):
A case study in Spain. Pools

12:10 **THE RISK OF SLIPPING WITHIN THE FRAMEWORK OF THE SUSTAINABLE DEVELOPMENT GOALS**
Domingo A. Martín Sánchez, Ana García Laso. *Universidad Politécnica de Madrid*

12:20 **NEW SPAINSH STANDARDS: UNE 41901:2017 AND UNE 41902:2017**
Elena Frías López, Juan Queipo de Llano Moya. *Eduardo Torroja Institute for Construction Sciences*

12:30 **ACCESSIBILITY AND SLIPPERINESS. ACCREDITED INSPECTION BODIES**
Daniel del Barrio. *LOEMCO. Laboratorio de ensayos*

12:40 **LABORATORY SLIP RESISTANCE TESTS: METHODS AND PROBLEMS**
David Rubio. *Laboratorio de Resbaladicidad*

12:50 **SLIP RESISTANCE REQUIREMENTS DURING PRODUCT LIFE: ANNUAL MONITORING**
Juan Iriarte. *Laboratorio de Resbaladicidad*

13:00 **THE SLIP RESISTANCE CONTROL IN NAVARRA REGION**
Teresa Ferrer Gimeno. *Instituto de Salud Pública y Laboral de Navarra. Gobierno de Navarra*

13:30 **THE NEED FOR THE IMPLEMENTATION OF CONTROLS IN POOL FLOORS**
Miguel Sánchez, Raquel García. *Slips Resistance Group of Spain. SRGS*

13:40 **SOFTWARE FOR SLIP RESISTANCE CONTROL IN REGIONAL GOVERNMENTS**
Ruben Navarro. *NOWTIC. Consultoría tecnológica*

13:50 **TEMPORARY SOLUTIONS TO IMPROVE SLIP RESISTANCE CONDITIONS**
Steven Philips. *BONASYSTEMS, UK*
Pablo Millán. *PEQUINSA, Preparados Químicos de Navarra. España*

14:00 Workshop (II)
Products and solutions

14:30 Lunch

16:00 Summary and Concluding Remarks
Richard Bowman. *Chair. Slip, Trips and Falls Technical Committee. International Ergonomics Association*
Miguel Sánchez Fernández. *President. Slips Resistance Group of Spain. SRGS*

16:30 Conference Closing

PART II. AUTHORS AND PAPERS

KEY LECTURES

USE OF 'MAINTENANCE' VALUES TO IMPROVE SLIP RESISTANCE ARCHITECTURAL SPECIFICATIONS, MAXIMISE PRODUCTIVE LIFE CYCLES AND FURTHER ENABLE THE DEVELOPMENT OF BUILDING CODES

Richard Bowman

Intertile Research, Melbourne, Australia

slipbusters@gmail.com

ABSTRACT

Socially responsible methods of sustainable slip resistance specification can be defined as a holistic process: the installed floor must be readily cleanable using bespoke procedures that thus ensure that the floor will be safe at the end of an economically reasonable life cycle. The proposed procedure is based on wet pendulum slip resistance assessment of hard surfaces that have been exposed to an accelerated wear conditioning (AWC) procedure, that defines a characteristic maintenance (M) value. This value and the ex-factory result are then considered in the light of the Australian HB 198 recommendations (and associated criteria for minimum maintenance values that have yet to be ratified). When specified, the M value (and the characteristic conditioning curve) can be used by facility managers to assess the results of slip resistance audits and to determine if any action should be taken. This initiative, partly based on McDonalds Australia's seemingly successful implementation of a similar scheme 15 years ago, draws a new line in the sand. This proposal, the first that seeks to conform with the safety requirements of EU regulation No 305/2011, is hampered by the limited data on the slip resistance changes that occur in different settings. While such a system should facilitate quantified deemed-to-satisfy building code solutions, changes might first be made in commercial and public areas. When determining 'safety' in residential settings, Universal Design principles might be adopted, seeking to recognise the innate differences between individuals and their life cycle needs.

Keywords: slip resistance, accelerated conditioning, safety, specifications

Topic: National and International Safety Standards

AN ENIGMATIC INTRODUCTION

This keynote address is more informal than most scientific papers. It documents several issues so future generations might have safer, more sustainable flooring surfaces that are easier to maintain. The European Union was right to require flooring surfaces be safe throughout economically reasonable life cycles. Spain is to be congratulated on introducing lifetime slip resistance requirements for floors, but improvements can be made.

Some elements of the international slip resistance fraternity have been in a state of war for years, seeking to protect and promote test methods that they have invested in, where other sectors have supported positions that favour perceived interests. Such conflict has led to the inclusion of many mistruths and unsubstantiated statements in the technical literature and even standards. If commissioned research falls short of appropriately rigorous standards, how can governments develop relevant policy, particularly if the regulatory framework consists of a complex mixture of various governmental bodies, research and construction section interests? They need to ensure that when someone is contracted to undertake the work, they are committed to doing so, rather than seeking to maintain a self-serving status quo. The team must accept the ambitions of the project, be intent on clearing the roadblocks, and keen to promote interim solutions that will progressively enable sensible policies to be enacted. This paper seeks to draw together many strands of work to provide an indication of how Building Codes might be further improved, while also providing an understanding of some of the contentious issues.

The struggle to realise a past vision for a safer future

Safe pedestrian surfaces are a fundamental societal need. Regulation (EU) No 305/2011 for construction products (CPR) essentially requires that “Floors must be safe (slip resistant) at the end of an economically reasonable working life”. This regulation repealed the similarly intentioned 1989 Council Directive 89/106/EEC.

EU M/119 Mandate (1994) to CEN, concerning the execution of standardisation work for harmonised standards, called for a single and unique slip resistance test method that could be applicable to all sorts of flooring product surfaces. CEN/TC 339, Slip resistance of pedestrian surfaces - Methods of evaluation, has published CEN TS 16165 and is about to release prEN 16165 for public comment. This contains three well established test methods, as well as a new test that is used to assess the slip resistance of existing floors.

In Australia and elsewhere, slip resistance specifications for various locations are typically based on the use of ex-factory slip resistance data, where the level of traction required is more likely to be based on theoretical safety requirements than rigorous analysis. It is not known which requirements contain a safety factor, and whether the requirement has been considerably inflated by well intending safety interests. Some requirements are deliberately inflated in order to allow a loss of slip resistance due to wear. However, some further allowance may need to be made for temporary soiling. If a floor theoretically requires a minimum coefficient of friction (COF) of 0.35 in order to be safe when wet, should a product initially have a COF of 0.50, or higher, to allow for the probable slip resistance loss in service. If so, this will obviously discriminate against suitable products, for example a vinyl with a wear coating where the COF should change little during its service life, assuming it is kept clean.

Inflating COF requirements to allow for slip resistance loss has led to the installation of many rough surfaced floors that have then had cleaning problems. Such products may not even have had the desired initial appearance. Aggressive maintenance regimes may be required to clean rough surfaces, and at greater cost than a preferred smoother flooring surface. Maintenance regimes may prematurely reduce the available slip resistance, but such information may not be available from the relevant suppliers. Building owners may have ongoing problems with floors of marginally acceptable appearance. The current system is not working satisfactorily.

When the judiciary has problems in interpreting slip resistance results for existing surfaces, we have a problem. In Australia, we rejected the concept of notional interpretations of the risk of slip, regardless of the environmental context or usage scenario. Although everything should be considered in context, there is a fundamental lack of relevant data. We have yet to benchmark the available traction in the existing environment; its typical variability; the traction demands of pedestrians; and how they vary as a function of footwear, activity, and intrinsic personal factors.

However, Spain is arguably the best placed to fulfil the EU ambition given that the Spanish Technical Building Code (CTE) already has a lifetime slip resistance requirement its current standards; its recent research; the several initiatives that are being taken to improve the performance of slip resistance testing laboratories; and thus the intelligence to progressively modify the existing building code.

The wet barefoot swimming pools problem

At the UKSRG Slips Trips and Falls Conference in London in 2016, Iriarte revealed[1] that since 2011 all wet barefoot areas in swimming pools in Navarra have had to pass a wet pendulum test before they can be opened for use. About 60% of new barefoot areas were not permitted to open: about half of these floors were treated with anti-slip products and the remainder were replaced. There were no slipping problems until after March 2014 when the CTE permitted the use of class B DIN 51097 tiles without any wet pendulum testing. The problem was compounded legally when DIN 51097:2016 was published. Products that were installed as class B or C now test as class A.

At Qualicer 2018, Bowman drew attention to inconsistent wet barefoot testing results related to proposed calibration boards, where a relevant German report[2] appears to have been suppressed (removed from the internet) without being distributed to the CEN/TC 339 members. DIN 51097:2019 has now been published. Since the limit values of the original DIN 51097 A, B and C boards were determined in the 1970s, was there sufficient stock of original calibration boards, in pristine condition, to ensure that future results would be equivalent to those obtained in 1992? If new calibration boards have been selected based on comparisons with worn calibration boards, the new standard may overestimate slip resistance of some products.

---

[1] "The necessity of on-site testing in barefoot areas" https://www.laboratorioderesbaladicidad.com/single-post/2017/08/06/Ponencia-de-nuestro-Director-T%C3%A9cnico-Juan-Iriarte-en-la

[2] FP341 Development of a calibration procedure for floor coverings in wet barefoot areas 27.02.2015 Institute of Wall and Floor Covering Säurefliesner-Vereinigung e. V. (SFV) and Institute of Occupational Safety of German Social Accident Insurance (IFA)
http://www.dguv.de/projektdatenbank/0341/ab_14.04.2015_fp341_final.pdf

BUILDING CODES

As far as construction of the built environment is concerned, building codes are at the apex of the pyramid, where many developed countries have replaced prescriptive regulations with a performance-based approach typically using a five-level hierarchy. The objectives are established and then expressed as performance or functional requirements. One may then have mandatory code basic documents that detail the level of performance required in various circumstances. There are then two underlying voluntary levels, where the verification methods and acceptable deemed-to-satisfy solutions are underpinned by approved documents, as well as some supporting documents.

Building Acts typically establish the minimum "basic building requirements" for functionality, safety and habitability, including requirements on accessibility, safety in use, hygiene, etc. but also structural requirements, fire resistance, energy efficiency, etc. While some minimum requirements may fall well short of best practice, one should consider whether any slip resistance requirements may be considered as lenient or onerous, and whether they are likely to be effective. Where a requirement only applies to new buildings, might this lead to lax practices where somebody else has to assume responsibility for the long-term performance? It may be quite counterproductive in situations where material characteristics are likely to change significantly, as is the case with the slip resistance of floors.

Appropriate building codes are concerned with weighing costs and benefits. If one wanted to determine the fitness for purpose of a code's slip resistance requirements, is there any reliable data available for analysis? When the Australian Building Codes Board sought to understand how the design of buildings influenced the occurrence of slips, trips and falls, they were unable to obtain data that (1) benchmarked the typical slip resistance of the built environment; and (2) quantified the slip resistance of floors where slips were claimed to have occurred (even though many logged slips may be due to misused semantics rather than being genuine slip incidents).

Spanish Building Code Slip Resistance Requirements

The Basic Spanish (SUA) Security of use and accessibility Document and its supporting document (DA DB-SUA/3) were again modified by Royal Decree 732/2019 of 20 December 2019. It now specifies the use of UNE 41901[3] and UNE 41902[4] for determining Rd, the pendulum slip resistance value, superseding UNE ENV 12633[5]. Slider 57 is used for wet testing and Slider 96 for dry testing. Table 1 summarises the minimum slip resistance requirements of the Spanish Technical Building Code (CTE), which has a critical requirement: this class shall be maintained for the life of the floor. Document SUA C contains useful guidance comments from the Ministry of Development (version 20 December 2019) including provisions for dealing with the transition zones between wet and dry areas.

[3] UNE 41901: 2017, *Surfaces for Pedestrian Transit - Determination of the Slip Resistance by Pendulum Friction Method - Wet Test*

[4] UNE 41902: 2017, *Surfaces for Pedestrian Transit - Determination of the Slip Resistance by Pendulum Friction Method - Dry Test*

[5] UNE ENV 12633:2003, *Method for determining the value of the slip / slip resistance of polished and unpolished floors*

Table 1 Summary of the Spanish Building Code (CTE) Slip Resistance Requirements

Floor surfaces	Class	Class requirements	
		Wet Rd value	Dry Rd value
Dry interiors with slope < 6%	1	**15 < Rd ≤ 35**	Rd > 40
Dry interiors with slope > 6% and stairs	2	**35 < Rd ≤ 45**	Rd > 65
Wet interiors with slope < 6%	2		
Wet interiors with slope > 6% Internal stairs with grease, lubricants, etc. Exteriors and swimming pools	3	**Rd > 45**	

Although DA DB-SUA/3 states there is no correlation between pendulum results and the German ramp tests, it considers products classified as R11 (DIN 51130) and as B (DIN 51097) as being suitable for any condition set out in the table without the need for pendulum testing. This has led to problems at swimming pools, as mentioned before.

Document DA DB-SUA/3 also contains a list of flooring materials that are considered to be safe without pendulum testing, including natural stone with flamed and bush hammered finishes, some concrete products and clay pavers provided they have not been manufactured with a "very smooth surface". None of these surfaces may be modified by subsequent treatment such as polishing. As highly polished porcelain tiles can have very low wet pendulum values and quite high dry pendulum values (at least with slider 96), I am surprised that the slip resistance of dry stairs seems to be specified solely by means of dry slip resistance.

A tiling nuisance?

UNE 138002:2017, *General rules for the installation of ceramic tiles with bonding materials*, when considering slip resistance of ceramic tiles, gives Table 1 and notes the R11 (DIN 51130) and B (DIN 51097) exemptions. It also notes that CEN/TS 16165 Annex C indicates (pendulum) results obtained on surfaces with reliefs greater than 500 microns may not be reliable.

As a Standards developer seeking enlightenment, what evidence supports such a contention? How can Standards publish such statements without referencing appropriate literature? Standards are primary reference documents in litigious matters, such that there is a need to understand the derivation of clauses and to be able to assess the truthfulness of generalisations.

Bumpy surfaces and unlevel playing fields

If one examines CEN/TS 16165:2016, a statement was added to clause C.3.4 late in the drafting process:

> If the measurement surface is not sufficiently flat, it will not be possible to carry out a reliable measurement. In that case, a different section of the measurement surface or the product should be measured or else a different product should be selected that does comply with the flatness criterion. The measurement surface should be rejected if the deviation from a straight line over the length of the surface exceeds 2.0 mm (concave or convex) or if the deviation from a straight line over the width of the surface exceeds 0.5 mm. This should be checked in the middle of the measurement surface

> with the help straight edges and a feeler gauge set over the appropriate length (135 mm) or width (80 mm).
>
> NOTE Products with Intended textures or profiles will in generally not fulfil these flatness criteria. Nevertheless, for some products Pendulum measurements might still be possible and the results might still be performance related.

Who is the authority behind these condemnatory remarks and where is the published study? Exactly how technicians should make such measurements reproducibly was not established. Do specimens have to be cut to size to enable measurements on concave surfaces? Why were the 130 x 80 mm dimensions selected - it is difficult to establish a 126 x 75 mm test area on such a sized specimen. If specialist tools are needed, why not base them on 126 x 75 mm templates?

Although the rejection comment (first paragraph above) is still in the current (2020) draft of prEN 16165, the explanatory note (second paragraph) has been deleted. However, a new clause C.3.5 Profiled surfaces, has been added:

> Where heavily profiled surfaces have been specifically manufactured to have high slip resistance, which relies heavily upon the interlock action between the highly profiled pedestrian surface and the heavily profiled soles of some footwear, the 'pendulum test' method may not provide accurate indications of the slip resistance. When testing highly profiled surfaces, slider 57 generally produces more consistent results than slider 96.

Considering the first sentence, should the draft include similar comments in the other normative annexes to draw attention to the limitations of the other test methods? The pendulum may not provide an accurate indication of the slip resistance due to the interlocking between a surface and a sole, but does the oil wet ramp test provide an accurate indication of the slip resistance between a surface and footwear that has a smooth sole?

Contemplating the second sentence, what is a highly profiled surface and how does one define consistent results? What is the context of this generalisation and is it supported statistically? Does it apply to wet testing, dry testing or both? Did the sample/s consist of one or more of the following surfaces: a flat profile and smooth touch; a flat profile and a gritty touch; a wavy profile; irregular relief; uniform geometric relief, where again the surface might have a matt or gloss glaze, feel smooth or gritty? Or does the seeming lack of consistency relate to an ability to discern variability in the inconsistent surface that is being tested? There seems to be a lack of consistency in prEN 16165 with respect to the application of biased comments, where the DIN 51097, DIN 51130 and DIN 51131 based methods escape criticism.

Surface topographies

The SlipSTD project yielded simple method of classifying surface topographies, using Pk and Pp three-dimensional surface roughness characteristics determined by sophisticated optoelectronic equipment, where there may be some differences between instruments. Engels (2020) has commented on the suitability of the different methods of slip resistance measurement with respect to the four surface topography groups. The ramp methods are not recommended for non-profiled, mainly smooth Group 1 surfaces. The ramp, tribometer and pendulum test methods are all considered suitable for micro rough Group 2 "gritty touch" surfaces that have Pk up to 100 µm and Pp up to 200 µm. However, the tribometer is either impaired by loss of surface contact or irregular traction where Group 3 textured and profiled "macro rough" surfaces have Pk above 100 µm and Pp above 200 µm. With the Upper Group 3 geometrically profiled surfaces that have Pk above 300 µm and Pp above 700 µm, the pendulum is still applicable but the "impact variation on profile" needs attention.

Muñoz (2019) adopted the following grouping based on simple psychophysical criteria (the visual and tactile aspects of surface topography) providing photographs, topographic maps and two-dimensional surface roughness data for each of 54 representative samples:

- Group 1. Surfaces of smooth profile and soft touch.
- Group 2. Surfaces of smooth profile and rough touch.
- Group 3. Surfaces with wavy profile.
- Group 4. Surfaces with irregular relief
- Group 5. Surfaces with uniform geometric relief.

Paying attention to the "impact variation on profile"

Aspects of setting up the pendulum to reproducibly test geometrically profiled surfaces are well set out in the 2013 Australian Standards AS 4586 and AS 4663. UNE 41901 has adopted the Australian offset of 10 to 20 degrees on mosaics. However, there is insufficient set up detail in the prEN 16165 draft, which instructs users that several tests at different angles may be necessary in order to determine the minimum slip resistance offered by that surface. However, is the lowest result always the most relevant measure of slip resistance?

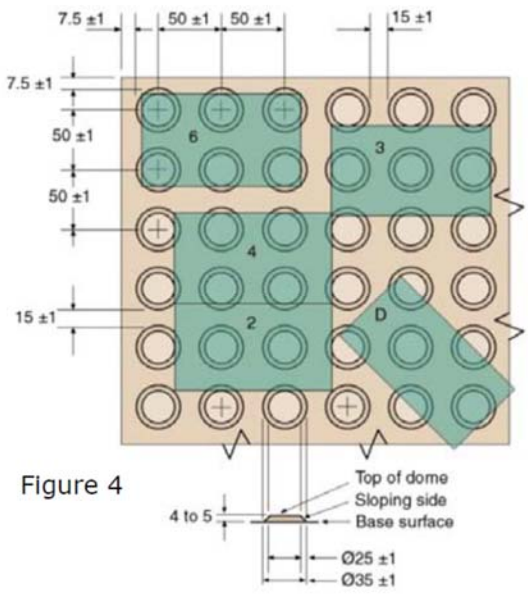


Table 3 Summary of test results for a warning tactile ground surface indicator

TGSI orientation	BPN	
	Four S	TRRL
6 dome tops	56	48
4 dome tops	50	35
3 dome tops	49	44
2 dome tops	42	32
4 domes (diagonal)	77	65

Figure 1 Which set up is most appropriate? [Figure 4 and Table 3 of Bowman (2010)]

Looking at Figure 1, the lowest slip resistance value was obtained when using 2 dome tops to test in an orthogonal direction. However, all the orthogonal direction tests are inappropriate as some impact occurs on the base of the test foot rather than on the prepared chamfered edge. The correct procedure is to test at an angle of approximately 30 degrees (as shown in AS 4586 and AS 4663) rather than at 45 degrees, as was inappropriately shown in Figure 4 from 2010.

Looking at Figure 2 none of the ten 2010 scenarios is appropriate. Testing at an angle of about 10 degrees, as shown in the 2013 Australian standards (and on the right of the Figures below), enables the wear along the top 25 mm surface of a directional indicator to be spread across the width of the 75 mm test foot. When using repeated swings of the pendulum to test regularly profiled surfaces, one must use an offset angle to ensure that one does not cut regular grooves into the test foot, whereupon the principles of hydrodynamic lubrication tests are invalidated. Having provided inappropriate guidance in 2010, Bowman made amends by supplying the revised directions for the Australian standards. This was based on testing several different types of tactical ground surface indicators (TGSIs) and structurally profiled stair nosing strips. However, the organisation that partially funded the research refused permission for its public release. Bowman is unaware of any dissent with the AS 4586:2013 and AS 4663:2013 directions.

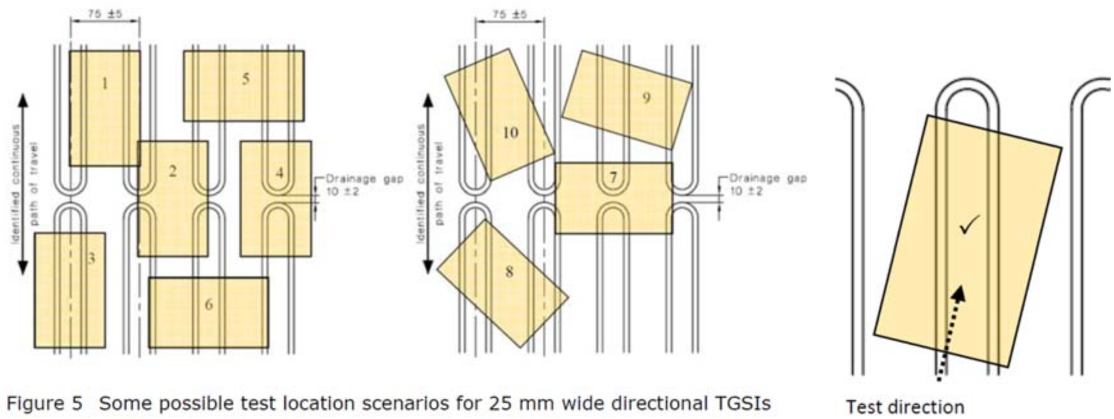


Figure 2 A review of pendulum set up positions when testing TGSIs**.**

In considering the Spanish slip resistance requirements, one should consider why there were so many slips and falls in swimming pool areas when class B products were used (Iriate, 2016). Does this relate to new calibration boards having less slip resistance than the original boards? Do the new calibration boards have similar slip resistance to worn original calibration boards?

The GMG 200 tribometer test method used in Annex D of prEN 16165 is not used to measure or classify new products. Is it suitable for assessing the slip resistance of geometrically profiled flooring materials that were originally classified with a ramp test? Engels analysis would suggest not. Given that the draft expresses doubts about the ability of the pendulum to measure profiled surfaces, it is surprising there is no mention of profiled surfaces in Annex D, where such an omission might lead one to assume the tribometer is suitable for measuring any surface.

TCNA is taking a sensible approach to classifying profiled surfaces (Davidson & Astrachan, 2020) where the BOT 3000E tribometer is used to determine two slip resistance categories for level internal spaces, and three other categories are based on manufacturer declarations.

The Spanish Building Code recognises that there is no correlation between the ramp tests and the pendulum test, it is sensible, contractually, to rely on pendulum testing from the outset.

The Building Code of Australia Slip Resistance Requirements

The Building Code of Australia (BCA) contains deemed-to-satisfy provisions for ramps steeper than 1:14, and for stairways, their treads, landing surfaces, nosing edges or landing strips. These are given in terms of minimum wet pendulum slip resistance classifications (or oil-wet inclining platform classifications) for both dry situations and wet situations.

As regards other areas, people must be provided with safe, equitable and dignified access to buildings and their services and facilities, as well as safe access while evacuating in an emergency. The BCA references AS 1428.1:2009, *General requirements for access – New building work*, where the standard requires "A continuous accessible path of travel and any circulation spaces shall have a slip-resistant surface". While there are, as yet, no deemed-to-satisfy provisions, Standards Australia Handbook 198:2014, *Guide to the specification and testing of slip resistance of pedestrian surfaces*, contains some recommendations in terms of minimum wet pendulum slip resistance classifications (and/or oil-wet inclining platform classifications) for dry situations, wet situations and transitional situations.

Rubbery statements

It should be noted that HB 198 contains many generalisations regarding the use of the soft and hard rubbers that should be substantiated by reference to published documents. Bowman considers that these generalisations might have derived from past research that was performed when the final preparation of the rubber test feet was performed with abrasive paper rather than lapping film. Are the following HB 198 statements universally correct or do they require substantiation?

- For surfaces that are particularly slippery, it is appropriate to use Slider 96 rubber.
- For surfaces of relatively high slip resistance, a softer rubber (such as Slider 55) provides relatively good discrimination (small changes in slip resistance corresponding to large changes in wet pendulum test reading).
- For surfaces of relatively low slip resistance, a harder rubber (such as Slider 96) provides relatively good discrimination.
- If Slider 57 has been used, the results will differ from what will be achieved using Slider 55.

Since Slider 55 rubber has long been used in the British and Australian slip resistance standards, and Slider 59 was used in some CEN standards, this led to a compromise Slider 57 requirement. There have certainly been some significant differences in the results that have been obtained using the Slider 57 materials produced by Smithers Rapra and BAM, although this is not so apparent in the data in Table 2 (from Bowman et al (2005), where the IRHD values of the rubbers were actually 52 and 61, such that neither would qualify as slider 57, although both had the optimum 69% initial rebound resilience).

Table 2 Mean slip resistance values (BPN) for a granite honed or polished to different finishes.

Finish	**Rz**	**Grade 60 paper**		**P 400 paper**		**Lapping film**	
	µm	Slider 55	Slider 59	Slider 55	Slider 59	Slider 55	Slider 59
120 grit	11.5	42	41	34	36	27	28
180 grit	11.4	42	41	35	33	25	26
320 grit	10.7	39	41	29	35	16	17
400 grit	9.1	36	35	25	28	15	14
600 grit	6.5	30	30	23	23	14	12

This study confirmed the importance of rubber preparation, and the potential folly of equating the risk of slipping with a slip resistance value. A coefficient of friction is not a material characteristic: it is a system property that depends on the nature and condition of the rubber test foot. In recognising this, if one is using slip resistance values to assess the risk of slipping, what method of rubber test foot preparation is appropriate, and where is the published determination? The prEN 16165 tribometer method uses 320 grade abrasive paper. The ANSI A326.3 test method uses a 400 grit, super fine, silicon carbide sandpaper.

There has been a suggestion that HB 198 should be revised to include the statement “When testing flooring materials in wet barefoot areas, or unusually rough products, the use of the softer more resilient Slider 55 is preferable”. Slider 55 rubber certainly yielded better agreement with wet barefoot ramp test results when the two rubbers were prepared using P400 paper, but the same agreement has yet to be found when looking at a sufficiently large sample of results.

Problems with the BCA slip resistance approach

It has long been known that most slip resistant materials lose slip resistance permanently as wear occurs, while soiling can temporarily reduce the level of slip resistance. Risk management principles require that building managers and employers maintain facilities in a safe condition. Although the cleanliness of surfaces is relatively easy to assess, determinations of slip resistance require the use of appropriate test devices. While wet pendulum measurements can be conducted in situ, the BCA fails to state what level of slip resistance is appropriate in the long-term; and the Australian Building Codes Board (ABCB) has failed to divulge their basis for establishing the BCA deemed-to-satisfy provisions.

The ABCB commissioned the Monash University Accident Research Centre to study the incidence of slips, trips and falls and their relationship to the design and construction of buildings. Unfortunately, the authors failed to publish any data that quantified the level of slip resistance in circumstances where slips had occurred. The final MUARC report, published in 2008, [MUARC] made three recommendations for the slip resistance of flooring surfaces:

> The ABCB include a thorough definition of slip resistance in future editions of the BCA, rather than referring to the definition included in Standards Australia Handbook 197: 2005. {NOTE: The BCA has yet to define slip resistance. SA HB 197 was published in 1997 and did not contain a definition of slip resistance.}
>
> Manufacturers and retailers should provide comparative information on slip resistance, and comparative slip resistive properties of different flooring surfaces, to consumers for consideration before purchase. {Some manufacturers and retailers were already providing consumers with wet pendulum and/or oil-wet ramp and wet barefoot ramp data. Some now also provide wet pendulum data after accelerated wear conditioning. The ABCB took no action.}
>
> Alteration of the BCA should be considered to require the installation of slip-resistant surfaces in the wet areas and external pedestrian areas of all new and renovated homes, and that the Local Government and Shires Association of NSW initiative, whereby certificates of occupancy are only issued to buildings where all floor surfaces meet the recommendations on slip resistance of pedestrian surfaces as outlined in the revised SA Handbook 197: 2005 is adopted and regulated nationally. {NOTE: While there was a proposal to modify the HB 197 guidance to include a recommendation for residential wet areas (a minimum wet pendulum value of 25 with slider 96) this had been successfully opposed in early 2007 by the Australian ceramic tile retailers.}

The MUARC report may have been excellent from an epidemiological perspective, in its analysis of data associated with fall related coronial fatalities, hospital admissions and separations.

Bowman and Graham-Bowman (2015) drew attention to the report's failure to quantify the incidence, frequency or severity of slips, trips and falls in relation to the design and construction of buildings, as well as the questionable nature of some of the content.

The MUARC report did not even start to consider what level of slip resistance might be required in specific situations. It failed to reflect that there was no publicly available data that benchmarked the slip resistance in the Australian built environment. When considering slipping and slip resistance, it eventually relied upon the papers of researchers and particularly Bowman with respect to slip testing and standards. The limitations of the MUARC report might be attributed to too great a degree of separation between the authors and the fine detail of the issues. The ABCB had expected to obtain data that would inform or enable changes in the BCA that would minimise the incidence and severity of falls. There were no productive outcomes from a slip resistance perspective. When commissioned studies fail to deliver critical information, credible proposals for productive research may have less chance of succeeding. More distressingly, any incorrect data or misleading conclusions in a seemingly authoritative study can cause both immediate and enduring harm.

The (supposedly) expert panel noted a general "over reliance on a surface's coefficient of friction (COF) measurement when ascertaining slip resistance". There was no clarification of the panel's suggestion that "a greater focus on factors other than COF could improve the slip resistance of flooring". The panel discussed "how increasing flooring slip resistance would increase the cost of flooring and it was suggested that the cost of provision of suitable slip resistance is, and should be, the responsibility of the manufacturer". Many manufacturers were already producing products of various slip resistance levels, whereby such suitable slip resistance would satisfy the needs for specific scenarios. As one size does not fit all, the cost increase speculation was naïve.

The expert panel noted that "flooring slip resistance was particularly important in aged care environments due to the greater likelihood of the elderly falling and the increased injury consequences of such falls". Bowman and Graham-Bowman (2015) challenged the report where it stated 67% of falls for the elderly were initiated by slips. The panel was presumably unaware that most elderly falls are due to a loss of balance, whereas slips are a comparatively rare cause. Epidemiological studies based on narrative text searches have always overestimated slips as the causation for a fall as "I slipped" is a common euphemism for "I fell due to some cause I can't explain"; or an excuse where blaming the environment is preferable to admitting one's frailty.

Although MUARC report 281 certainly fell short of expectations, it became the basis for changing the BCA slip, trip and fall provisions. The ABCB initiated a stakeholder forum to better understand the views of stakeholders and to identify a way forward. It then prepared Consultation Regulation Impact Statements (RIS) to inform stakeholders about proposed changes in regulation to reduce the risk to the community, and particularly to children, of falls on stairs, from windows and over balustrades in new buildings.

The HB 197 (1999) slip resistance recommendations were inflated to allow for slip resistance loss in use. This reflected the ABCB decision requiring separate standards for new and existing floors. AS/NZS 3661.1: 1993 had required slip resistant floors to have a mean wet SRV of 39. It was known vast numbers of existing floors did not comply, and some may never have complied. As such the HB 197 recommendations were only ever considered to apply to new floors. This is also the case with the HB 198 (2014) recommendations, as is reinforced in its text.

Bowman made several comments on the proposed changes, finishing with "We need to adopt relevant slip testing procedures that enable manufacturers to make declarations about the anticipated slip resistance of their products at the end of an economically reasonable life cycle". The only form of ABCB feedback was indirect, where they then prepared suitable guidance[6] to differentiate between wet and dry surfaces. It is a shame that the slip resistance requirements do not have to apply **over the life of the building**. The manner in which the requirements are mandated reinforces the fact that the regulations only apply to new building works: the stipulated surfaces "must have a slip-resistance classification not less than that listed . . . . when tested in accordance with AS 4586". AS 4586 relates to new pedestrian surfaces, while AS 4663 is concerned with testing of existing pedestrian surfaces.

Although AS 4586 regrettably lacks a dry pendulum test, it was surprising that an accommodation was to be made for the dry testing of carpets (for dry area usage). This delayed the publication of both the standard and the regulations. Hopefully the ABCB will enable dry pendulum testing to be extended to other materials. The difference between dry and wet pendulum results is a good measure of the risk of slipping.

In 2013, Bowman reminded the ABCB that some flooring products suffer rapid slip resistance loss once installed, and that this loss was one reason why some tile and stone merchants opposed accelerated wear conditioning (AWC) procedures: they were more concerned to be able to sell products than ensuring suitable products were sold, reflecting concerns expressed in the MUARC report about the reliability of the information provided to consumers.

Bowman was again contemplating AWC procedures when he ended his 2013 comments with the rationalisation, "If poorly thought through measures are adopted, they are likely to have unfortunate and costly repercussions for generations to come. In having overcome the principal limitations associated with wet pendulum testing, we should give ourselves the time to identify the potential benefits that are there for the taking if only we take the trouble to do so".

Compliance with Disability Discrimination Acts

The 2019 Guide to NCC Volume 1 summarises details of a long-awaited review of compliance with the *Disability Discrimination Act 1992* (DDA). Section 23 of DDA makes it unlawful to discriminate against another person on the ground of the person's disability in relation to a number of aspects of access to, or use of, premises. The DDA also provides that the relevant Minister may, by legislative instrument, formulate standards in relation to any area in which it is unlawful to discriminate against another person on the ground of a disability. The Disability (Access to Premises — Buildings) Standards (Premises Standards) were formulated following requests for improved certainty under the DDA in satisfying its requirements for non-

[6] To determine the appropriate slip-resistance classification surface to apply to a ramp, it is necessary to determine the conditions (either dry, wet or both) that the relevant surface is likely to be subjected over the life of the building. (Underlining emphasis added)

A dry surface is one that is not normally wet or not likely to become wet other than by accidental spill. A wet surface is one that is normally wet or likely to be made wet other than by an accidental spill. This could include a surface that is exposed to weather such as an external ramp ,and a surface that may, on occasions, become wet such as a surface in a transitional space like an entrance airlock or entrance lobby. Other potentially wet affected areas such as bathrooms are not included in the NCC (slip resistance) provisions unless they have a ramp incorporated in them. **Surfaces affected by commercial or industrial processes are regulated by the relevant workplace safety authority**. (bold emphasis added) discriminatory access to premises. The BCA provisions for access for people with a disability have been aligned with the technical provisions in the Premises Standards. This results in a uniform set of requirements that will apply both in relation to non-discriminatory access under the DDA and in relation to the requirements for access that must be complied with in order to obtain a building approval under building law.

The Premises Standards have been subject to a 5 yearly review that commenced in 2015 and was completed in May 2016. The review was undertaken by the Commonwealth Department of Industry, Innovation and Science in consultation with the Attorney General's Department, with input provided by the ABCB. In response to the recommendations of that review, amendments have been made to the BCA.

In fact, there have been no significant changes to the slip resistance provisions. The BCA still references AS 1428.1:2009 which requires that accessways to and within buildings be slip resistant. It is not known if or when the regulatory authorities will seek to quantify slip resistance requirements to enable access for people with a disability, or to quantify requirements for residential wet areas. AS 4226 (2008), Guidelines for Safe Housing Design, already states that HB 197 provides useful information on slip resistance issues within residential buildings, having expected that appropriate residential guidance would be provided when HB 197 was revised. However, this public good ambition was thwarted by self-interested parties.

Wear resistance of flooring materials to foot traffic

The preface to Harper, Warlow and Clarke's landmark 1961 study, "*The forces applied to the floor by the foot in walking*", commences "General-purpose machines for the measurement of abrasion resistance have proved unsuitable for assessing the resistance of flooring materials to wear by foot traffic. This is evidently attributable to the complexity of the interaction between foot and floor during walking, and to the existence of a number of mechanisms of wear which probably depend upon the materials involved. The most promising approach to this problem appeared to lie in the design of a testing machine that would simulate the abrasive interaction as closely as possible. To this end, measurements have been made of the forces applied to a floor surface by the foot, both in straight walking and in turning on the level". While this study generated the data that Pye used to relate the COF to the risk of slipping (as adopted in the UKSRG guidelines), there is still no single accelerated wear machine that will reproduce the effects of foot traffic on all flooring surfaces.

Mature tribometric experts have accepted there will never be a single tribometric device that will yield a reliable indication of slip resistance for all surfaces, contaminants, footwear types, outsole materials and shoe wear patterns. Similarly, there will never be a single AWC procedure capable of replicating and combining all of the environmental factors that can cause different flooring materials to degrade as they do naturally. Timbers exposed to weather conditions will wear quite differently to those installed in dry internal situations.

While we instinctively know whether to view objects using a telescope, glasses or microscope, we need to ensure tribometers are only used where they are capable of producing sensible results, even if further studies are required to allow for different types of footwear and outsoles. While different types of slip resistance tests may tend to rank floorings in a similar order, a change of test foot material or condition can change the ranking order for individual devices. We should expect that AWC procedures that work well for some materials may be inappropriate for use on others. It is the responsibility of individual industries to determine what procedure might best achieve the likely condition of their product at the end of their service life.

While Bowman initiated the quest for an AWC procedure for ceramic tiles at CSIRO, Strautins (2008) developed a system that appears suited to ceramic tiles, stones, and some vinyl products. This uses a linear-reciprocating washability machine and a commercially available abrasive pad. The worn area is suitable for the 126 x 75 mm required for a pendulum test.

Silva et al (2020, and earlier) have made many studies of the abrasion wear resistance of ceramic tiles, and also resilient PVC and laminates. They have measured gloss loss and wet pendulum slip resistance after AWC procedures, as well as in settings where actual wear has occurred, and the number of pedestrians determined. Silva et al have also performed many studies involving footwear, where the significant influence of footwear is evident, as previously shown in the Wetzel's monumental thesis (2013). Silva's preliminary conclusions are:

- There are significant differences between the wear mechanisms in actual conditions with and without direct outdoor access;
- At external entrances, three body abrasive wear may be the main mechanism, removing material from the surface and causing deep grooves or scratches;
- In internal conditions, the loss of material at the surface may be due to an erosive wear mechanism, similar to a polishing process;
- Each of these mechanisms causes a different evolution of the floor surface characteristics, such that one cannot predict their performance without using an appropriate wear process; and
- Different test conditions should be used to classify floors according to their intended use, for indoor or outdoor environments.

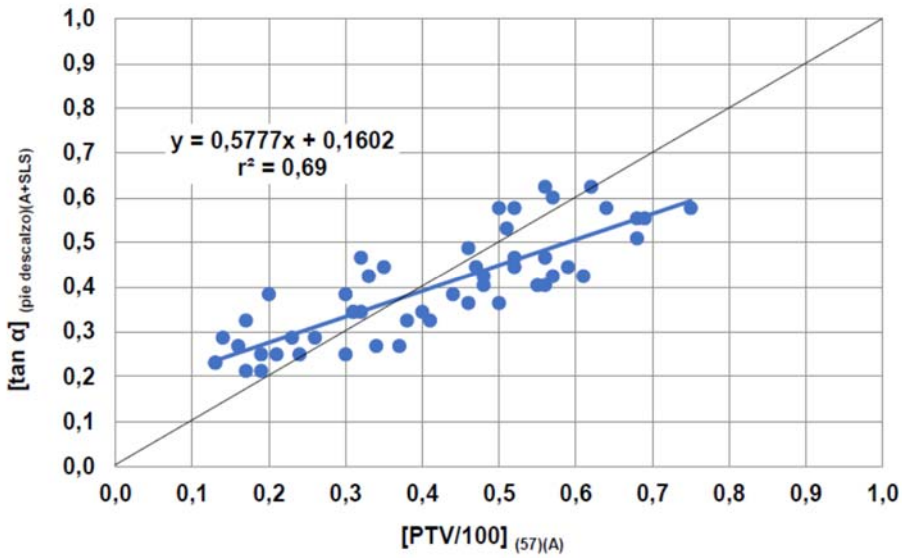


Figure 3 Muñoz plotting of wet barefoot ramp and Slider 57 test results for 51 ceramic tiles.

The moderate R-squared value indicates that a wet pendulum value may give a poor indication of a wet barefoot angle, and vice versa. However, where tan α values of 0.32 and higher indicate class B tiles and Rd > 35 indicate class 2 tiles, most class 2 tiles are also class B tiles, whereas many class B tiles are not class 2 tiles.

A Potential Solution

In 2011, Bowman presumed that everyone concerned with slip resistance standardisation would want flooring products to have adequate slip resistance at the end of an economically reasonable working life; floors to be maintained using green cleaning practices; and slippery floors to be replaced or remediated (with sufficient slip resistance for an adequate life cycle).

Bowman suggested establishing minimum maintenance levels of slip resistance for various environmental contexts and usage scenarios. This would allow a direct comparison with audit and accident investigation test results thus providing a relevant basis for assessing risk. Such maintenance level recommendations might be partly based on benchmark data for the existing environment, reflecting whether areas were fundamentally wet, dry or transitional, among other relevant considerations.

Once recommended maintenance levels were established, these would naturally form the basis for specifications of new flooring products. In 'working backwards' one would ideally determine whether potential candidate materials for a project would have sufficient slip resistance after an appropriate AWC treatment (that was considered to cause a similar amount and type of wear to that expected throughout the service life of the floor).

For hard surfaces, Strautins (2008) accelerated wear conditioning procedure seem appropriate. Other AWC procedures have been used for other materials, such as clay and concrete pavers. Whether alternative AWC procedures might be more appropriate for various products is largely a matter for the relevant manufacturers. Natspec has promoted the use of AWC procedures since 2009, but appropriate detailed guidance is still required.

Some European standards have involved the determination of both unpolished and polished pendulum slip resistance values, so the use of AWC procedures as part of a slip resistance test method is well accepted. It is simple to make provision in the existing standards for reporting of one or more polished values in addition to the existing unpolished value. However, in the case of some materials, the manufacturer might prefer to publish an unpolished value, and to declare a characteristic minimum (worn or service) value that should not be transcended, effectively declaring an end of life value, where some remedial or investigative action is required. Such declarations might be based on longitudinal slip resistance studies of old floors.

As Natspec first recommended such AWC procedures in 2009, this obvious requirement should be standardised. Although some laboratories use Strautins' procedure, others have slightly deviated from it without any published justification. The Australian Ceramic Society proposed the preparation of a Standards Australia Technical Specification (TS) to re-establish a level playing field, whereupon consumers should receive consistent AWC slip test data. It was anticipated that the TS might be incorporated within AS 4586 which already has a wet pendulum test method clause "If a product Standard or specification contains a requirement for the permanence of slip resistance, this requirement shall be determined after the appropriate accelerated ageing or wear testing procedure". As HB 198 notes, AS 4586 does not dictate a particular method of AWC. "If accelerated wear conditioning or testing is required, the specifier should consider whether the particular procedure accurately reflects the wear expected in-service. Guidance may be available from experienced testing organizations".

In 2011, a technician from an experienced testing organization proposed a CAWT accelerated wear test classification system, stating many pedestrian surface materials were unsuitable to accelerated wear testing, including concrete, natural stone, rubber, vinyl, PVC, terrazzo and coating applications. Indeed, only ceramic products were considered suitable. It was stated that "The application of accelerated wearing techniques on ceramic surfaces is an extremely harsh test. It has been found that some ceramic products degrade faster under accelerated testing, than surfaces in the field." Given AWC is intended to expedite wear, it should induce rapid degradation. Natural wear should occur at rates that reflect the amount of pedestrian traffic, the type and amount of scratching dirt, among other variables. While specific details of the supposedly extensive data bank have been sought, they have never been forthcoming. The CAWT classification procedure was nonsensical. While the CAWT proposal was never seriously entertained, one organisation still considers it credible and has used it as evidence of the limitations of the use of AWC procedures.

Sadly, the 2019 proposal to develop a Technical Specification for an AWC procedure was deemed to not meet the net benefit criterion sufficiently, so the Committee must consider its next steps. Since 2011, it has been stated that the proposed AWC procedure should only be used for flooring products, where industries or manufacturers considered it to be appropriate. Where standards are intended to cater for all flooring products, it is unfortunate if limited sectoral interests can take precedence over broader societal needs. As participation in standards development may require signing of a confidentiality agreement, this may prevent the frank disclosure of critical aspects that should be publicly addressed.

External events

Livable Housing Australia (LHA) has been developing practical, common sense universal design guidelines to livability that embrace inexpensive design features to better meet the changing needs of occupants over their lifetimes. The original idea behind the LHA Guidelines was to prepare have them applied to all new housing by 2020. These Guidelines were endorsed by the Council of Australian Governments, the peak intergovernmental forum in Australia, and are cited in government policy documents. However, it is difficult to apply voluntary guidelines in an industry governed by mandatory building codes and standards.

Slip resistant floors have featured prominently in the guidelines as a requirement in the higher voluntary performance levels. The Guidelines have noted "Slip Resistance is referenced in the National Construction Code and ultimately, Livable Housing Australia would like to defer to the NCC and the Australian Building Codes Board (ABCB) for rulings related to slip resistance. Standards Australia publish a number of standards as well as a handbook that address slip resistance of surfaces." While there was some reference to the NCC although there were no slip resistance requirements for the relevant locations, there has thus been no quantification of the necessary slip resistance, although there have been some inappropriate suggestions.

Following extensive feedback from the developing Specialist Disability Accommodation (SDA) market for greater certainty in the design process, the National Disability Insurance Agency (NDIA) engaged LHA to develop a technical guide for expanding the amount of relevant detail available about the minimum criteria whilst simplifying processes. The 2019 NDIA SDA Design Standard sets out the future requirements of well designed and built form of new SDA consistent with the NDIS. It is anticipated this will spur a new era of housing construction and enhancement for Australians with disability, where there is also an expectation that the tasteful incorporation of such sensible design features will add to the value of the property.

The NDIA SDA Design Standard[7] quantifies the slip resistance requirements as P4 or R11 for pedestrian entry from the site boundary, car parking areas, and ramps up to 1 in 14, where P5 or R12 are required for short 1 in 10 step ramps. There is a minimum requirement of P3 or R10 for all internal floor finishes and stairways, where this requirement is again identified in wet areas (sanitary facilities, kitchens and laundries).

It is unfortunate that HB 198 followed HB 197 in adopting oil-wet ramp recommendations for public locations where there is no control over footwear. The Germans have recognised the oil wet ramp test is one of physical-interlock-slip-resistance, where this mechanism is unavailable to people wearing shoes with unprofiled soling materials (as generally occurs in private homes).It was anticipated that HB 198 would recommend pendulum values as the principal measure when specifying external areas; public, civil and commercial offices; and residential scenarios. The pendulum test may have been secondary to the ramp tests in public wet barefoot areas and those commercial and industrial situations where safety footwear is mandated.

If the German oil wet ramp test correctly determines the traction available to someone with heavily profiled soles, does it provide suitable guidance when people may wear footwear that lacks a profiled sole? Does intensive polishing of the pendulum rubber sliders underestimate the wet traction available on surfaces where heavily profiled soles will be worn? While boat shoes and hiking boots are both designed to prevent falls, the design solutions for the expected conditions are quite different.

A further folly of the SDA specification using the R10, R11 and R12 ratings is that the oil-wet ramp test can only be performed in laboratories. Several commercial disputes have arisen when newly installed R10 products have failed to achieve a P3 rating (minimum 35 SRV). While there was never any equivalence between the HB 198 wet pendulum (P) and oil-wet ramp (R) recommendations, only the pendulum test can be conducted in situ.

Once 'new' floors are handed over and become 'existing' floors, the surface is tested to AS 4663 rather than AS 4586. The subtle difference is that AS 4663 test surfaces "shall reflect the nature and purpose of the testing", where a minimum of five locations are used for each site condition. Given that the nature and purpose of the testing can influence the selection of locations and how they are prepared, test reports should have to state the nature and purpose of the testing, so it is apparent to anyone considering the report. AS 4663 reports should give the result for each location and the mean SRV for the sample, but not an AS 4586 P classification (but an equivalent P classification might be given in an informative note).

Considering maintenance values

For the purposes of initiating discussion in early 2011, Bowman suggested the maintenance level (M) values shown in Table 3, as minimum values that might be acceptable when locations were tested in situ, where the type of rubber test foot was not indicated. Table 3 also includes the HB 198 minimum values recommendations for ex-factory products (in terms of slider 96 results).

---

[7] http://www.livablehousingaustralia.org.au/library/SLLHA_GuidelinesJuly2017FINAL4.pdf

In a webinar in 2019, Bowman assumed that Strautins' AWC procedure may cause wear that might not occur in the real world, so that slip resistance results (for prolonged AWC) represented the worst-case scenario. If so, he postulated that the result after 500 wear cycles might present a reasonable indication of the slip resistance after long term wear. He then suggested that such values also be called a maintenance value (M). Such M values[8] could obviously be used as a minimum value for specifications, as well as a critical check point for onsite audits (providing a linkage with the previously mentioned maintenance levels).

Table 3 Bowman's proposed 2011 maintenance values and HB 198:2014 general recommendations

Location (not sloping)	M	HB 198
External footpath, car parks, pedestrian crossings, school yards	35	45
External domestic paving, balconies	25	-
Supermarket aisles except fresh fruit and vegetable areas	15	12
Bathrooms, ensuites in hospitals, aged care facilities	30	35
Residential bathrooms, toilets, kitchens, laundries	15	35*
Hotel, motel, safety housing bathrooms, toilets, kitchens, laundries	20	25
Wet - entries & access areas, public buildings	25	35
Transition - entries & access areas, public buildings	20	25
Toilet facilities in public buildings	30	35
Communal change rooms	25	35

* NDIA SDA requirement used due to the absence of any HB 198 residential recommendation.

Bowman then proposed simply linking the existing slider 96 pendulum (P1 to P5) classifications with some new maintenance (M1 to M5) classifications, as shown in Table 4. In introducing a consensus scheme, one might consider whether 500 cycles with the nominated scouring pad is always appropriate, and whether appropriate allowance has been allowed for wear. While Muñoz has provided useful Slider 57 data for consideration, there is insufficient comparable publicly available Slider 96 data.

Table 4. Some proposed Australian Maintenance Values for Slider 96

Existing classifications		(AWC) Maintenance Values		
Class	Minimum SRV	Class	Minimum Mean SRV	Individual SRV
P5	55	M5	40	32
P4	45	M4	35	28
P3	35	M3	27	22
P2	25	M2	25	20
P1	12	M1	12	10

[8] Bowman, R. (2019) Slip Resistance – Getting it Right, Informed Webinar. https://informedprofessionals.com.au/events-new/120919-webinar-slip-resistance-getting-right/

The vast majority of products that have been subjected to AWC procedures in Australia have been expected to be class P3 or higher. If one considers the marginally slip resistant class P2 products being used in residential situations, we expect any contamination would be promptly cleaned up. Table 4 implies minimal SRV change if P2 products were submitted to AWC. If so, it would seem pointless to submit class P2 products to AWC procedures unless they were quite marginal (SRV of 25 or 26). However, we should not fool ourselves as to the absolute accuracy of wet pendulum results. There is an obvious need to conduct sufficient verification testing before assuming any individual product will not lose its ex-factory slip resistance after installation, except if it becomes soiled. As discussed elsewhere, Munoz has found such products lose slip resistance in real life conditions as well as after AWC, so Table 4 needs modification.

How much wear and slip loss occurs in Class 1 tiles? How much does this depend on the environment, the amount and type of scratching dirt, and the type of footwear? How many existing residential bathrooms have floors that do not meet the Class 1 requirements? Are they problematic? Would more onerous requirements infringe on civil liberties? Would compliance increase property values in properties that are otherwise accessible?

Silva et al (2020) have shown that the slip resistance of the STD-P and Eurotile 2 reference tiles decreases by about 10 BPN over 500 AWC cycles for slider 96, and a little more for slider 57. Most of this loss occurs in the first 100 AWC cycles. Should 100 AWC cycles be considered for maintenance levels in residential situations and 500 cycles in commercial situations?

While the use of 3 µm lapping film to prepare pendulum rubber test feet has become accepted practice, there is still a need to consider what proportion of soling materials have such highly polished surfaces. Many flooring products yield similar results when slider 96 rubber was prepared with either lapping film or 400 mesh abrasive paper (Bowman, 2010). However, lapping film preparation causes much lower results in some products, for example a decrease from 37 BPN (with abrasive paper preparation) to 12 BPN (with lapping film preparation). The notional risk of slipping increased from one in a million to highly probable. The adoption of lapping film preparation may have reduced the ratings of many flooring products, possibly with some commercial effect. However, there has probably been no study to determine whether or the products concerned are dangerous. There was no published paper to indicate (1) any deficiency with the results obtained using abrasive paper preparation, or (2) any benefits from adopting the lapping film preparation based on the improved reliability of any risk analysis.

Australia followed BS 7976-2002 in adopting lapping film preparation of the rubber sliders, largely because this extended the bottom end of the wet pendulum range when testing smooth surfaces. Perhaps the results provide a better indication of risk if someone is wearing shoes where the soling material is improbably highly polished?

At Qualicer 2008, Bowman stated “It is anticipated that a series of new Australian slip resistance design recommendations will be issued in 2008, based to a greater extent on pendulum results, where the pendulum test method has been modified to enable better discrimination between the wet slip resistance of products at the slippery end of the spectrum. The guidance will also recognise the need to be aware of the potential loss of slip resistance with wear.” This partially referred to the intended adoption (in the Australian standards) of the 3 µm lapping film for preparing the rubber test feet (that was achieved in 2013). It also recognised the significant slip resistance loss occurred after product installed, Strautins’ AWC procedure, its adoption by McDonalds Australia, as well as its use by some smart tile merchants and architects.

In her PhD thesis, Muñoz (2019) unites much of the excellent research that ITC has published over the last two decades. Using Slider 57, Muñoz has found good correlation between the wet pendulum slip resistance of a wide range of ceramic tiles that were exposed to pedestrian traffic and an AWC procedure, as shown in Figure 4. Based on Strautins' procedure, it uses scouring pads mounted in industrial tile polishing equipment. Muñoz has suggested that a simple AWC procedure should be developed, possibly based on Strautins procedure, conveniently modified to equate with the wear and tear produced by real pedestrian traffic. However, as one travels from the dry Castellon environment, one will encounter different wear conditions. Accelerated wear procedures, consisting solely of abrasion, do not include many alteration mechanisms that occur in real life. Any abrasion-based process can only model one of a wide range of typical abrasive conditions. Any AWC procedure is a compromise. If one is unprepared to accept some limitations, one will never develop a procedure. One Muñoz abrasion stage might equate with more or fewer pedestrian passages elsewhere, depending on the local conditions.

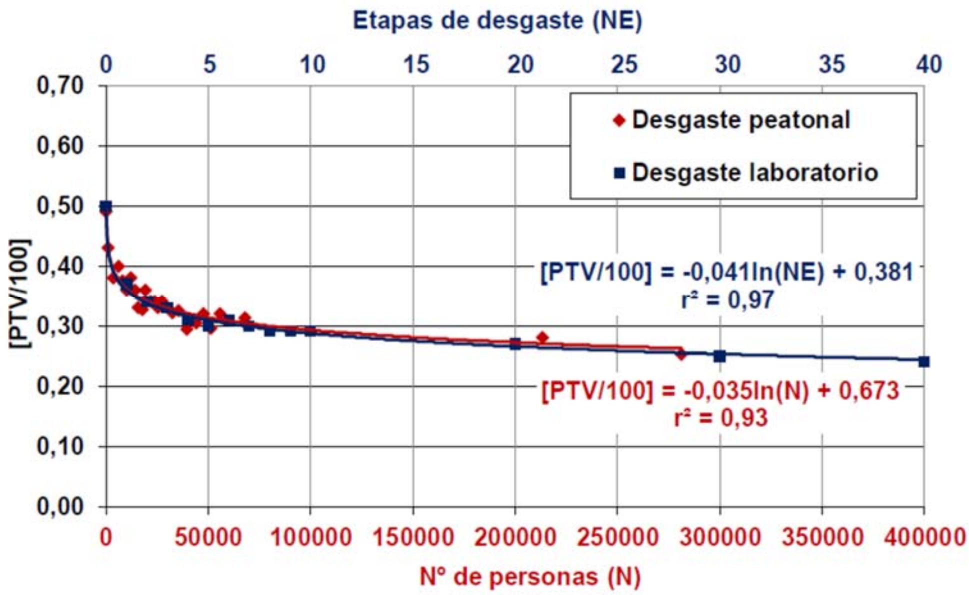


Figure 4 A comparison of the wet pendulum slip resistance of a matt glazed extruded stoneware tile with irregular relief after exposure to pedestrian traffic and cumulative AWC stages.

Fact checkers required

There are too many unidentified unsubstantiated statements in the public domain. When we conduct studies, we observe trends and reach generalised conclusions for public consumption. As some elements of studies may not be published in detail, our conclusions may become more authoritative, particularly with increased research experience. However, our samples may only be subsets of the total ceramic tile or flooring population. A sample may be biased towards particular subsets, just as it may be compromised by missing subsets. We need to know the limitations associated with generalisation before they become regarded as indisputable facts.

Muñoz has studied many more tile types than normal, sensibly describing their characteristics according to a psychophysical classification, pictorially, and in terms of their surface roughness. In conducting such a detailed study over such an extended period, not all the specimens could be exposed to extensive foot traffic or subjected to her AWC procedure. While some tiles behave better than others, and she may be able to explain this in terms of chemical or mineralogical composition, there is only so much detail that one can go into in most publications.

Authors must be cautious when summarising the work of others and then reporting conclusions, particularly if they are making broad generalisations without any form of qualification and without reference to the original authors. While the world seeks simplification, an unfortunate aspect is that the simplification process often leads to statements that are mistaken as factual and all-encompassing, particularly when published in guidance that supports the use and application of standards. We need to identify any half-truths and maliciously biased content. We must modify or delete misleading material, providing any necessary clarification and, ideally, readily accessible supporting references. Since much practice and experience is never captured in publications, and not all papers are readily accessible (often due to language limitations), we are likely to be unable to locate papers when we search for the evidence to substantiate some statements that may have derived from anecdotal comments based on niche circumstances.

The preceding broad review of some of the issues involved in slip resistance testing and specification practices would ideally have been complemented with several litigious examples that confirm the nature of some associated problems with the slip resistance Standards, their specification in Building Codes, and other circumstances .

Several issues do not appear to have not been addressed in the drafting of prEN 16165, where it should be noted that AS 4586 has included the wet pendulum test method, the two German ramp tests and a dry tribometer test (not the GMG 200) since 1999. Given that CEN/TC 339 was created in mid-2001, it is disappointing that there is no evidence of any determined intent to realise the very reasonable EU expectation that floor surfaces should be safe at the end of an economically reasonable working life. In circumstances where the drafting process is allowed to become protracted, Standards will eventually be published. This may please those seeking to protect a status quo.

The acceptance of slip resistance standards that are capable of improvement appears to be commonplace. Given our seeming acceptance of somewhat flawed test methods, should we expect the impossible, that a single AWC procedure will be suited to all flooring surface materials and exposure conditions?

In Australia, Bowman has proposed the use of Strautins AWC procedure to provide an indication of the probable level of slip resistance at the end of an economically reasonable working life, presuming that floors are sympathetically maintained. Such an AWC procedure might be used by manufacturers who consider it appropriate. Other suppliers might consider it appropriate to declare a compatible (end of service life) maintenance value. Specifiers might then choose to select products based on such end of service life slip resistance expectations. Where products experience little change in slip resistance, they would no longer be discriminated against by the inflated values used in the higher classifications. When initially proposing the SA HB 197 recommendations, Bowman allowed for a slip resistance loss of 10 to 20 BPN units based on brick industry data for brick pavers (something he has not previously disclosed). He also considered that less loss would occur in products that initially had lower levels of slip resistance, such that it might even be considered negligible for products with 25 BPN or less, where the results may be more susceptible to the relative accuracy with which one can make wet pendulum measurements.

However, since Muñoz has disclosed losses of up to 30 BPN with some ceramic tiles[9], we must now consider whether such guidance is fit for purpose. Muñoz' AWC procedure suggests that further wear will occur (when do the processes of degradation ever cease?) and that this will lead to further losses of slip resistance, particularly in highly trafficked areas. Muñoz has disclosed losses of 4 to 6 BPN of three tile types on or just above the 15 BPN class 1 threshold, where 20,000 uses might void the lifetime requirement. The relative accuracy of pendulum measurements may become quite important in such contexts. Muñoz has reported that the loss can be so important in some cases, that, after one or two years of its installation, it may no longer be suitable for the place where it is placed, especially if it is a public area and high traffic.

Flat profiled specimens, with high values of slip resistance were observed to experience a greater loss of slip resistance in the initial stages of wear, stabilizing after the transit of approximately 50,000 people. Wavy profiled and embossed samples generally maintained their slip resistance better throughout the wear process, albeit being somewhat dependant on their original profile. Muñoz' findings on profiles, slip resistance loss and cleanability needs to be considered together with Engels' many contributions.

It is probably again worth considering, in an historical context, that as specimens become more worn, they are likely to lose some slip resistance as a consequence of the smoother nature of the rubber being used. Products that were once considered to have sustainable slip resistance might need to be re-evaluated.

How then does one progressively introduce productive reforms? Bowman has proposed the use of Strautins AWC procedure for selecting products that are likely to provide reasonably economic lifetime performance, although he has not sought to define how many uses this might represent. While Muñoz has had the data to equate each stage with pedestrian use, such quantification has still to be undertaken for Strautins procedure. The most expedient means of doing so might be for ITC to undertake the work on specimens where the pedestrian usage history has been established.

Muñoz has developed an AWC procedure where each stage fortuitously corresponds to the passage of ten thousand people. Such results can only be converted into time by assuming similar wear conditions to those at the ITC campus, and by assuming expected user numbers. The equivalent result for a stage may be in units of days or years depending on location and circumstances. Based on the knowledge generated during the development of her AWC procedure, Muñoz has recommended developing a smaller but equally effective transportable device, where it may be possible to fine tune Strautins procedure to obtain wear and tear commensurate with that produced by pedestrian traffic. Again such work might be conducted at ITC. It could even be extended to looking at different pads for better simulating wear in wet barefoot areas or other locations that may be of high interest.

Even without such validation of the Strautins procedure, one might make a series of assumptions about how much wear is appropriate for specific locations. However, a more pressing issue is how much slip resistance is required in various locations to cater for the whole population, and whether less traction is acceptable in some circumstances. This essentially requires an

[9] Tile 2.8 decreased from the very top of class 2 (Rd = 45) to class 0 (Rd = 13) after the passage of little more than 30,000 people. In Australia, the tile would fall from the highest class P5 to the equivalent of the lowest class for slider 55, P1. Only new products are classified by the Australian standards.

understanding of where slip-initiated falls are occurring, whether they were due to genuine slips, and, if so, what was the slip resistance at that time and were there any unusual or mitigating circumstances (reckless behaviour, maintenance issues, etc.)? Furthermore, is the traction available at those incident sites typical or atypical of such locations? Ideally one should establish lifetime minimum requirements based on real needs and risks rather than theoretical safety doctrinaire. If one considers that the risk of slipping on a wet surface with Rd = 35 is one in a million if an unencumbered person paying normal care and attention is walking in a straight line, then the difference between the SUA requirements might reflect the relative risk of someone encountering a wet surface in a dry area, an internal wet area, and an external area where there may be minimal maintenance and people may want to hurry to avoid getting wet. If the risk of slipping on a floor surface with Rd = 24 is one in twenty, and much higher where the slip resistance is lower, there is an increasing need to keep such surfaces clean and dry and to pay considerable attention to them when they are being used.

If a project was to be specified where the minimum lifetime resistance was to be Rd = 35, 25 or some other figure, there would still be a benefit in auditing floors to ensure that their slip resistance correlates with AWC data and expectations of appropriate maintenance practices.

The availability of such AWC data presents a valuable opportunity for tile manufacturers to improve the slip resistance performance of their product range and to better ensure that the most appropriate types of surfaces are specified for particular projects. Cleanability is an important characteristic that needs to be considered as an element of the tiling specification. Soiling also reduces slip resistance. There is little point in having to expose products to onerous cleaning regimes if this causes wear that reduces the effective slip resistance life cycle.

Engels (2018) has reported that in Germany are increasingly commissioned to evaluate slip resistance as a function of the wear to be expected on tile surfaces in private and occupational areas. He has questioned the choice of reference surfaces given their characteristics and their changed slip resistance performance as they wear. Both surface topography measurements and defined abrasion simulation have a high potential to help manufacturers of slip resistant tiles to investigate, develop and control durable slip resistant surfaces. Continuative investigations are essential to live up to growing requirements regarding reliable safety in use, as is included in international and national regulations, and to match these with the high aesthetic quality which the market requires. He has identified the need to develop reliable, controllable and transferable sets of reference surfaces for the slip resistance measurement methods.

IN CONCLUSION

When it comes to establishing appropriate maintenance values that can be used in building codes, the Slip Resistance Group of Spain may be well placed to assist with ensuring:

- much of the needed data is accumulated;
- the needs of all the relevant sectors are properly considered; and
- any external reviewing takes advantage of an international perspective.

There is much data to be analysed, and any new system would ideally detail all the assumptions made, even if such data is in a separate report.

REFERENCES

Bowman R., (1999) 'An introductory guide to the slip resistance of pedestrian surface materials'. Standards Australia Handbook 197: 1999.

Bowman, R., Strautins, C. and Do, M.D. (2005) Beware of conflicting stone slip resistance reports, Discovering Stone, March 2005, pp 26-36.

Bowman, R. Slip resistance testing - zones of uncertainty, Qualicer 2010, Castellon, 15-16 February 2010. Also Bol. Soc. Esp. Ceram. V. 49, 4, 227-238 (2010)

Bowman, R and Graham-Bowman, N. (2015) Goldilocks, slip resistance and the wicked problem of falls prevention. Proc. 19th IEA Triennial Congress, Melbourne. http://ergonomics.uq.edu.au/iea/proceedings/Index_files/papers/1125.pdf.

Bowman, R. (2016). Can we develop slip resistance metrics that ensure appropriate tile selection? 14th World Congress on Ceramic Tile Quality.

Bowman, R. (2018). The competitive advantages arising from accelerated conditioning of ceramic tiles. 15th World Congress on Ceramic Tile Quality. DOI: 10.13140/RG.2.2.16798.84805

Engels M., Tenaglia A., Tari G., (2008) "The classification of hard floor coverings according to slip risk: a new approach for ceramic floor coverings", Qualicer 2008 Proceedings.

Engels, M., (2016) "New practice-oriented testing possibilities regarding the durability of slip resistance and cleanability", Proceedings of Qualicer 2016.

Engels, M. (2018) The correlation of slip resistance and durability with surface topography, Proceedings of Qualicer 2018.

Engels, M (2020) The importance of surface characterization for slip resistance: an overview. Slips, Trips and Falls Conference, Madrid.

Muñoz-Lázaro, A. Problemática del resbalamiento en pavimentos cerámicos [PhD Thesis]. 2019 Castellón (Spain). Universitat Jaume I, https://www.tesisenred.net/handle/10803/667413#page=1

Natspec Technote DES 001 (2009) Slip resistance performance.

Ozanne-Smith, J., Guy, J. Kelly, M.& Clapperton, A. [2008] The relationship between slips, trips and falls and the design and construction of buildings Monash University Accident Research Centre - Report #281. https://www.monash.edu/muarc/archive/our-publications/reports/muarc281

Silva, G. Muñoz, A. Monterde, B. Quereda, F. (2006). Comparative analysis of slip resistance requirements in trafficked public premises. Qualicer 2006.

Silva, G. Muñoz, A. Felíu, C. Monzó, M. Barberá, J. Soler, C. (2006). Proposal of a standard method for determining the durability of flooring exposed to pedestrian traffic.

M. López , A. Muñoz , R. Domínguez , J. Gilabert , G. Silva , M.C. Segura ,(2014) Analysis of the life span of flooring slip resistance performance**,** Qualicer 2014.

Silva; G., Beltrán; A., Muñoz; A., Escrig; A., Llobell; C., Sanchís; M., Lillo, G. (2018) Optimised combinations of ceramic flooring and footwear for work environments**.** Qualicer 2018.

Silva, G., Muñoz, A., Beltrán, A., Domínguez, R., López, A.M. & Bañuls, M. (2020) Comparative Study of Methods for Simulating Wear in Actual Service Conditions, Qualicer Conference.

Strautins, C. (2008). Sustainable slip resistance: an opportunity for innovation. Qualicer 2008.

Tari G., Brassington K., Tenaglia A., Thorpe S., Engels M., (2009) "SlipSTD Publicly Available Specification (SlipSTD PAS) - Classification of hard floor coverings according to their contribution to reduce the risk of pedestrian slipping", (available M. Engels).

Tari, G., Engels, M., (2008). 'The SlipSTD European Collective Research Project: Development of slip resistant standard surfaces', Qualicer 2008.

FOOTWEAR FOR THE PREVENTION OF HUMAN SLIPS: FROM FRICTION MECHANICS TO ERGONOMIC SOLUTIONS

Kurt E. Beschorner, Ph.D.[1], Sarah L. Hemler, Seyed Reza M. Moghaddam, Ph.D., Arian Iraqi, Ph.D., Mark Redfern, Ph.D.

[1] University of Pittsburgh

beschorn@pitt.edu

ABSTRACT

Slip and fall accidents are an important contributor of slip and fall events. Liquid contaminants are frequently the cause of these accidents. Our research team has aimed to develop novel experimental and modelling methods to characterize the mechanics of shoe-floor friction. Notably, these methods include measuring under-shoe fluid contaminant pressures and using finite element analysis to simulate friction due to contacting shoe and floor surfaces. Applying these methods has revealed new knowledge on the mechanics of shoe-floor friction and identified footwear tread features that are relevant to slip risk. These mechanics-based experiments and models have informed observational assessments that further defines the "real-world" problem. Thus, studies based on rigorous mechanics-based experiments and models can inform practical ergonomic solutions to slip and fall events.

Keywords: slips and falls, coefficient of friction, footwear, hydrodynamic lubrication, hysteresis friction

Topic: Footwear

1. BACKGROUND AND MOTIVATION

Falling accidents are the leading cause of emergency department injuries in both the United States (Centers for Disease Control, 2016) and the European Union (Eurosafe, 2016). Slipping is a common cause of falls among workers and community-dwelling adults (Berg et al., 1997; Courtney et al., 2001; Talbot et al., 2005). Slips commonly occur due to the presence of liquid contaminants (Bell et al., 2008). Strategies to prevent falls have the potential to protect individuals against suffering and ease cost burdens.

Increasing friction is a well-established pathway to reduce slip and fall accidents. Friction is commonly assessed using the coefficient of friction (COF), defined as the ratio of friction to normal force. The COF has been found to predict slip and fall accidents both in controlled laboratory settings (Burnfield & Powers, 2006; Hanson et al., 1999; Iraqi et al., 2018) as well as in occupational settings (e.g. (Verma et al., 2011)). Furthermore, interventions like utilizing and even mandating the use of high-performance slip-resistant shoes, which are associated with increased COF (Beschorner et al., 2017; Iraqi et al., 2020; Jones et al., 2018), have been effective at preventing slips (Bell et al., 2019; Verma et al., 2011). Knowledge on friction mechanics may enable the identification and design of even better slip-resistant shoes with the potential to further prevent slip-and-fall events.

Research that connects shoe and floor design to COF performance can be broadly categorized into statistics-based analyses and mechanics-based analyses. For example, statistics-based analyses have been used to quantify the relationship between COF and tread design features (Blanchette & Powers, 2015; Iraqi et al., 2020; Jones et al., 2018; K. W. Li & Chen, 2004, 2005; K. W. Li et al., 2006), floor roughness (Chang, 1998; Chang et al., 2004; Chang et al., 2001a; Chang et al., 2010; Cowap et al., 2015; Iraqi et al., 2020; Jones et al., 2018), liquid contaminant properties (W.-R. Chang et al., 2004; Cowap et al., 2015; Jones et al., 2018; Strobel et al., 2012), and testing conditions (Aschan et al., 2005; Beschorner et al., 2019; Beschorner et al., 2007; Grönqvist, 1995; Iraqi et al., 2018). These statistical analyses are important for demonstrating that the above-mentioned parameters have an influence on friction. However, mechanics-based analyses are needed to identify the mechanisms by which these factors influence COF. Mechanics-based studies have modeled contaminant film dynamics (Chang et al., 2001b; Proctor & Coleman, 1988; Strandberg, 1985) and bending mechanics (Yamaguchi et al., 2017) but, overall, mechanics-based analyses are published less frequently than statistics-based analyses. In this paper, we describe our mechanics-based analyses that have identified links between footwear tread design features and slip and fall risk.

2. THIN-FILM FLUID DYNAMICS

The COF occurring between a shoe and floor surface in the presence of a liquid contaminant is the net result of multiple mechanical phenomena. These phenomena can be broadly categorized into thin-film fluid dynamics and contact friction.

Thin-film fluid dynamics are described by the Reynolds' equation, which is derived from the Navier-Stokes equations (Hamrock et al., 2004). The Reynolds' equation relates fluid pressure, film thickness, fluid viscosity and velocities of the two surfaces. The Reynolds' equation can be further solved by assuming simplified geometries and motion profiles. For example, Proctor and

Coleman applied a solution by Fuller for calculating the minimum film thickness, h_0, as a function of fluid viscosity (μ), geometric size (width: *b*, length: *l*) of the shoe sample, sliding speed (*u*), and normal force (*F*), Eq. (1) (Proctor & Coleman, 1988). This solution was based on an inclined rectangle (i.e., the shoe outsole) in steady-state motion relative to a flat surface (i.e., the floor).

$$h_0 = \sqrt{\frac{6\mu u b l^2}{F}} \tag{1}$$

Our research team has utilized a combination of modeling and experimental methods to: 1) quantify the contribution of thin-film fluid dynamics to shoe-floor friction; and 2) quantify the contribution of shoe design on fluid dynamics. This work has determined that fluid dynamics are powerful for explaining how shoe design influences friction in some, but not all, circumstances.

Our research into thin-film fluid dynamics are largely enabled based on new experimental techniques to measure fluid pressures in the shoe-floor interface. Our research team has embedded fluid pressure sensors in the floor surface such that the top of the sensor is in the same plane as the floor surface (Beschorner et al., 2014; Singh & Beschorner, 2014) This technique has revealed that fluid pressures can be substantively high in cases when shoes lack drainage channels (i.e., no channels designed into shoe or the tread has become worn) and a high viscosity contaminant is present (Fig. 1A) (Beschorner & Singh, 2012; Hemler et al., 2019; Singh & Beschorner, 2014). Subsequently, thin-film mechanics principles do not seem appropriate for describing factors that influence friction in the presence of low-viscosity fluids (water) or for shoes with well-designed drainage channels.

A: B:

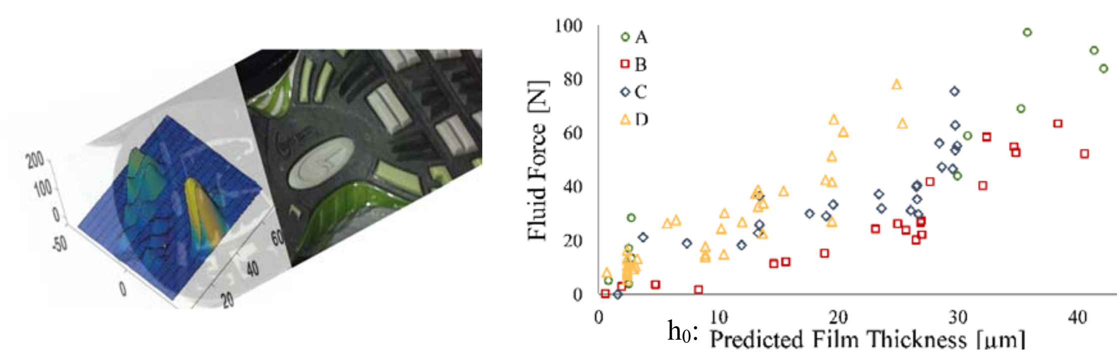


Figure 1: Modeling and experimental work on fluid dynamics. A: Experimentally-measured fluid pressures across a shoe tread surface; B: Correlation between model predictions and measured fluid force (reused from (Hemler et al., 2020a) with permission from Elsevier Ltd).

Fluid pressures appear to be the link between worn shoes and an increase in slipping risk. As shoes become worn, we have noted an increase in under-shoe fluid pressures, which are simultaneously associated with a reduction in COF (Beschorner & Singh, 2012; Hemler et al., 2019; Hemler et al., 2020b) and an increase in slipping severity (Beschorner et al., 2014). As shoe tread wears, a worn region develops on the heel surface, which grows as the shoe continues to wear (Hemler et al., 2020a; Hemler et al., 2019; Hemler et al., 2020b; Moghaddam et al., 2019). The equations presented by Fuller (Fuller, 1956) and applied to slipping accidents by Proctor and Coleman (Proctor & Coleman, 1988) predict the experimentally-measured under-shoe fluid dynamics based on the size of the worn region (Fig. 1B) (Hemler et al., 2020a). Thus, the risk of unfavorable under-shoe fluid dynamic conditions can be estimated based on the size of the worn region.

3. FRICTION OF CONTACTING ASPERITIES

Friction occurring at the shoe-floor contact interface can be further divided into friction generated by adhesion or hysteresis (Chang et al., 2001b; Strobel et al., 2012). Adhesion is sensitive to fluid viscosity with higher viscosity/longer molecular chain fluids causing reduced adhesion forces (Cowap et al., 2015; Sivebæk et al., 2004; Strobel et al., 2012). When applied to oily contaminants, adhesion is believed to minimally contribute to friction (Cowap et al., 2015; Moghaddam et al., 2015). Hysteresis friction is caused by energy lost in elastomeric shoe tread material during sliding (Moghaddam et al., 2015; Moore, 1972). As a shoe slides across a floor surface, cyclic deformation of the shoe material will occur as it encounters alternating peaks and valleys of the floor asperities. More energy is typically required to compress an elastomer than is released during relaxation (a process known as hysteresis), which leads to energy loss during sliding. The force required to offset this energy loss is known as hysteresis friction. Unlike adhesion friction, hysteresis friction is not believed to be sensitive to the liquid contaminant present in the shoe-floor interface (Cowap et al., 2015; Strobel et al., 2012). Thus, enhancing hysteresis friction is expected to yield surfaces capable of high COF even in oily conditions.

We have developed new modeling techniques to quantify and predict friction of contacting asperities. This research is applicable to oily conditions where fluid pressures are minimal (i.e., applicable to shoes with tread channels) (Hemler et al., 2019). Specifically, a multiscale finite element model was developed to simulate the hysteresis friction across the shoe surface. A micrometer-scale model was developed to simulate the friction originating in the sliding between floor asperities and elastomeric shoe materials (Fig. 2A) (Moghaddam et al., 2015). The micrometer-scale model was performed at varying contact pressures and the hysteresis friction was quantified as a function of contact pressure (Moghaddam et al., 2018). A separate model was performed of the whole shoe tread against the floor surface to simulate the contact pressures across the shoe surface (Fig. 2B). The results from the micro-meter scale model were then mapped to the whole-shoe model based on the contact pressures. This model was validated against experimentally-measured contact area, contact pressures, and COF (Fig. 2C) (Moghaddam et al., 2018; Moghaddam & Beschorner, 2018). A key finding from this modeling work was that shoe-floor friction was sensitive to contact pressures. Higher contact pressures were associated with lower COF values. Thus, shoe design features that reduce contact pressures (e.g. beveling the heel (Moghaddam & Beschorner, 2017), reducing hardness (Moghaddam & Beschorner, 2015), increasing surface area) are expected to increase shoe-floor COF.

A: B: C:

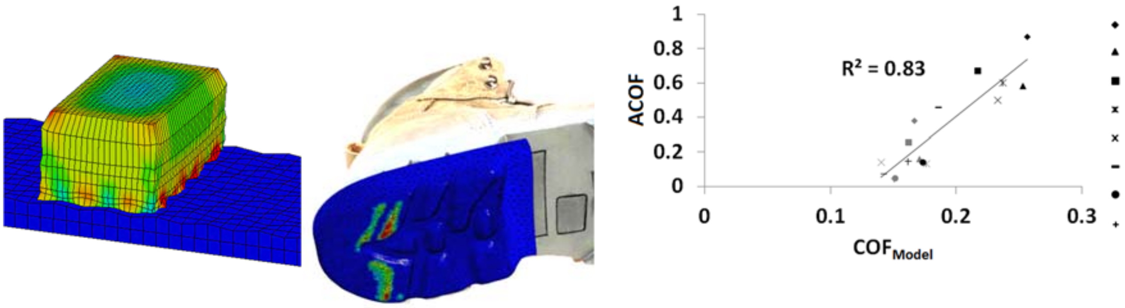


Figure 2: A: Finite element analysis simulation of shoe and floor asperities in relative sliding; B: Simulation of contact pressures across entire shoe surface; C: Comparison between model-predicted COF values (COF_{Model}) and experimentally-measured COF values (ACOF) (Moghaddam et al., 2018).

4. SIMPLE ASSESSMENTS INFORMED BY MECHANICS EXPERIMENTS/MODELS

Our previous work in modeling under-shoe fluid pressures (Beschorner et al., 2009; Hemler et al., 2020b) and experimentally measuring under-shoe fluid pressures (Beschorner et al., 2014; Beschorner & Singh, 2012; Hemler et al., 2020a; Hemler et al., 2019; Hemler et al., 2020b; Singh & Beschorner, 2014) enable confidence in making simplified recommendations. This research demonstrated that the size of the worn region strongly influences fluid dynamics and COF when walking, especially when shoes are intended to be used in conditions where high viscosity contaminants are present (oil, bio-fluids, etc.). Both models and experimental data revealed that under-shoe hydrodynamic conditions were sensitive to the size of the worn region. Thus, these mechanics-based studies informed a simple parameter (size of the worn region), which appears salient in predicting under-shoe hydrodynamics. Importantly, the size of the worn region can be easily measured using a ruler or by comparing the worn region to a common object (i.e., a AAA battery) (Fig. 3A) (Beschorner et al., 2020).

A: B:

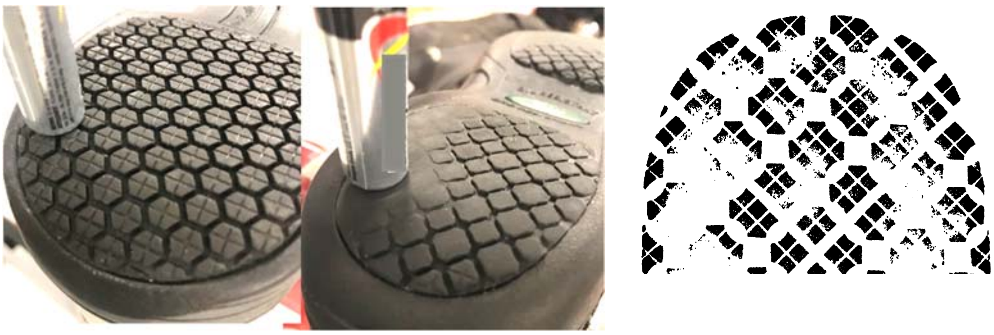


Figure 3: A: Using the base of a AAA battery to assess the size of the worn region. B: Tread surface area imprint made using ink and paper.

Follow-up experimental work was performed to confirm whether shoe tread features that were predicted to improve COF actually achieved that result. We performed an experimental study that used statistical modeling methods but targeted tread parameters that were predicted to improve COF (heel beveling, hardness, and surface area). These parameters were strongly associated with COF consistent with model predictions. In fact, this study discovered that reasonable predictions of shoe-floor friction could be made based on a few shoe tread parameters (tread surface area, Shore A hardness, and heel beveling), which could be collectively measured for under $100 (Iraqi et al., 2020).

5. LOOKING FORWARD: OPPORTUNITIES TO EXTEND SHOE-FLOOR COF RESEARCH

Extending these research findings beyond laboratory walls could provide vital insight into demonstrating the real-world utility of the developed footwear assessment tools. Our research (Beschorner et al., 2020; Iraqi et al., 2018; Iraqi et al., 2020) and that of others (Health and Safety Executive, 2020; Wilson, 1990) have developed new methods for assessing shoe tread. Greater confidence in the validity and utility of these various metrics could be realized through epidemiological research (prospective cohort study or intervention-based studies). A coordinated effort that tracked natural slips would provide needed insight into the benefits and weaknesses of these assessments.

Improving mechanistic models is also necessary. For example, incorporating small-scale topography has the potential to improve our understanding of shoe-floor mechanics. Floor topography, and to a lesser extent, shoe topography, are known to influence the shoe-floor friction (See Section 1). Preliminary data (Jacobs et al., 2018) and mechanics models (Hyun & Robbins, 2007; Persson, 2006) suggest that small-scale topography could have a major contribution to shoe-floor friction. Different topographical/roughness scales (mm-scale versus µm-scale) contribute to different aspects of friction (Chang et al., 2004). However, we have an incomplete understanding on how smaller scales (sub µm-scale) contribute to shoe-floor friction. This limited knowledge is due to the technical limitations in stylus and interference profilometry (Jacobs et al., 2017), which are commonly used in shoe-floor friction research. Utilizing other measurement systems such as optical microscopy, scanning electron microscopy, and transmission electron microscopy can unlock new topographical information at the nm and Angstrom scale. Recent spectral analysis methods have enabled characterizing roughness and quantifying roughness parameters (i.e., average slope of asperities) that utilize the full range of scales (Jacobs et al., 2017). Thus, opportunities exist to improve understanding of friction and design the next generation of high traction materials by considering the role of smaller scales.

The fundamental mechanics of adhesion friction, based on intermolecular forces, is still not easily predictable for shoe-floor-contaminant friction, but could also lead to improved design. Adhesion is relevant to slips that occur in wet but not oily conditions. Recently, the spreading coefficients (based interfacial surface energies) were found to correlate with COF (Nishi et al., 2020; Shibata et al., 2019). In addition to understanding the intermolecular forces, predicting adhesion also requires estimation of the real area of contact (Nishi et al., 2020; Shibata et al., 2019). While different mechanics-based models are available for making these estimations (Greenwood & Williamson, 1966; Persson, 2001) in the tribology and contact mechanics disciplines, models to predict shoe-floor friction will require a substantial dedicated research effort. However, such work has the potential to extend the modelling efforts presented within this paper to a broader range of surface conditions including wet, soapy, and dry conditions.

Lastly, extending shoe-floor-contaminant friction to outdoor walking surfaces is a major opportunity. Work at Toronto Rehabilitation Institute has extended shoe assessment research to include shoe-ice friction. This research has established test methods for evaluating shoes (Hsu et al., 2015; Hsu et al., 2016), developed mechanics models for how elastomers with embedded filaments can enhance friction (Rizvi et al., 2015), and developed tools for their results to be utilized by consumers (Idapt, 2017). To a lesser extent, slip and fall research has also started to expand into soil and solid contaminants (gravel, soil, clay, salt) (Clarke et al., 2013; Li & Pei, 2014; Mills et al., 2009). Continuing this work to expand shoe-floor research to develop new experimental methods and simulation techniques relevant to outdoor surfaces will greatly expand our ability to prevent outdoor slip and fall accidents.

6. ACKNOWLEDGEMENTS

This research was funded by the National Institute for Occupational Safety and Health (R01 OH 010940, R01 OH 008986), the National Institute of Arthritis and Musculoskeletal and Skin Diseases (R43AR064111), and the National Science Foundation (NSF GRFP 1747452).

7. REFERENCES

Aschan, C., Hirvonen, M., Mannelin, T., & E., R. (2005). *Applied Ergonomics, 36*, 585-593.

Bell, J. L., Collins, J. W., & Chiou, S. (2019). *Scandinavian journal of work, environment & health, 45*(2).

Bell, J. L., Collins, J. W., Wolf, L., Grönqvist, R., Chiou, S., Chang, W.-R.,. Evanoff, B. (2008). *Ergonomics, 51*(12), 1906-1925.

Berg, W. P., Alessio, H. M., Mills, E. M., & Tong, C. (1997). *Age and ageing, 26*(4), 261-268.

Beschorner, K., Lovell, M., Higgs III, C. F., & Redfern, M. S. (2009). *Tribology Transactions, 52*(4), 560-568.

Beschorner, K. E., Albert, D. A., Chambers, A. J., & Redfern, M. R. (2014). *Journal of biomechanics, 47*(2), 458-463.

Beschorner, K. E., Iraqi, A., Redfern, M. S., Cham, R., & Li, Y. (2019). *Ergonomics, 62*(5), 668-81.

Beschorner, K. E., Jones, T. G., & Iraqi, A. (2017). *The Combined Benefits of Slip-Resistant Shoes and High Traction Flooring on Coefficient of Friction Exceeds Their Individual Contributions.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Beschorner, K. E., Redfern, M. S., Porter, W. L., & Debski, R. E. (2007). *Applied Ergonomics, 38*(6), 773-780.

Beschorner, K. E., Siegel, J. L., Hemler, S. L., Sundaram, V. H., Chanda, A., Iraqi, A., . . . Redfern, M. S. (2020). *Applied Ergonomics, in review*.

Beschorner, K. E., & Singh, G. (2012). *A Novel Method for Evaluating the Effectiveness of Shoe-Tread Designs Relevant to Slip and Fall Accidents.* Paper presented at the Human Factors and Ergonomics Society, Boston, MA.

Blanchette, M. G., & Powers, C. M. (2015). *Applied Ergonomics, 50*, 237-241.

Burnfield, J. M., & Powers, C. M. (2006). *Ergonomics, 49*(10), 982-995.

Centers for Disease Control. (2016). *National Estimates of the 10 Leading Causes of Nonfatal Injuries Treated in Hospital Emergency Departments, United States - 2015*. Atlanta, GA Retrieved from https://www.cdc.gov/injury/images/lc-charts/leading_causes_of_nonfatal_injury_2015_1050w760h.gif

Chang, W.-R. (1998). *Safety science, 29*(2), 89-105.

Chang, W.-R., Grönqvist, R., Hirvonen, M., & Matz, S. (2004). *Ergonomics, 47*(8), 890-906.

Chang, W.-R., Kim, Manning, D. P., & Bunterngchit, Y. (2001a). *Ergonomics, 44*(13), 1200-16.

Chang, W.-R., Matz, S., Grönqvist, R., & Hirvonen, M. (2010). *Applied Ergonomics, 41*(1), 27-33.

Chang, W. R., Gronqvist, R., Leclercq, S., Myung, R., Makkonen, L., Strandberg, L., . . . Thorpe, S. C. (2001b). *Ergonomics, 44*(13), 1217-1232. Retrieved from 11794765

Clarke, J., Carre, M. J., Damm, & Dixon, S. (2013). *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 227*(3), 149-60.

Courtney, T. K., Sorock, G. S., Manning, D. P., Collins, J. W., & Holbein-Jenny, M. A. (2001). *Ergonomics, 44*(13), 1118-1137. Retrieved from 11794761

Cowap, M., Moghaddam, S., Menezes, P., & Beschorner, K. (2015). *Tribology-Materials, Surfaces & Interfaces, 9*(2), 77-84.

EuroSafe. (2016). *Injuries in the European Union, Summary on injury statistics 2012-2014*. Amsterdam

Fuller, D. D. (1956). *Theory and practice of lubrication for engineers*: Wiley New York.

Greenwood, J. A., & Williamson, J. P. (1966). *Proceedings of the royal society of London. Series A. Mathematical and physical sciences, 295*(1442), 300-319.

Grönqvist, R. (1995). *Ergonomics, 28*, 224-241.

Hamrock, B. J., Schmid, & Jacobson, B. O. (2004). *Fundamentals of fluid film lubrication*: CRC press.

Hanson, J. P., Redfern, M. S., & Mazumdar, M. (1999). *Ergonomics, 42*(12), 1619-1633.

Health and Safety Executive. (2020). *GRIP ratings*. Retrieved from https://www.hsl.gov.uk/publications-and-products/grip/grip-ratings

Hemler, S., Charbonneau, D., & Beschorner, K. (2020a). *Tribology International*, 106161.

Hemler, S., Charbonneau, D., Iraqi, A., Redfern, M. S., Haight, J. M., Moyer, B. E., & Beschorner, K. E. (2019). *Applied Ergonomics, 80*(October 2019), 35-42.

Hemler, S. L., Pliner, E. M., Redfern, M. S., Haight, J. M., & Beschorner, K. E. (2020b). *Journal of safety research, in review*.

Hsu, J., Li, Y., Dutta, T., & Fernie, G. (2015). *Applied Ergonomics, 50*, 218-225.

Hsu, J., Shaw, R., Novak, A., Li, Y., et al. (2016). *Ergonomics, 59*(5), 717-728.

Hyun, S., & Robbins, M. O. (2007). *Tribology International, 40*(10-12), 1413-1422.

iDapt. (2017). Rate My Treads. Retrieved from http://www.ratemytreads.com/

Iraqi, A., Cham, R., Redfern, M. S., & Beschorner, K. E. (2018). *Applied Ergonomics, 70*, 118-126.

Iraqi, A., Vidic, N. S., Redfern, M. S., & Beschorner, K. E. (2020). *Applied Ergonomics, 82*, 102963.

Jacobs, T. , Junge, & Pastewka (2017). *Surface Topography: Metrology and Properties, 5*, 013001.

Jacobs, T. D. B., Gujrati, A., Jones, T. G., & Beschorner, K. E. (2018). *Probing the Connection Between Surface Topography and Shoe/Floor Friction in Slip-and-Fall Accidents.* Paper presented at the STLE Annual Meeting, Minneapolis, MN.

Jones, T. G., Iraqi, A., & Beschorner, K. E. (2018). *Applied Ergonomics, 68*, 304-312.

Li, K.-W., & Pei, T. (2014). *Friction measurements on floors under solid contaminated conditions.* Paper presented at the 2014 IEEE International Conference on Industrial Engineering and Engineering Management.

Li, K. W., & Chen, C. J. (2004). *Applied Ergonomics, 35*(6), 499-507.

Li, K. W., & Chen, C. J. (2005). *Safety science, 43*(7), 391-405.

Li, K. W., Wu, H. H., & Lin, Y.-C. (2006). *Applied Ergonomics, 37*(6), 743-748.

Mills, R., Dwyer-Joyce, R., & Loo-Morrey, M. (2009). *Tribology International, 42*(3), 403-412.

Moghaddam, S., Acharya, Redfern, M., & Beschorner, K. (2018). *J biomechanics, 66*, 145-152.

Moghaddam, S. R., & Beschorner, K. E. (2015). *Multiscale Computational Modeling of Shoe-Floor Hysteresis Friction.* Paper presented at the American Society of Biomechanics, Columbus, OH.

Moghaddam, S. R., & Beschorner, K. E. (2017). *Sensitivity of a Multiscale Model of Shoe-Floor-Contaminant Friction to Normal Force and Shoe-Floor Contact Angle.* Paper presented at the Society of Tribologists and Lubrication Engineers, Atlanta, GA.

Moghaddam, S. R. M., & Beschorner, K. (2018). *Tribology & Lubrication Technology, 74*(3), 26-28.

Moghaddam, S., Hemler, S., Redfern, M., Jacobs, T., & Beschorner, K., (2019). *Wear, 422*, 235-41.

Moghaddam, S. R. M., Redfern, M. S., & Beschorner, K. E. (2015). *Tribology Letters, 59*(3), 1-10.

Moore, D. F. (1972). *The friction and lubrication of elastomers, International series of monographs on material science and technology*: oxford: pergamon press.

Nishi, T., Yamaguchi, T., Shibata, & Hokkirigawa, K. (2020). *Tribology International, 141*, 105921.

Persson, B. N. (2001). *The Journal of Chemical Physics, 115*(8), 3840-3861.

Persson, B. N. (2006). *Surface science reports, 61*(4), 201-227.

Proctor, T. D., & Coleman, V. (1988). Slipping, Tripping and Falling Accidents in Great Britain- Present and Future. In *Journal of Occupational Accidents* (Vol. 9). (Reprinted from: (1988)).

Rizvi, R., Naguib, H., Fernie, G., & Dutta, T. (2015). *Applied physics letters, 106*(11), 111601.

Shibata, K., Warita, I., Yamaguchi, T., Hinoshita, M., Sakauchi, K., Matsukawa, S., & Hokkirigawa, K. (2019). *Tribology International, 135*, 89-95.

Singh, G., & Beschorner, K. E. (2014). *IIE Transactions on Occupational Ergonomics and Human Factors, 2*(2), 53-59.

Sivebæk, I. M., Samoilov, V., & Persson, B. (2004). *Tribology Letters, 16*(3), 195-200.

Strandberg, L. (1985). *Ergonomics, 28*(1), 131-147. Retrieved from 3996350

Strobel, C., Menezes, P., Lovell, M., & Beschorner, K. E. (2012). *Tribology Letters, 47*(3), 341-347.

Talbot, L. A., Musiol, R. J., Witham, E. K., & Metter, E. J. (2005). *BMC public health, 5*(1), 86.

Verma, S. K., Chang, W. R., Courtney, T. K., Lombardi, D. A., Huang, Y.-H., Brennan, M. J., . . . Perry, M. J. (2011). *Occupational and environmental medicine, 68*(4), 279-285.

Wilson, (1990). *Slips, Trips, and Falls: Pedestrian Footwear and Surfaces, ASTM STP 1103*, 113-23.

Yamaguchi, T., Katsurashima, Y., & Hokkirigawa, K. (2017). *Tribology International*.

TECHNICAL SESSIONS (I)
Safety Standards, Regulations and Design Criteria. The role of Architectural Design

PLAN EILA: SPANISH CONTRAST INTERLABORATORIES ESSAYS

Victoria A. Viedma Peláez[1], Fernando Meseguer Peña[1], Emilio Meseguer Peña[1], Elvira Salazar[2]

[1] Coordinación General del EILA de CICE- SACE

[2] Comité de Infraestructuras para la Calidad de la Edificación (CICE)

vaviedma@gmail.com

ABSTRACT

In 2010 comes into effect the "*Royal Decree 410/2010 whereby requirements are developed to testing entities and laboratories of assays for quality control of the construction, for the exercise of its activity"* and with it disappears public administration accreditation. The laboratories of assays must have implemented a system of quality management according to the UNE-EN ISO/IEC 17025 standard, which indicates as one of the activities to ensure the quality of the results of tests is participation in comparisons ring or proficiency testing programs.

The Administrative Subcommittee for the Quality of the Construction (SACE), in which all the Regional Councils are members, agreed in October 2013, organizing in five- year period the "Spanish Interlaboratory Tests Plan" (EILA) at the national level.

EILA has been developing every year from 2014. We can say that the level of participation has been increasing and EILA 2019 surpass 200 laboratories throughout Spain. It is carried out around 10-15 tests between concrete and building materials and looked for among the most frequent in daily activity. On this occasion, we will focus on the wet friction pendulum test demanded in the National Building Code (EILA 2017 and EILA 2019).

It involved all kinds of laboratory of assays. It didn´t seek the best results but it assessed by calculating intra- and interlaboratory reproducibility in the "real world", with street laboratories of assays. There isn´t a Patron laboratory in the intercomparison, discusses the contrast itself.

Keywords: contrast interlaboratory assay, UNE EN 17025, laboratory values of intra- and interlaboratory reproducibility, performance of the assay procedure, Protocol.

Topic: Improvement of the Quality of the Building

1. BACKGROUND

1.1 Building tradesmen

Building quality control testing entities and laboratories are defined as building agents in Article 14 of Law 38/1999, of 5 November, on Building Regulations.

Paragraph 2 of that article defines **the testing laboratories for building quality control** (Lecces) and paragraph 3 of the same article 14 establishes the obligations of the quality control laboratories:

"(a) To provide technical assistance and deliver the results of its activity (...)

(b) Prove that they have a quality management system in place which defines the procedures and methods for testing or inspection used in their activity and that they have adequate capacity, staff, means and equipment"

1.2 Criteria and requirements for the organization, coordination, and development of an inter-laboratory comparison exercise

In Annex II of the "*Royal Decree 410/2010 which develops the requirements for building quality control bodies and testing laboratories for quality control of the building, for the exercise of their activity*" sets out the requirements to be met by quality control laboratories:

a) To list the tests they carry out, in the document called Responsible Declaration.

b) To have implemented a quality management system in accordance with the **UNE-EN ISO/IEC 17025 standard**.

c) Comply with **safety, technical and environmental condition**s.

1.3 Administrative subcommittee for building quality (SACE)

Royal Decree 315/2006, of 17 March, which created the Council for Sustainability, Innovation and Quality in Building (CSICE), **created SACE, the Administrative Sub-Committee for Building Quality**, which advises the Commission for Building Quality and among the functions to be carried out, facilitates cooperation between the Autonomous Communities and the General State Administration, in relation to actions to promote quality in building and proposes the modification of the requirements for entities and laboratories, as well as carrying out evaluation and contrast activities between them.

With these two functions in mind, the Administrative Subcommittee for Building Quality (SACE), at the proposal of the **Committee on Infrastructures for Building Quality** (CICE), approved on 20 November 2013, the **Interlaboratory Testing Plan (EILA) 2014-2019**, a plan that is being developed at a national level, on an annual basis and proposing the testing of building materials and products.

2. PLAN EILA 2014-2019

The **basic objectives of the EILA plan** are as follows:

- To evaluate the competence of the laboratories,
- Improve knowledge of the procedure and the accuracy of the different test methods,
- To promote and ensure the quality of services provided by laboratories with a responsible declaration
- To provide each LCCE with one of the tools for monitoring the validity of the test results, in order to ensure the quality of the results of their tests, according to sections 4.2.1 and 5.9 of **UNE EN ISO/IEC 17025:2017.**

In short, these quality control procedures highlight "the capacity of the laboratories to carry out a specific test, obtaining external information with which the laboratory ensures, as far as possible, that the validation of its procedure and its internal quality control strategy are sufficiently effective, and ensures with a certain degree of confidence that it is not biased in its routine results.

2.1 Rules for application in intercomparison exercises or proficiency testing

The regulations applicable to intercomparison exercises or proficiency tests are as follows:

- **ISO/IEC Guide 43-1:1997** Proficiency testing by interlaboratory comparisons Part 1: Development and functions of proficiency testing schemes
- **UNE EN ISO/IEC 17043:2010** Conformity assessment. General requirements for proficiency testing.

The statistical treatment of the results obtained by the laboratories is analyzed following:

- **UNE 82009-2:1999** "Accuracy (truthfulness and precision) of results and measurement methods. Part 2: Basic method for the determination of repeatability and reproducibility of a method
- **UNE-EN ISO/IEC 17043:2010** "Conformity assessment. General requirements for proficiency testing"

In addition, the assistance documents drawn up by ENAC for carrying out intercomparison exercises are applied:

- **NT-03** "ENAC Policy on Intercomparisons".
- **G-ENAC-14** "Guide on participation in intercomparison programmes".

2.2 Participation in EILA

It consists of carrying out tests on concrete and building materials and products, for which the laboratories declare that they meet the applicable requirements.

- Starting hypothesis:
  - 461 laboratories declared (Lecces) and registered in the Technical Building Code (CTE)
  - 17 Autonomous Administration (CCAA)

  - Coordination and management of the Eduardo Torroja Institute
  - Testing of building materials and products and concrete.
- TERRITORIAL organization:
  - Ministry of Development
  - Coordinators of the Autonomous Administration
  - EILA General Coordinators
  - Coordination and management of the Eduardo Torroja Institute

CC.AA.	Materiales					
	2014	2015	2016	2017	2018	2019
Andalucía	23	14	20	23	26	26
Aragón	9	8	13	12	13	10
Asturias	--	4	4	3	3	4
Baleares	6	7	7	8	7	8
Canarias	8	11	9	12	10	13
Cantabria	6	5	5	2	3	4
Castilla La Mancha	12	9	11	10	9	8
Castilla León	13	12	12	10	8	11
Cataluña	12	10	17	13	10	12
Extremadura	6	2	3	3	4	4
Galicia	3	4	3	5	6	7
La Rioja	2	3	4	3	4	4
Madrid	14	19	16	17	22	26
Murcia	9	9	10	10	12	11
Navarra	7	8	8	9	6	7
País Vasco	11	9	9	10	9	9
Valencia	16	12	15	12	14	16
TOTAL	**157**	**146**	**166**	**162**	**166**	**180**

Figure 1. Result of participation in the PLAN EILA 2014-2019

3. WET SLIP RESISTANCE TEST

This test has been a constant in the EILA plan, coinciding with the changes and evolutionary developments of the UNE standard in Spain for the determination of the slip resistance value of pavements, in particular with unpolished or poorly polished ceramic tiles:

- **In 2016**, the UNE-ENV 12633:2003 standard was made compliant, in wet, with the participation of 73 laboratories. Four tiles were sent to be cut to test their two halves.
- **In 2017**, with the same test standard: UNE-ENV 12633:2003 and in collaboration with the Eduardo Torroja Institute to carry out research work, it was also done dry, sending a zapata with IRHD 96 hardness and a protocol with its own results sheet to all the participating laboratories. The level of participation in both cases was 72 laboratories. Three 30x60x0.5 cm pieces were sent to be cut to test their two halves.

- **In 2019**, the determination of the slip resistance value in pedestrian traffic pavements was applied. Wet and dry, according to the respective standards UNE-41901 EX and 41902 EX. The level of participation was 68 wet laboratories and 56 dry laboratories. As a novelty in this exercise, not only were some large-sized tiles (100 x 80 cm) sent out, but also the service tests (in situ) were conducted in specific locations. They were sought in 11 Autonomous Administration, inside a building (to control ambient conditions) and in two low spaces: one in a wet room and the other in a dry room. It can be said that the presence of the coordinators and the preparation of a Protocol that indicated step by step everything that the laboratories had to do, has achieved that it is not only a test of high level of effectiveness and good results, but it has also served as complementary training for the workers who carried out the test in aspects that in previous EILAs we had observed Non-conformities.

3.1 EILA16

About the parameters analyzed and requested to the laboratories for the contrast, the following should be highlighted:

- The pendulum check: Of the 73 laboratories, only 38 laboratories did it.
- The ambient conditions of the laboratory were established in standard at 20± 2ºC. As it happened with the previous conditions, most of them comply with it, except for 27.40% that indicate values higher than 22ºC, standing out in some cases with 29.7ºC.
- The test had to be repeated in duplicate so that the statistical analysis and the contrast would make sense, but 39.73% of the laboratories provided the measurement of four tiles, 31.51% tested five tiles, and 28.80% provided the value of the eight tiles requested in the Protocol.
- Statistical results of the 38 laboratories after discarding those that did not perform the verification:

Table 1. Eila16. Statistical results

National (n 38)	**Average**	**Deviation**	**Coef. Variation**
WET SLIP RESIST. TEST	24,89	6,83	27,44

Table 2. Eila16. Results provided by the laboratories that performed the pendulum test

CÓD. LAB.	**ATTACK EDGE**	**VERIFICATION TEST**					**ROOM TEMP**	**WET SLIP**	**UNCERTAINMENT**
73	1,2 mm	70	70	69	69	70	20,8 °C	18	
147	2,0 mm	27	27	26	26	26	23,0 °C	25	5
167	2,0 mm	2	2	2	2	2	21,2 °C	31,95	
30	1,7 mm	59	59	61	61	61	22,0 °C	20	4
41	1,1 mm	69	70	70	70	69	25,0 °C	20	1
92	0,4 mm	61	61	62	61	61	19,6 °C	25,08	10
97	1,2 mm	68	69	69	69	69	27,0 °C	19	3
136	1,5 mm	60	62	61	62	61	22,0 °C	24	
132	2,0 mm	60	60	60	60	60	20,0 °C	24	1
140	1,0 mm	0	0	0	0	0	21,5 °C	22	0,5

CÓD. LAB.	ATTACK EDGE	VERIFICATION TEST					ROOM TEMP	WET SLIP	UNCERTAINMENT
117	0,0 mm	120	118	119	119	120	20,0 °C	20,2	--
144	76,3 mm	62	62	62	62	62	22,0 °C	23	1
127	1,5 mm	60	61	61	60	61	22,0 °C	23	
13	1,4 mm	50	50	49	49	48	20,0 °C	30	1
16	75,7 mm	55	55	55	55	55	21,5 °C	17	
84	1,4 mm	97	96	96	95	96	22,4 °C	17	U=2 (Kp=2 (95,45%))
80	1,5 mm	65	65	65	65	65	21,3 °C	25	
122	1,3 mm	76	75	76	75	76	20,0 °C	24	
143	1,0 mm	60	60	61	60	60	22,0 °C	20	0
165	1,5 mm	58	57	56	56	56	21,0 °C	20	-
175	0,4 mm	58	59	58	58	57	20,0 °C	18,7	-
184	1,5 mm	58	59	58	60	60	20,3 °C	25	±5
51	24,8 mm	62	60	59	57	58	22,0 °C	19	0,1
58	1,0 mm	35	37	35	36	37	20,0 °C	34,56	0,1
63	76,0 mm	35	35	35			22,0 °C	22	
115	126,0 mm	126	126	127	126	126	21,0 °C	53	1,2
119	1,2 mm	58	58	58	59	59	26,6 °C	20	4,5
159	0,3 mm	54	55	54	54	55	21,0 °C		
94	1,2 mm	1	2	3	4	5	29,7 °C	20	
96	2,0 mm	84	84	84	84	84	22,5 °C	20	5
25	2,0 mm	47	46	47	48	46	21,4 °C	30 (CLASE 1)	
110	1,5 mm	60	59	61	61	63	24,0 °C	20	U= ±2 (K=2)
31	20,0 mm	20	21	19	20	21	18,0 °C	35,75	
170	75,8 mm	56	56	56	56	56	20,5 °C	19	1,27
32	1,4 mm	60	60	60	60	60	23,0 °C	20	
145	1,7 mm	59	59	61	61	61	22,0 °C	22	
146	126,0 mm	70	70	70	70	70	21,2 °C	26	
23		97	97	95	97	95	21,0 °C	48,4	
77	1,1 mm	61	62	63	63	63	23,0 °C	36	1,63
17	1,3 mm	55	55	55	55	55	22,0 °C	20	

- **Evidence detected:** Errors in the execution of the test, do not give importance to the previous verification of the pendulum each time it moves, and therefore, do not use 3M 261X Imperial TM Lapping Film grade 3 µm (hereinafter pink film) and also, that it is new for each verification. This makes, even discarding those who did not do the test well, that the dispersion is remarkable, as can be seen in the following figures:

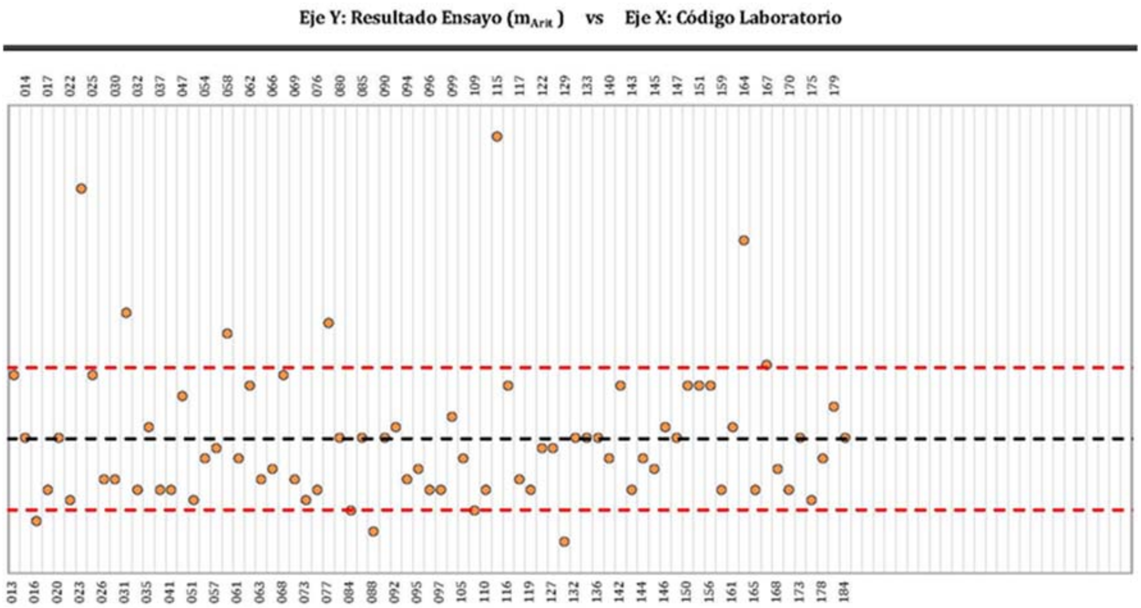


Figure 2. Eila16. XY Diagram Dispersion of the calculation mean according to test standard. The black line marks the mean value and the red lines plus/minus the standard deviation from the mean.

- The z-score assessment, therefore, also showed this variability (27,44%).

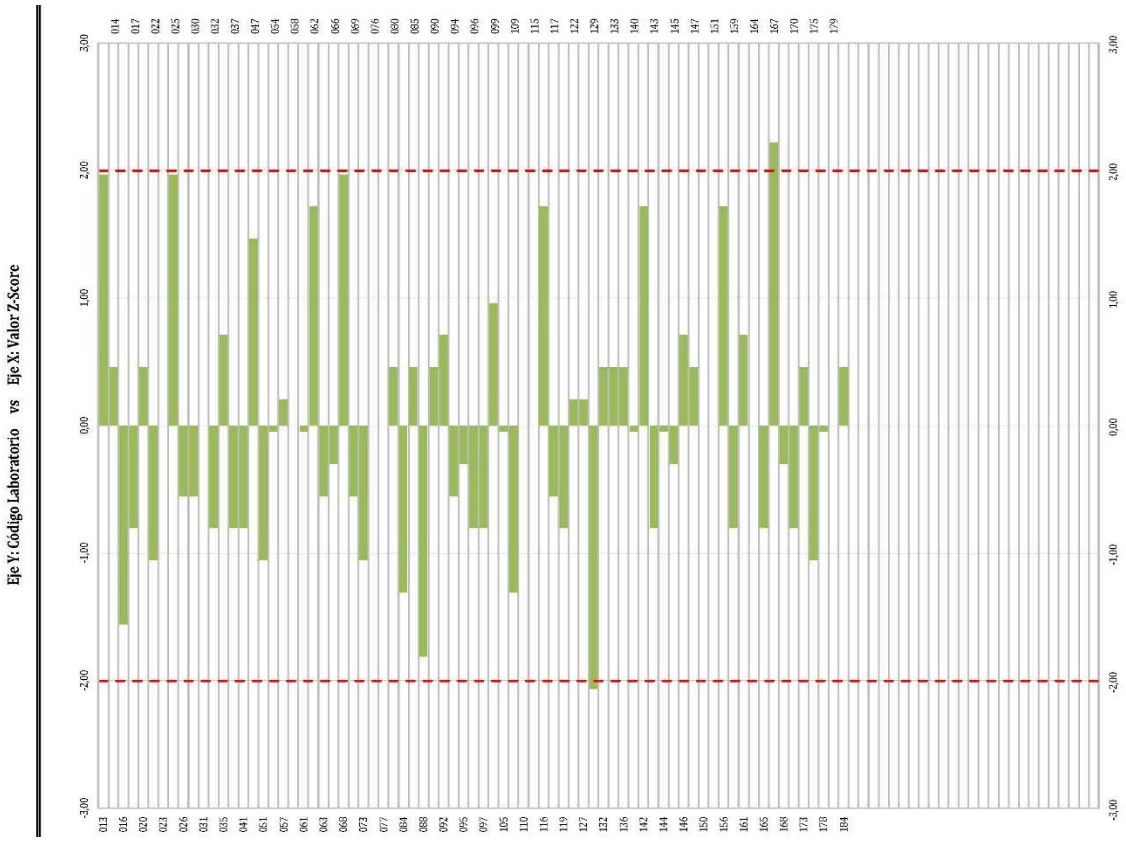


Figure 3. Eila16. Z-score diagram of the results provided by the laboratories Results are considered satisfactory if the absolute value of the Z-score at ≤ 2, Doubtful if it is between 2 and 3 units and Unsatisfactory if it is ≥ 3 units. Satisfactory results are reflected between the two red reference lines in this figure.

3.2 EILA17

About the parameters analyzed and requested to the laboratories for the contrast, the following should be highlighted:

- Pendulum verification: Of the 73 laboratories that provided the last 5 readings, 67 laboratories
- The ambient conditions of the laboratory, which were established in the standard at 20± 2ºC, were met by all but two laboratories with temperatures above 25ºC.
- The calibration of the equipment (the pendulum) provides the date of the same 48 laboratories, and four exceed the 3 years established in the standard.
- The width of the edge of the zapata allowed, between 1mm and 2.5 mm, means that there are 5 laboratories that do not comply.
- The test had to be repeated in duplicate so that the statistical analysis and contrast would make sense, but 13.89% only tested the first three and 86.10 delivered the value of the six tiles requested in the Protocol.
- When the dry test was performed for the first time, and the Protocols sent were not read in detail, some laboratories became confused, not knowing that two tests had to be performed with different footings (the dry one, footings with IRHD 96 hardness, sent through Torroja to all the participants, and the wet one, with the footings owned by the laboratory, of 66-73% (ISO 4662) and IRHD 59±4 hardness (ISO 48)) and in a certain order. This means that, in some cases, they do not perform the test with the appropriate zapata and the tile in the conditions established for doing so.
- Statistical results from 67 laboratories, after discarding those that did not perform the verification, which did not meet the validation criterion and the width of the zapata used:

Table 3. Eila17. Statistical results

National (n 65)	**Average**	**Deviation**	**Coef. Variation**
WET SLIP RESIST. TEST	21,52	12,80	0,59

- **Evidence detected:** Errors in the execution of the test are reduced with respect to the EILA16. The previous verification of the pendulum each time it moves makes it 91.81%, but it is still not clear that they change the pink sheet for each verification. Likewise, the calibration of the equipment that the standard established every three years, 35% does not give the data and the confusion caused by the use of two different shoes, leaves us with doubts about the effectiveness of the test in this exercise.
  Therefore, discarding those who did not do the test well, the dispersion is as can be seen in the following figures:

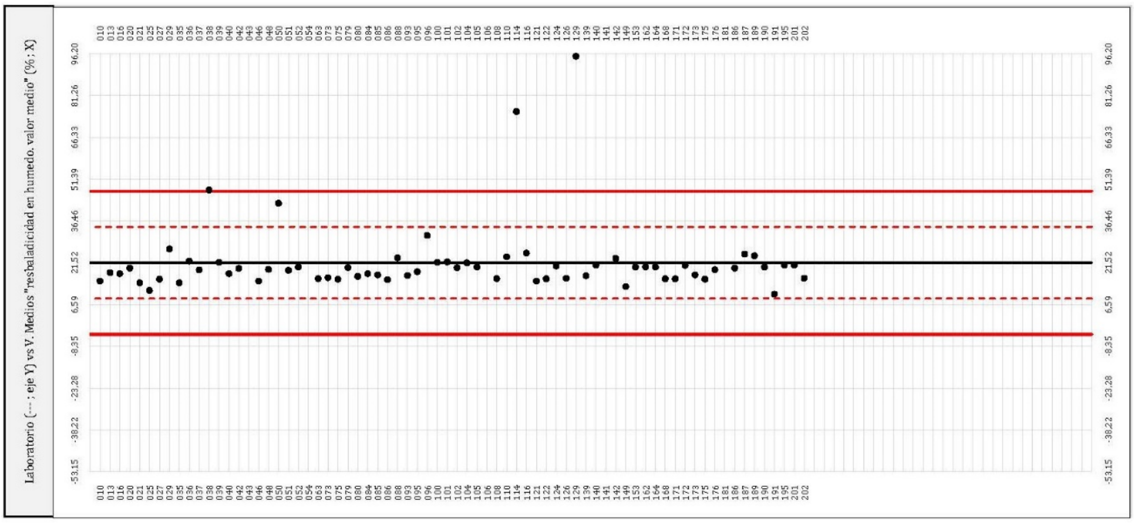


Figure 4. Eila17. XY Diagram Dispersion of the calculation mean according to test standard. The black line marks the mean value and the red lines plus/minus the standard deviation from the mean.

- Therefore, the z-score assessment also showed a significant improvement over the EILA16 in terms of the Coefficient of Variation, but not the Standard Deviation which gave worse results (12,80%).

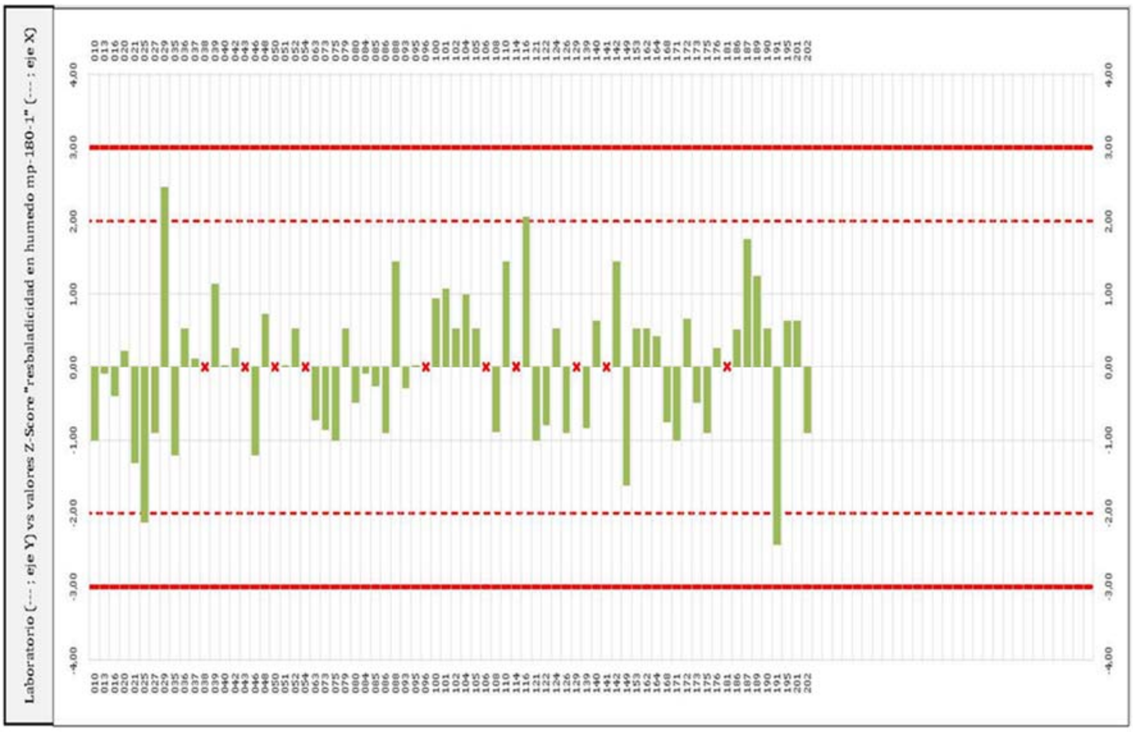


Figure 4. Eila17. Z-score diagram of the results provided by the laboratories Results are considered satisfactory if the absolute value of the Z-score at ≤ 2, Doubtful if it is between 2 and 3 units and Unsatisfactory if it is ≥ 3 units. Satisfactory results are reflected between the two red reference lines in this figure.

3.3 EILA19

About the parameters analyzed and requested to the laboratories for the contrast, the following should be highlighted:

- The verification of the pendulum with the 3M verification foil (pink paper) and the STD-Preference surface: To say that out of the 68 laboratories, only 2 did not perform the 5 oscillations at some point during the test, either at the beginning and/or at the end of the test. On the other hand, the new standard UNE-41901 EX establishes some limits in Table 3 of its section 9: **PTV LAM 60±5** and **PTV STD-P 25±5** that when applied to the laboratories are 8 laboratories that do not comply at the beginning and at the end of the test. However, as established in the particular protocol for this test at EILA19, since the laboratory had moved to perform it, they were included in the statistical analysis but their evaluation was marked as having failed the verification.
- The ambient temperature and the temperature of the tile surface, as this test is considered to be a service test, must be measured. Depending on the location, the temperature range is between 22ºC (Galicia) and 29 ºC (Valencia).
- The calibration of the equipment (the pendulum) is carried out by 40 laboratories out of 68, but except for four laboratories that do not provide the data, the rest at least indicate the type and model and the date of verification within the permitted range, which with the UNE-41901 EX standard becomes two years.
- The average width of the leading edge of the shoe of all the laboratories is 1.5 mm and 66-73% (ISO 4662) and IRHD hardness 59±4 (ISO 48)), therefore, all of them comply with being below the 2.5 mm stated in section 4.1.2.15 of the aforementioned standard.
- As the test is carried out in situ, in the presence of the coordinators who mark the order of the test, all 4 test points are carried out, both at 0º and 180º at each point.
- Regarding the statistical results of the 68 laboratories, it should be noted that 3 laboratories were discarded because they did not meet the validation criterion of section 7.3 of the standard, which states that "If the difference between the 4 results is greater than 8 units, 4 new tiles shall be tested". In this exercise, if this happened they were left out of the statistical analysis:

Table 4. Eila19. Statistical results

National (n 67)	**Average**	**Deviation**	**Coef. Variation**
WET SLIP RESIST. TEST	45,63	7,14	0,16

- **Evidence detected:** Errors in the execution of the test are reduced with respect to EILA16 and EILA17, practically in their entirety. The previous verification of the pendulum each time it moves is 100%, being sure that this has been done and that they have used a new pink sheet at the beginning and end of the test. Likewise, the calibration of the equipment that now the standard establishes every two years, 94% give the data and 59% comply with it. In addition, carrying out the test on site helped to correct in some laboratories the way the pendulum was held so that it would not move and to take care in its transfer from one point to another on the ground to continue with the test. Therefore, discarding those that did not meet the validation criterion of section 7.3 of the standard, the dispersion is as shown in the following figures:

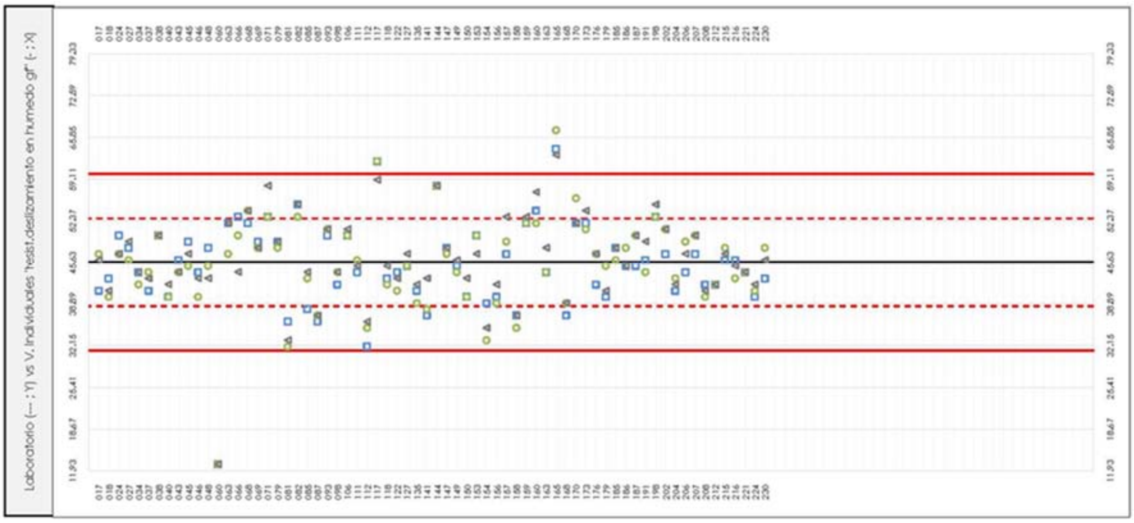


Figure 5 Eila19. XY Diagram Dispersion of the calculation mean according to test standard. The black line marks the mean value and the red lines plus/minus the standard deviation from the mean.

- Therefore, the z-score assessment also showed a significant improvement over both previous EILAs by giving values of more proportionality between them:

Figure 6 Eila19. Z-score diagram of the results provided by the laboratories Results are considered satisfactory if the absolute value of the Z-score at ≤ 2, Doubtful if it is between 2 and 3 units and Unsatisfactory if it is ≥ 3 units. Satisfactory results are reflected between the two red reference lines in this figure.

- To conclude, in the wet test, the standard establishes that the PTV slip resistance value must be corrected when it is > 35, correcting it when it happens with the temperature difference with respect to -20ºC, and applying the formula according to section 7.3 of the standard: **PTV+0.55 (Δt)**, the following table of EILA19 results are obtained, discarding those that did not meet the validation criteria:

Table 5 Eila19. Results provided by laboratories that have performed the EILA pendulum test19 and meet the validation criteria of section 7.3 of the standard

COD. LAB.	attack edge mm	Initial average lam. verification	Initial average STD-P	Final average lam. verification	Final average STD-P	wet slip	Average. temperature (ºC)	Corrected slip resistance	uncertainment
034	1.8	55				40	25.8	**43**	
071	2.2	56.6	27	65	27.4	53	22	**54**	5
111	1.5	55	24	59	24	44	25	**47**	2
118	1.6	64.8	21.2	57.4	23.2	42	25	**44**	2
135	1.3	61	21	59	23	40	23.2	**42**	
150	1.5	62	20	60	24	39	24.2	**42**	
156	1.3	58.4	20	58.8	20.4	39	24.8	**41**	2
158	2.3	55	25	57	20	37	21.8	**37**	2
160	2.1	65	25	64	27	52	26.3	**55**	
017	1.2	56	22	56	22	41	27.55	**45**	5.13
037	1.6	58	18	54	18	40	27	**44**	2
043	2.0	56	25			45	21.5	**46**	1
068	1.5	59	24	59	24	51	24.3	**54**	2
176	1.9	57	20	60	20	43	24.8	**45**	5.3
179	2.0	57	21	60	24	41	25	**43**	
186	1.8	34.8	20.4	42	20.8	44	24	**46**	
085	1.6	57	20	57	20	39	25.5	**42**	
202		55	25	55	25	47	25.4	**50**	
207	1.6	52	20	53	20	46	27	**49**	
018	1.1	49	23	47	25	38	26	**41**	1.6
024	1.6	59.8	20	59.6	21.8	44	26.2	**47**	±3
040	1.0	51.2	23.6	59.2	21.2	40	23	**42**	
046	2.5	56				39	26.9	**42**	
048	1.3	64	23	63.4	23.2	42	27.2	**46**	6
060	1.7	63	23	63	22	13	26	**-**	
081	1.2	49.6	23.6	50.4	27.73333	33	27	**-**	
154	1.2	60	23	61	23	35	23	**-**	0.65
027	1.4			61.8	25	46	23.6	**47**	2
038	1.5	60	24	61	24	48	22	**49**	
082	1.7	88	30	55	25	53	21	**46**	
147	1.6	62	25	61	24	48	22	**49**	3
159	1.4				28.2	53	21	**54**	
163	2.1	64	23	56	24	46	20.5	**47**	
173	2.0	64.4	29.8	60.6	27.2	53	21.6	**54**	
087	1.4	61.6	27.6	61.6	27.2	48			
069	1.6	65	24	63	24	47	22.3	**51**	7
079	1.5	64	25	60	24	47	24.2	**48**	
093	1.8	61	24	58	24	49	24.9	**49**	
098	1.3	62.8	29.2	59.4	28.8	42	22.5	**51**	1
117	1.7	60	26	60	27	59	24.2	**43**	5
144	1.5	63	56	64	56	57	23.5	**61**	5

COD. LAB.	attack edge mm	Initial average lam. verification	Initial average STD-P	Final average lam. verification	Final average STD-P	wet slip	Average. temperature (ºC)	Corrected slip resistance	uncertainment
153	1.0	60	25	56	22	48	23	**59**	2
157	1.1	60	22	59	23	48	23.4	**50**	7
165	2.0	57	28	61	30	64	21.4	**49**	
170	1.1	64.2	25	64.4	25	51	23.9	**65**	2.140
127	1.2	55	25	55	24	45	20	**45**	
141	1.5	64.2	24.8	63.8	24.6	38	26.3	**41**	3.48
149	1.9	56	25.2	54.4	25.4	44	22.3	**45**	
191	1.3	55	24	56	25	45	23.3	**47**	
198	2.0	62	27	58	26	53	22	**54**	
168	2.2	41.6	20	46.2	20	36	25.4	**39**	
185	1.8	63	28	59	27	46	22	**47**	
187	124.3	65	26.2	56	26.8	45	26.9	**49**	
204	1.9	60	24	60	24	40	25.4	**43**	2
206	1.4	58	20	59	21	45	25	**47**	
208	1.3	60	25	60	25	39	25.1	**42**	
212	1.7	59	24	58	25	40	23.8	**42**	
215	1.7	62	24	61	23	47	21.7	**48**	U=2(K=2)
224	1.5	61.4	24.2	61.8	23.2	40	23.15	**41**	
230	1.4	60	20	60	20	42	25.5	**45**	5
106	1.5	55	23	56	23	46	28.8	**51**	
112	1.0	61	29	61	29	34	28.4	**-**	
122	1.1	60	21	60	21	36	31.5	**42**	3
216	1.0	55	22	55	20	39	29.6	**45**	
221	1.3	57	23	58	21	40	28.6	**45**	

4. REFERENCES DOCUMENTS OF PLAN EILA

Website:https://www.codigotecnico.org/index.php/menu-05-registro-entidades-laboratorios/menu-registro-general-laboratorios-ensayos-control-edificacion.html

Madrid, 13th January 2020

EXISTING AND DEVELOPING REQUIREMENTS IN THE UNITED STATES FOR COMMUNICATING TRACTION AND AREAS OF USE FOR FLOORING

Grant Davidson[1], Eric Astrachan[1]

[1]Tile Council of North America (TCNA)

GDavidson@tcnatile.com; EAstrachan@tcnatile.com

ABSTRACT

The ceramic tile industry is working to develop requirements to more effectively communicate areas of use and the relative traction of flooring products. Five mandatory categories are anticipated for inclusion in ANSI A137.1, *American National Standard Specifications for Ceramic Tile.* Two categories would be based on DCOF measurements per ANSI A326.3, *American National Standard Test Method for Measuring Dynamic Coefficient of Friction of Hard Surface Flooring Materials,* and three would be manufacturer-declared. This paper will overview recent and anticipated changes to the relevant standards, the five categories in particular, and the suitability of manufacturer-declared determinations.

Recent regulatory decisions, work in progress, and criteria in the United States relevant to traction reporting for ceramic and resilient flooring will also be addressed, and the potential impact on exporters to the U.S.

Keywords: Traction, DCOF, Standardization, Regulation, ANSI A326.3, ANSI A137.1, “Areas of Use”

Topic: Existing and Developing Requirements in the United States for Communicating Traction and Areas of Use for Flooring

1. INTRODUCTION

Standardization of slip resistance-related test methods in North America has been ongoing for decades, particularly through standards development bodies such as ANSI and ASTM. Currently, test methods and standards that have been developed in the United States for measuring the COF of flooring do not provide any "area of use" or "product use" classifications that could direct consumers towards appropriate product applications depending on specified criteria. In comparison, the German criteria in BGR-181 provide extensive detail with R values for well over 100 different work environments.[10] The R values are derived from the German Ramp standard DIN 51130[11] which provides a five-level evaluation, from R9 to R13. Similarly, the North American ceramic tile industry is working to define a five-category classification system to communicate areas of use that is anticipated for inclusion in ANSI A137.1, *American National Standard Specification for Ceramic Tile*, and ANSI A326.3, *American National Standard Test Method for Measuring Dynamic Coefficient of Friction of Hard Surface Materials*.

Two of the product classification categories would be based on measured wet DCOF values (measured per ANSI A326.3), while the other three categories would be manufacturer-declared, based on criteria determined by the product manufacturer.

This paper discusses ANSI A137.1 and ANSI A326.3 in Section 2.0, the "areas of use" classification currently under development in Section 3.0, recent regulatory action related to slip resistance of flooring in Section 4.0, plastic based material (PBM) flooring research in Section 5.0, expected impact of an "areas of use" classification system on exporters of ceramic tile to North America in Section 6.0, and conclusions in Section 7.0.

2. NORTH AMERICAN DCOF STANDARDS ANSI A137.1 AND ANSI A326.3

2.1. ANSI A137.1

ANSI A137.1 is used as a reference standard for buyers and specifiers of ceramic tile in the North American marketplace.[12] It lists and defines various types, sizes, and physical properties of ceramic tile, and is utilized by all North American tile manufacturers and those exporting ceramic tile to North America. Within the United States, it is specified in all commercial procurement and in every commercial specification for the installation of ceramic tile. Additionally, it is the definitive criteria for ceramic tile performance in U.S. slip/fall litigation. Since 2012, the standard requires mandatory DCOF reporting for mosaics, quarry tile, pressed floor tile, and porcelain tile. The most recent version of ANSI A137.1, published in July 2019, specifies that users test the wet DCOF of their flooring products per ANSI A326.3.[13]

---

[10] BGR-181 (Rules on Occupational Safety and Health), *Floors in working rooms and working areas subject to a risk of* slipping. October 1993.
[11] DIN 51130, *Testing of floor coverings; determination of the anti-slip properties; workrooms and fields of activities with slip danger; walking method; ramp test* German National Standard.
[12] See ANSI A137.1-2019 Section 1.0 *Purpose*.
[13] Prior to the 2019 publication, ANSI A137.1 contained language for a standardized test method to measure the wet DCOF of ceramic tile. The 2019 publication removed that language and specified that the wet DCOF of ceramic tile products should be measured using ANSI A326.3.

2.2. ANSI A326.3

ANSI A326.3 was developed by ANSI Accredited Standards Committee A108, which has over 60 voting members representing a broad spectrum of stakeholders across the flooring industry. It describes the test method for measuring the DCOF, in wet or dry test conditions, of hard surface flooring materials with use both in the laboratory and in the field.[14] Section 3.0 of the standard specifies that hard surface flooring materials suitable for level interior spaces expected to be walked upon when wet shall have a wet DCOF of 0.42 or greater when tested per ANSI A326.3. Surfaces not intended to be walked upon when wet shall have a dry DCOF of 0.42 or greater when tested per the dry DCOF method contained in the standard.[15] ANSI A326.3 specifies use of the BOT 3000E tribometer[16], an automated drag-sled device capable of testing dry or wet DCOF on hard surface flooring materials, including but not limited to, ceramic and porcelain, marble, granite, polished concrete, terrazzo, engineered stone, quarry tile, vinyl composition tile, and LVT (including LVP and other rigid forms of PBM).[17]

3. PRODUCT "AREAS OF USE" CLASSIFICATION

The scale under development by the U.S. ceramic tile industry for inclusion in ANSI A137.1 has five "area of use" classification categories:

1) SR-Dry
2) SR-Interior, Wet
3) SR-Interior, Wet Plus
4) SR-Exterior
5) SR-Oils/Greases

Two categories utilize wet DCOF criteria per ANSI A326.3, with a limit value of 0.42 for level, interior spaces expected to be walked upon when wet, and three are based on manufacturer declarations. For each category, examples of the appropriate areas of use are provided.

3.1 Wet DCOF classification criteria

3.1.1 SR-Dry classification

Products meeting "SR-Dry" criteria shall have a dry DCOF value of at least 0.42 when tested per ANSI A326.3. These products shall be kept dry and free of contaminants when in use and offer little slip resistance when wet.[18]

[14] The laboratory test and field test are described in ANSI A326.3-2017 Section 8.0 *Test Procedure – Dynamic COF with 0.05% SLS Water*. For wet testing, a BOT 3000E tribometer, 0.05% Sodium-Lauryl Sulfate (SLS) solution, and SBR sensors are specified.
[15] Dry testing may be conducted per ANSI A326.3-2017 Section 9.0 *Dry Dynamic Coefficient of Friction (DCOF) – If Desired*.
[16] Or equivalent.
[17] https://www.walkwaymg.com/pages/bot3000
[18] See ANSI A326.3-2017 Section 3.2.

Possible areas of use: Subject to determination by specifier and the criteria in the ANSI A326.3 standard, may include, but not limited to, indoor shopping malls (excepting food courts), hotel lobbies, office buildings, home interiors without water sources and other areas where surface will be kept dry when walked upon and proper safety procedures will be followed when cleaning the hard surface flooring materials. Walk-off mats may be necessary for use in entrance areas of the possible areas of use where water or other contaminants are occasionally or consistently transported onto the flooring surface. Surfaces not intended to be walked upon when wet shall have a measured dry DCOF value of 0.42 or greater when tested per Section 10.0 of ANSI A326.3.

3.1.2 SR-Wet, Interior classification

"SR-Interior, Wet" products shall have a wet DCOF value of 0.42 or greater (per ANSI A326.3) and may be walked upon when wet if clean, maintained, and free of standing water or other contamination.[19]

Possible areas of use: Subject to determination by specifier and the criteria in the ANSI A326.3 standard, may include, but not limited to, entry foyers, public restrooms (without showers), food courts, grocery stores, "front of the house" areas in restaurants, and home interiors including bathrooms and kitchens.

3.2 Manufacturer-declared classification criteria

Some hard surface flooring materials cannot be well characterized by tribometry due to surface texture, projections, or other traction-enhancing aspects necessary for safe applications in complex wet conditions, exterior conditions, or contaminated conditions. DIN 51130 addresses this through the V4 – V10 displacement space or volume measurement contained in the standard. There is no equivalent to that scale at present in ANSI A326.3. The three manufacturer-declared categories are as follows:

3.2.1 SR-Interior, Wet Plus classification

"SR-Interior, Wet Plus" products may be used in areas that require measures to avoid slipping greater than anticipated for products only suitable for "SR-Interior, Wet" areas, where floors may be walked upon when wet if clean, maintained, and free of standing water or other contaminants.

Possible areas of use: Subject to determination by specifier and the criteria in the ANSI A326.3 standard, may include, but not limited to, public showers, interior pool decks, locker rooms, covered exterior areas, ADA compliant ramps, steam rooms, "front of the house" applications in fast food restaurants, and food areas in gas stations.

Minimum DCOF criteria for inspection purposes are also being reviewed at the time of writing this report.

---

[19] See ANSI A326.3-2017 Section 3.1.

3.2.2 SR-Exterior classification

"SR-Exterior" products may be walked upon when wet in level, exterior applications (excluding ice or snow) if clean, maintained, and free of standing water or other contaminants.

Possible areas of use: Subject to determination by specifier and the criteria in the ANSI A326.3 standard, may include, but not limited to level exterior pool decks, exterior walkways, exterior patios, and sidewalks.

3.2.3 SR-Oils/Greases classification

"SR-Oils/Greases" products may be used in level areas where oil, grease, fats, and/or water may be present so long as such floors are regularly cleaned, maintained, and free of standing water or contaminant build-up.

Possible areas of use: Subject to determination by specifier and the criteria in the ANSI A326.3 standard, may include, but not limited to areas regularly exposed to automotive fluids, "back of the house" fast food or family style restaurants, food preparation areas involving grease or oil, and deep-fry equipment.

3.3 Use of the five-category classification system

The "area of use" system is intended for inclusion in ANSI A137.1 for product classification purposes; manufacturers can utilize the system to communicate the relative traction of their flooring products. However, it is not a requirement for box labeling. Issues associated with product labeling based on wet DCOF testing are discussed in Section 4.0 of this paper.

3.4 Five-category classification system, DIN 51130 and BGR-181

DIN 51130 acceptance angles and "R groups" including examples of work areas per BGR-181, are as follows:

Table 1: DIN 51130 acceptance angles, assessment groups, and examples of work areas and premises

Acceptance Angle	Assessment Group (R Group)	Examples of work premises and areas (as described in BGR-181)
>35°	R13	Sausage kitchens, vegetable processing, delicacies, or mayonnaise manufacture
>27° to 35°	R12	Commercial kitchens serving over 100 meals per day, manufacture of fats or oils, sculleries, etc.
>19° to 27°	R11	Commercial kitchens serving up to 100 meals per day, machining areas, vehicle repair areas, etc.
>10° to 19°	R10	Garages, damp storage areas, coffee kitchens, sanitary areas, etc.
>6° to 10°	R9	Foyers (indoor), customer and eating areas, corridors, stairways, etc.
<6°	-	Areas without slippery substances

Work premises and areas contained in BGR-181 are similar to the "areas of use" in the five-category classification system for ANSI A137.1 and ANSI A326.3. Categories listed in "R9," such as those intended only for dry use, are similar to those included in SR-Dry. "R10" categories, such as restrooms and restaurant service counters, are similar to the "areas of use" in SR-Interior, Wet.

The manufacturer-declared categories differ in that manufacturers are able to classify their products based on criteria other than measured COF values. Products which may not be easily characterized by tribometry, such as heavily textured surfaces, can be manufacturer-declared for exterior areas, areas where oils/greases are present (comparable to areas listed as "R13" in BGR-181), or areas that require measures to avoid slipping greater than anticipated for products suitable for SR-Interior, Wet areas.

4. RECENT REGULATORY ACTION ON SLIP RESISTANCE OF FLOORING

In 2016, the United States Consumer Product Safety Commission (CPSC) voted to deny a petition that proposed a labeling scheme for hard surface flooring products. In 2019, they voted to deny a resubmission of the petition. Public comments in response to each petition pointed out several concerns, including that the DCOF labeling as suggested in the petition would result in more slips as opposed to fewer and be highly misleading to consumers. Tile Council of North America alone provided twenty-one deficiencies in the petition.[20] CPSC staff concluded "that it is unlikely that the action requested by the petitioner will reduce injuries from slips and falls,"[21] and the Commissioners voted to deny the resubmission.

During public meetings held in 2018 with CPSC Commissioners and technical staff concerning the resubmitted petition, Commissioners and staff members discussed their interest in communicating safe use of flooring products to consumers and their ideas to help educate consumers on the complexities of slip resistance. The "area of use" classification system, developed by the ceramic tile industry, was developed out of those conversations to provide guidance to consumers and specifiers on where flooring products can be potentially used.

5. PLASTIC BASED MATERIAL RESEARCH

5.1 Overview

The Tile Council of North America Product Performance Testing Laboratory, under the direction of Dr. John Sanders of the Bishop Materials Laboratory at Clemson University, measured the wet DCOF of 22 plastic-based material (PBM) flooring products that manufacturers advertise or claim to be waterproof or water resistant, or depict being used in areas where flooring gets wet.[22] The

[20] Tile Council of North America. *Public Comments of the Tile Council of North America regarding Resubmission of Petition to Mandate a Uniform Labeling Method for Traction of Floor Coverings, Floor Coverings with Coatings, and Treated Floor Coverings*. August 6, 2018. pp. 3-4.
[21] United States Consumer Product Safety Commission. *Staff Briefing Package Petition CP 18-2: Labeling Requirements Regard Slip Resistance of Floor Coverings.* July 17, 2019.
[22] Sanders, John, and Grant Davidson. *Wet Slip Resistance of Plastic Based Material Flooring (PBM Flooring)*. Clemson University, December 2019.

report provides an assessment as to whether the tested flooring products are suitable for wet use, or instead should carry a dry use-only caution. ANSI A326.3 was used to measure the wet DCOF of each PBM product sample.

5.2 Wet DCOF results and directionality

Eighty-two percent (18 out of 22) of the tested product samples had wet DCOF values below 0.42. Per ANSI A326.3, those 18 samples are not suitable for wet use, although each sample was advertised as waterproof, water resistant, or depicted being used in areas where flooring gets wet. Six out of 22 product samples exhibited “directionality,” meaning a DCOF measurement along one edge differed from a measurement at a right angle by at least 0.05. Directionality can be caused by texture, surface roughness, and surface patterning on the flooring, and affect the traction experienced when turning a corner. If an unexpected change in traction occurs, the change could result in a slip or fall. In total, 91% of the samples either measured below 0.42 in one or more directions or exhibited directionality.

5.3 Report conclusions and relationship to “area of use” classification

The report suggests that, at a minimum, a dry-use only warning should be indicated for such products that exhibited directionality or measured below 0.42 wet DCOF per ANSI A326.3. Use of the five-category “area of use” classification, which could be potentially be applied to PBM products in addition to ceramic tile, would require that manufacturers classify those products as “SR-Dry.” Such a classification would indicate to users that such products shall only be installed in areas where the flooring is expected to be walked upon when dry and level.

6. IMPACTS OF THE “AREA OF USE” CLASSIFICATION

6.1 Acceptance and implementation

Just as the categories in BGR-181 developed out of the five-level R9 - R13 system, we anticipate commercial specifications will develop around the five-category area of use system discussed in this report. This will also likely lead to its use classifying other flooring surfaces, especially given the absence of this information at the current time.

6.2 Impact on exporters of ceramic tile to North America

When ANSI A137.1 requires slip resistance “area of use” classification, although a voluntary standard, we anticipate imported products will also need to meet the same criteria to satisfy commercial procurement and installation criteria. As mentioned in Section 3.3 of this report, the classification system is not a requirement for box labeling but rather so that manufacturers can communicate the relative traction of their flooring products. As a result, costs to implement the “area of use” system are expected to be low for manufacturers and exporters.

7. CONCLUSION

The "area of use" product classification, currently under development by the U.S. ceramic tile industry, is based on the wet DCOF specification in the ANSI A326.3 test method, and manufacturer self-declarations. It is anticipated for inclusion in ANSI A137.1 and ANSI A326.3 and is intended to direct consumers towards appropriate product applications based on slip resistance-related criteria.

The proposed classification scale can be potentially applied to other hard surface flooring materials in addition to ceramic tile flooring. Importantly, it is the first step in providing manufacturers and specifiers a standard so that ceramic tile products can be classified based on a measurement of slip resistance and areas of use. Inclusion of the system in ANSI A137.1 and ANSI A326.3 can have a major impact on the North American marketplace, result in better specifications, and through such potentially result in a reduction of slip and fall injuries on hard surface flooring.

ERGONOMICS AND DESIGN FOR ALL IN THE BUILT ENVIRONMENT

Steffan, Isabella Tiziana[1], Thomas, Carol[2]

[1] Studio Steffan- Design and Research

[2] Access Design Solutions UK Ltd

info@studiosteffan.it

ABSTRACT

Design for All/Universal Design is a transversal design approach that can be applied to communication systems, environments, public services and fast-moving consumer goods, so that each environment/product can be used by as broad a range of the population as possible. The methodological approach of ergonomics can represent the necessary pragmatic contribution to this approach, providing concrete tools and assessment methods typical of the ergonomic quality of the products / environments / services, able to transform the concept of Design for All into design solutions. Standards are recognized as crucial tools for gathering useful information for ergonomic intervention. This contribution will in particular outline of Mandate M/420, on Accessibility and usability of the built environment, the prEN 17210:2019 which main reference standard is ISO 21542. It contains functional requirements for a range of elements of the built environments including pavements and surfaces. A technical report with related technical requirements is in progress: slip resistance data might be required to allow inclusive access. Within the main clause on access in the outdoor environment, also shared spaces are addressed. They should be safe places for pedestrians, but there are some critical issues related to the mobility of people with vision and cognitive impairments. More researches and discussions are needed on accessibility for all users.

Keywords: Ergonomics, Design for All/Universal Design, Standards, Shared spaces, Surfaces

Topic: The role of Architectural Design

1. INTRODUCTION

Terms such as “Universal Design” (born in USA) “Design for All” (born in Europe), “Inclusive Design” (born in UK), are often used interchangeably with the same meaning. It is a transversal design approach, that shares with Ergonomics a user centred focus. In fact, it focuses on human diversity and diverse desires and needs, and can be applied to communication systems, environments, public services and fast-moving consumer goods. Its aim is that each product, service, built environment can be used by “All”, which in practice means “by as broad a range of the population as possible” (Steffan, 2014).

The movements that have given rise to the spread of this approach have different geographical roots and motivations, but tend to share the same contents and objectives, and to be an inspiration for similar movements. Japan, for example, was inspired by the American model Universal Design, with attention to the aging of the population, while Italy and India were inspired by the European model Design for All, attentive to disability and social diversity.

Regardless of the starting point, Design for All shares with Ergonomics the multidisciplinary approach and the centrality of the user, enhancing the specificity of each individual. By placing human diversity and variability at the centre of the analysis, attention is shifted from design to user categories, to planning for the needs and expectations of users.

Considering the physical, cultural and temporal variability, in order to achieve the expected usability results, that is to say effectiveness, efficiency, satisfaction typical of ergonomics, means to consider essential the so-called "seven principles of Universal Design". These are the functionality requirements, flexibility, ease and autonomy of use, safety and tolerance to error, psycho-physical comfort and pleasantness, compatible with different abilities and preferences. Ergonomics and Design for All are therefore recognized in an identical conceptual approach.

Ergonomics is nowadays recognized as necessary to provide the pragmatic contribution to Design for All, providing concrete cognitive tools and assessment methods typical of the ergonomic quality of products / environments / services. Standards are recognized as crucial tools for gathering useful information for ergonomic intervention as well (Steffan, Tosi, 2012).

The European Community has considered standards as strategic tools to improve the conditions of accessibility for people with disabilities and, with reference to the UN Convention on the Rights of Persons with Disabilities in the EU (which indicates the path that the countries of the world must travel to guarantee the rights of equality and social inclusion of all citizens with disabilities) and the European Strategy on Disability 2010 - 2020, issued a series of standardization mandates. These have produced, with a long participatory process at international level, some innovative rules on the subject of accessibility in the ICT sector and on the Design for All approach.

This contribution will in particular outline Mandate M/420, the prEN 17210:2019 “Accessibility and Usability of the Built Environment. Functional requirements”. It contains functional requirements for a range of elements of the built environments including pavements and surfaces. Its main reference standard is ISO 21542:2011 “Building Construction. Accessibility and Usability of the Built Environment”, currently under revision.

2. MANDATE M420

The main objective of this mandate is to facilitate accessibility of the built environment following a 'Design for All' approach, especially for public procurement, but also for designers, facility managers and ergonomists.

Phase I of M 420, developed by eleven experts, comprised an inventory on existing standards, building codes, technical regulations and other guidance documents for accessibility to the built environment including buildings and public places, parking, schools, hospitals, sports facilities, public transport facilities. The Phase 1 report included an analysis of gaps which identified areas where no accessibility standards, or guidance documents exist, together with a proposal for a standardization work program to be further developed in Phase II.

Since 2016 this mandate is in Phase II, and 6 experts have already developed a third draft of prEN 17210 "Accessibility and usability of the built environment – Functional requirements". They are Ms Monica Klenovec (as Project Team Leader), Ms Katerina Papamichail, Mr Søren Ginnerup, Mr Delfín Jiménez, Ms Carol Thomas, Ms Isabella Tiziana Steffan.

In the light of the outcome of Phase I, it was agreed that the following three deliverables would be elaborated in Phase II: a European Standard and two Technical Reports.

The European Standard (EN) is at the level of common functional requirements, and contains a set of functional European accessibility requirements of the built environment to be used as either technical specifications or as criteria for awarding public contracts (in the sense of the Public Procurement Directives). As this EN is intended to be the base of the deliverable used for conformity assessment, it will follow the principles of the Conformity Assessment toolbox (ISO/CASCO) and CENCENELEC TC 1 Criteria for conformity assessment bodies as appropriate and will contain the functional accessibility requirements to be used in the technical specifications and the necessary award criteria in a fully demonstrable and/or testable form that is suitable for use in any future public built environment procurement legislation as well as other accessibility legislation. Contents of this EN are:

1. Scope 2. Normative References 3. Terms and definitions 4. Legal and policy background 5.Diversity of users and design considerations 6. Wayfinding 7. Access in the outdoor environment 8. Arrival and departing areas- Parking areas 9. Horizontal circulation in buildings 10. Vertical circulation in buildings and outdoors 11. Specific areas, equipment and provisions 12. Sanitary accommodation 13. User interfaces, controls and switches 14. Fire safety for all - Evacuation and emergency exits 15. Environmental conditions in Buildings. 16. Accommodations 17. Cultural, leisure and sport buildings 18. Administrative, service and employment buildings 19 Outdoor and urban areas 20. Transport facilities.

Particular interest for this congress can be clauses 7.5 'Shared Space' design approach, 7.1.5 "Surface of the accessible route or footpath" for outdoor and 9.6 "Surface finishes and materials" for indoor.

The Technical Report 1 will support this EN and will describe the technical performance criteria to be able to fulfil the above-mentioned functional accessibility requirements. This TR 1 may include a list of the standards and technical specifications used for the compliance requirements for accessibility set out in the EN. The technical report with related technical requirements is in progress.

The Technical Report 2 will contain reference documents needed to assess conformity, whether declared or assessed. This document will be coordinated with the EN and with TR 1.

The main reference for drafting prEN 17210 has been ISO 21542, which is currently under revision. The revision of the ISO standard is supported by many members of the prEN 17210 development team to achieve harmonization between these two standards as far as possible.

3. ACCESS IN THE OUTDOOR ENVIRONMENT.

Access routes in the outdoor environment include footways (also known as pavements), footpaths and other rights of way, such as pedestrian routes through a public space.

A quite controversial issue is shared spaces. Are shared spaces safe enough for all users? Within the main clause on access in the outdoor environment the shared space design approach is addressed.

PrEN 17210: 2019 contains some functional requirements and recommendations about this, that are based on the outcome of Phase I and diverse researches. Some of them are described here below.

3.1 Shared spaces

A shared space is “a street or place designed for pedestrians, cyclists and drivers to share the space without the conventional separation between them” (prEN 17210:2019), without the usual physical differentiation between roadway and pavement.

When designed with a level surface across the full width, theoretically this is without the main barriers for the mobility of users with impaired mobility; and therefore, less possibilities for slips, trips and falls. There have, however, been concerns raised across the disability sector.

According to Thomas (2008) there is support for some of the ideas behind the ‘shared space’ concept, such as streets that are attractively designed and reduced vehicle speed, but concern about the creation of ‘shared surfaces’ for drivers, cyclists and pedestrians in the name of ‘shared space’.

The removal (or non-provision) of traditional features used by blind people for guidance and wayfinding such as pavements with kerbs affects their ability to use the area independently. Shared space is described by a leading advocate as where ‘all street users move and interact in their use of space on the basis of informal social protocols and negotiations’ (Hamilton-Baillie, 2008; p166). Thus, a shared space is said to rely on negotiating priority and movement between vehicles and pedestrians through ‘eye contact’. This puts blind and partially sighted people at an immediate disadvantage. Research commissioned by Guide Dogs UK contends that ‘shared surfaces’ affect the safety, confidence and independence of blind and partially sighted people.(Thomas, 2008. Parkins, 2012). Similarly, research from the Netherlands found that areas that adhere to the shared space concept are less accessible for people with visual disabilities than conventionally designed environments (Melis-Dankers, Havik, Steyvers 2015). The absence of conventional pavements may also affect persons with learning difficulties, and persons with hearing impairments focused on communicating through looking at people rather than negotiating with other road users. Children who are familiar with use of pavements with kerbs, and tourists who are unfamiliar with 'Shared Space' areas may also experience difficulties with ease of navigation. Furthermore, people with impaired mobility, while benefitting from a level surface, may not feel confident sharing a space with vehicles and cyclists without the perceived safety of a pavement and crossing points.

Lack of kerb elements may also cause difficulties when deploying taxi and bus ramps and for people stepping down from side access minibus transport.

Moody and Melia (2011) reported negative views about a flagship shared space scheme in Ashford Kent from a wide range of pedestrians, particularly among women, with 91% of women reporting anxiety about sharing the space with vehicles in comparison to 58% of men. They also found that people who used the scheme on a daily basis were more likely to want to make changes to the layout (83%) than those who used it less than once a week (56%). This seems to discredit the assumption that once people are familiar with a scheme, they will adjust to it.

Sharing space is a choice: Not all areas have to be shared. Pedestrians should be able to choose whether or not they interact with other traffic. (Thomas, 2008; Havik, E.M., & Melis-Dankers Royal Dutch Visio, 2015).

Karndacharuk, Wilson, Dunn (2014) assessed a range of shared space schemes in different countries including UK, Austria, Netherlands, Australia and New Zealand and recommend a "safe zone" to both sides of street for vulnerable pedestrians. This should be a continuous, barrier-free and recognizable route between crossings and decision points (Havik, E.M., & Melis-Dankers Royal Dutch Visio, 2015)

PrEN 17210: 2019 contains the following functional requirements and recommendations:

Careful consideration of many factors is required before implementing a 'Shared Space': The implications of the absence of kerbs and pedestrian orientation; possible traffic reorganization and measures for traffic calming; and the new use of space for pedestrians and drivers.

According to the location and pedestrian traffic density in 'Shared Space', compared to conventional spaces, it is important to consider carefully the possibility of accidental or intentional traffic incidents involving moving vehicles, affording maximum protection of pedestrians from collision and injury.

A 'gateway' should be provided between a conventional street layout and a 'Shared Space' to differentiate the space, for example, through narrowing of the carriageway, a change of visual contrast and tactile walking surface indicators (TWSI) on both the pavement and road as they become a 'Shared Space'.

Consideration should be given to design measures such as introducing visual narrowing of the street or space, and the location of trees, cycle parking, street furniture and public art to influence driver behaviour and encourage pedestrians to use the full space.

3.2 Pedestrian zones

Pedestrian zones, known as 'comfort zones' in some countries, provide pedestrian-only routes designed to prevent or discourage vehicular access so that pedestrians can use these zones in comfort and relative safety and choose whether to mix with vehicles or not. These do not prevent the rest of the area being shared by vehicles and those pedestrians able and willing to do so.

Shared space designers consider it preferable that 'Shared Spaces' are single level spaces. Due to this, kerbs should be avoided and other reference elements, such as street furniture, should be used. However, where kerbs are provided (or retained) to delineate the comfort zone, the kerb upstand shall be adequate to be detected as very low kerbs can be missed or become a trip hazard; and regular flush kerb pedestrian crossings should be provided with the associated TWSI.

Tactile walking surface indicators (TWSI) should be used, where necessary, to guide within the comfort zones. TWSI shall be detectable (through the soles of shoes and by a white cane) with visual contrast to assist people with residual vision; be of adequate depth to allow time for people to detect it and respond such as by stopping; and there shall be adequate clear space alongside the TWSI to provide an obstacle free route. Changes in direction shall be referenced and detectable.

Pedestrian crossings should be provided at regular intervals to enable all pedestrians to cross safely and in comfort from one side to the other.

4 PAVING AND SURFACE MATERIALS

The paving material used in a 'Shared Space' can enhance the perception of pedestrians and drivers that this is a space used by pedestrians where the vehicle driver is a guest and is expected to behave accordingly.

PrEN 17210: 2019 contains some key functional requirements and recommendation in 7.5 "Shared spaces. Design approach", such as in sub-clause 7.5.6. Paving material:

The paving surface shall be suitable for pedestrians and shall also be suitable for vehicular traffic with adequate load bearing capacity to prevent the paving surface from breaking; overly decorative patterns in the paving surface which could cause users to be disorientated shall be avoided; the paving material should not cause rainwater ponding, be slip resistant and should not constitute a danger with freezing temperatures.

In clause 7.1.5 "Surface of the accessible route or footpath" some more functional requirements are listed; among others:

a) The surface shall be even to prevent users from tripping and falling.
b) The surface shall be firm, so that shoes and wheels do not sink in.
c) The surface shall have adequate slip-resistant properties, whether wet or dry, to avoid slipping hazards.
d) The surface materials shall have low reflective properties to avoid glare or obscure any orientation signs and hazard warnings.

In 9.6 “Surface finishes and materials” related to Horizontal circulation in buildings, some functional requirements refer to the importance of providing, e.g.: floor surface finishes that are even, with minimal height differences, to prevent users from tripping and falling, floor surface with low reflective properties, to avoid or reduce glare from bright sunlight from windows or other light sources, to avoid discomfort, confusion and disorientation of users and to be slip-resistant to avoid slipping hazards.

5. CONCLUSIONS

Standards are very useful tools to support implementation of Design for All approach in the built environment. After finalization of the PrEN 17210 and related TRs, new state-of-the-art documents from the planning to the execution of works for improved accessibility in the built environment, including public procurements, with a design for all approach, will be available.

Key issues still to be addressed are: how ‘safe pedestrian zones’ can have effective delineation from the shared zone which is sufficiently distinct and recognisable for blind people, while not impeding the mobility of people with physical impairments; how drivers can be prevented from encroaching on the pedestrian zones, while not affecting the nature and appearance of the rest of the area as a shared space for drivers, cyclists and pedestrians; and what slip resistance data might be required to allow inclusive and safe access for all. This will need to be explored in the TR1.

6. REFERENCES

AENOR (2011) M/420 Phase I joint report. https://www.cencenelec.eu/standards/Sectors/Accessibility/BuiltEnvironment/Pages/default.as. Accessed 24 Apr 2018

CEN/CENELEC Built environment. https://www.cencenelec.eu/standards/

EC (2010) European disability strategy 2010-2020: a renewed commitment to a barrier-free Europe. European Commission

European Commission (2010) Employment, social affairs and equal opportunities DG, standardization mandate to CEN, CENELEC and ETSI to include “design for all” in relevant Standardization Initiatives, M/473

Hamilton-Baillie, B. (2008). Towards shared space (PDF). Urban Design International 13. 13(2), pp 130-138. Accessed on 10th December, 2019, from https://www.researchgate.net/publication/248956209_Towards_shared_space

Havik, E.M., & Melis-Dankers, B. J. M., Shared spaces for blind and partially sighted people: a challenge for designers. Issues and advice for accessible public spaces. Royal Dutch Visio, Centre of Expertise for Blind and partially sighted people. Huizen, the Netherlands. Accessed on 20th December 2016 from http://www.eccolo.nl

Karndacharuk, A., Wilson, D, J. & Dunn, R. (2014). A Review of the Evolution of Shared (Street) Space Concepts in Urban Environments.Transport Reviews. 34(2), pp 190-220. Accessed on 19th December, 2016, from http://www-tandfonline-com.salford.idm.oclc.org

Melis-Dankers, B. J. M., Havik, E. M., Steyvers, F. J. J. M., Petrie, H. & Kooijman, A. C. (Feb-2015) Enabling Access for Persons with Visual Impairment : Proceedings of the International Conference ICEAPVI Athens, Greece, February 12-14, 2015. Kouroupetroglou, G. (ed.). p. 120-128. Accessed on 15th December 2016 from https://www.rug.nl/research/

Moody, S., & Melia, S. (2014). Shared space - implications of recent research for transport policy. Proceedings of The Institution of Civil Engineers-Transport. 167(6), pp 384-392. Accessed on 15th December, 2016, from http://sal-primo-production.hosted.exlibrisgroup.com/primo_library

Parkins, J., & Smithies, N. (2012) Accounting for the Needs of Blind and Visually Impaired People in Public Realm Design. Journal of Urban Design 17(1):135-149 · February 2012. Accessed on 10th December 2019 from https://www.researchgate.net/publication/233014901_Accounting_for_the_Needs_of_Blind_and_Visually_Impaired_People_in_Public_Realm_Design

Thomas, C. (2008). Discussion: shared space- safe space? Proceedings of Institution of Civil Engineers Municipal Engineer. 161(2), pp 59-60. Accessed on 10th December, 2019, from http://www.icevirtuallibrary.com

Tosi, F., Steffan, I.T.,(2012) "Ergonomics and Design for All" in: Soares Marcelo M., Jacobs K. "IEA 2012: 18th World congress on Ergonomics – Designing a sustainable future", Work. A Journal of Prevention, Assessment and Rehabilitation, n.41, supplement 1, IOS Press, USA

Steffan, I.T – edited by - (2014) "Design for All – The project for everyone. Methods, tools, applications. First part", pp.249, (http://www.maggiolieditore.it/ebook/tecnica/design-for-all-the-project-for-everyone-first-part.html) Ed. Maggioli, Santarcangelo di Romagna (Rimini), ISBN 978-88-9160-420-0

United Nations Organization (2006) Convention on the rights of persons with disabilities. United Nations, New York, USA

THE WORK OF THE UK SLIP RESISTANCE GROUP

Stephen C. Thorpe, Simon Hall.

[1] Olver & Rawden, Consulting Forensic Engineers, Green Lane, Balsall Common, CV7 7EJ, UK.

[2] Lucideon Limited, Queens Road, Stoke on Trent ST4 7LQ, UK.

thorpes1867@gmail.com

ABSTRACT

The UK Slip Resistance Group (UKSRG) was formed in 1986. The Group is now over 30 years old. This presentation will outline the past and current work of the Group and suggest some possible areas of future work. The Group publishes Guidelines that detail the preferred operating procedure of the pendulum test in the UK. The current version was published in October 2016. This version will be reviewed and some important points will be considered and discussed in more detail. A number of areas where the Guidelines might be updated will also be outlined. More recently the Group introduced a pendulum verification process that it recommends is undertaken each time the pendulum is used. The development of and continuing work on this process will be discussed. More recently the Group has started to develop guidance in other important areas. To date this includes guidance on stairs, footwear and cleaning. An overview of the work in these different areas will be presented. Some ideas for possible areas of future work and further guidance will be briefly discussed.

Keywords: Slip resistance, pendulum test, risk assessment, stairs, footwear, cleaning.

Topic: Slip resistance. https://ukslipresistance.org.uk/

1. INTRODUCTION

The Group has approximately 70 members drawn from various sectors with an interest in slipping including: flooring companies, cleaning companies, pendulum manufacturers, test houses, research organisations and engineers. The majority of members are based in the UK but there are also members based in Australia, Ireland, USA, South Africa, Spain and Germany. The Group meets 3 times a year, and working groups involved with specific projects meet as appropriate. Several members are actively involved in current Standards work in a range of BS, CEN and ISO committees.

2. GROUP OBJECTIVES

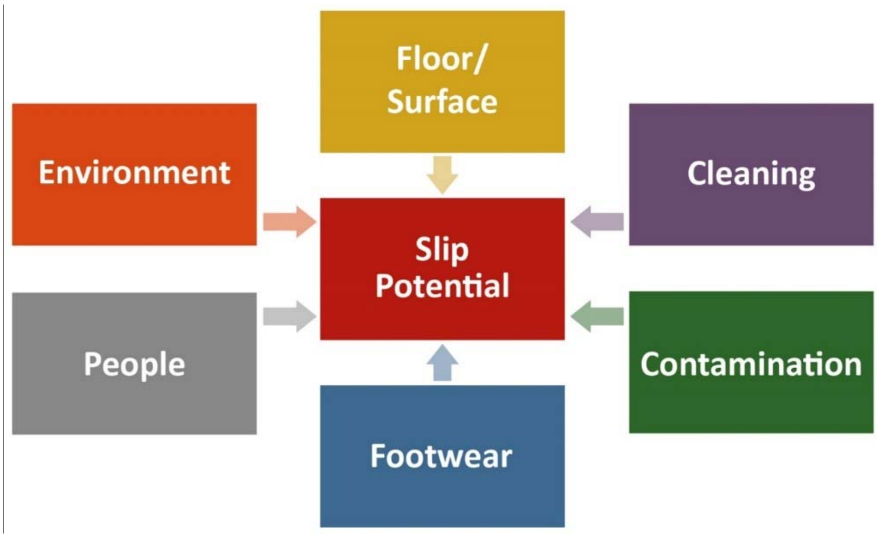
The Group objectives are to:

- Promote a wider understanding of pedestrian slipping.
- Identify and disseminate ways to reduce pedestrian slipping.
- Promote the use of appropriate means of measuring and assessing slip resistance, particularly by means of the Group's Guidelines.
- Monitor and encourage research on pedestrian slipping.
- Monitor developments in the field of pedestrian slipping.
- Commission appropriate technical work.

3. THE SLIP POTENTIAL MODEL

In the UK the Health and Safety Executive (HSE) promotes a risk assessment based approach to managing occupational risk including the risk of slipping. The HSE preferred method of test for the measurement of slipperiness is the pendulum test. Further details about the pendulum test can be found in the relevant British Standard (1). Further information on the HSE approach can be found on the HSE website (2, 3). The Slip Potential Model is an important part of this approach (4). The UKSRG has developed a version of the Slip Potential Model which is reproduced below and has started to develop guidance around the various elements of the model. This guidance may be used to assist dutyholders when developing and reviewing their risk assessments.

Historically the Guidelines were the main output of the Group. The Guidelines have been updated periodically, the current issue (version 4) was published in October 2016. The key development in the current version is the inclusion of a verification process for the pendulum test. The verification process uses 3 surfaces, float glass, pink lapping film and a specific ceramic tile. This process has been successfully used by the pendulum operators in the Group for around 10 years. Recently stocks of the ceramic tile have run low and work during the last 12 months has successfully identified and characterised a similar ceramic tile which will come into service in the near future. During this process we have also engaged with colleagues in Europe and Australia and contributed to a programme of proficiency testing led by Carl Strautins from Safe Environments in Australia (www.SafeEnvironments.com.au). We are planning to continue and further develop this work in the near future. We hope that our experience in developing the pendulum verification process will inform this work.



The pendulum test is the preferred method of test in the UK (5). The Guidelines outline the methodology followed when using the using the pendulum test to characterise a surface. The pendulum and the methodology can be used in the laboratory (for example testing samples of a flooring material) and on site (for example to understand how an installed floor is performing in service). The guidelines also include details of how the pendulum may be used on profiled surfaces, slopes and stairs.

The slip resistance properties of installed surfaces will be affected by effective cleaning (the removal of contamination) and maintenance. The Group has developed guidance on cleaning and maintenance. In occupational settings footwear can be an effective control and help to reduce the risk of slipping. The Group has developed guidance on the selection and use of footwear in the workplace. As it is developed draft guidance is discussed and reviewed in Group meetings and when it is finalised the guidance is placed in the members' area of the Group website.

The Group have also developed guidance on steps and stairs, in acknowledgment of the number of serious accidents and injuries that occur on steps and stairs.

Recently the Group have started developing guidance considering entrance systems (an example of environment) this guidance will be further developed in the coming months.

We have also very recently begun a review of the current version of the Guidelines to ensure they remain up to date and reflect developments in other areas.

4. FUTURE WORK

Members are encouraged to suggest new areas of work and any proposals put forward are considered and discussed in Group meetings. A smaller working group is then formed and tasked with taking the proposal forward. The topic of accelerated wear and the durability of the slip resistance of installed floors was discussed at a recent meeting. This is likely to be adopted as an area of future work. Barefoot slip resistance and human factors are two more areas where guidance may be developed.

The Group is looking to continue to grow and develop and to diversify its membership base. It also hopes to develop further liaisons with similar Groups in other countries. The Slip Resistance Group of Spain is the first example of this.

If you are interested in learning more about the Group and its work or would like to join the Group please visit the website for further details.

5. REFERENCES.

(1) BS 7976-1:2002 + A1:2013. Pendulum testers. Specification.

BS7976-2:2002 + A2:2013. Pendulum testers. Method of operation.

BS7976-3:2002 + A2:2013. Pendulum testers. Method of calibration.

(2) https://www.hse.gov.uk/simple-health-safety/risk/index.htm

(3) https://www.hse.gov.uk/pubns/indg225.pdf

(4) https://www.hse.gov.uk/slips/preventing.htm

(5) https://www.hse.gov.uk/pubns/geis2.pdf

FUNCTIONAL DIVERSITY AND DESIGN INDICATORS FOR THE IMPROVEMENT OF ACCESSIBILITY ON THE FLOOR OF URBAN PEATONAL ROUTES

Delfín JIMÉNEZ[1], Jesús HERNÁNDEZ-GALÁN[2], Jose L. BORAU[3]

[1] EQAR, Urbanismo Edificación y Accesibilidad

[2] Fundación ONCE

[3] Fundación ONCE

d.jimenez@eqar.es

ABSTRACT

The present study develops the theoretical basis of foundation and analysis for applied research on how the diversity of ergonomic factors and human behaviour can determine the functional keys of urban design for the prevention of slips, trips or falls in public space. For this, the DALCO criteria (Spanish acronym for Moving, Grasping, Location and Communication; MGLC in English) developed by the UNE-170001-1 are taken as an initial reference, and its application is analysed for the different types of pavements and different existing situations on the surface of the urban pedestrian routes.

On the other hand, an analysis of the ergonomic and human behaviour factors is carried out, which translate into a diversity of use of the pavements and surfaces of urban pedestrian routes. With the comparison of both analyses, the specific indicators are expected to be obtained in order to carry out a practical investigation with people with different functional capacities in a specific urban environment. Both the initial basics study developed here, and the subsequent applied research, will focus especially on the needs of two vulnerable groups (elderly and visually impaired) to increase accessibility and security on the surface of pedestrians' routes in general and urban pavements in particular.

Keywords: safety indicators, diversity of needs, design criteria

Topic: Architectural design in the prevention of falls. Ergonomic and human behaviour factors

1. INTRODUCTION

1.1 Background

ONCE (National Organization of the Blind) and its foundation (Fundación ONCE) have been assuming for decades a concern for the needs of people with disabilities in the physical environment, and in particular they have also had and have a great interest in everything related to urban pavements, as key elements in the accessibility of public space in cities. From this perspective, the implementation of a Research and Development (R&D) project on Accessibility in Urban Pavements is proposed: AUP-Project

1.2 Scope

Initially, a national geographic scope is proposed, with Spanish companies and entities. However, a possible revision of this scope is not ruled out to give it an international dimension. In that case the table of participating entities (e.g. European universities) would be expanded.

Similarly, the temporal scope is initially considered as one year, although if the extended option of the project is chosen, its development could be two years.

2. APPROACH

2.1 Goals

The ultimate goal of the project is to boost existing knowledge on pavement accessibility and encourage the development of new products with new alternatives that improve current models. For this, the following operational objectives are established:

- Technically develop the analysis instruments that allow to have a greater knowledge of the accessibility of these urbanization elements.
- Involve the industry sector to promote the development of more accessible new products
- Directly validate with the users, especially the most vulnerable groups, the accessibility of urban pavements
- Involve public entities in charge of the management and promotion of new urbanization / redevelopment initiatives in the urban public space.

2.2 Participation

These operational objectives also respond to the initial premise of the ONCE Foundation to propose research from a holistic perspective, where there is participation and involvement of:

- Experts in the field (accessibility in urban pavements)
- Private sector companies in the pavement industry,
- Users and especially vulnerable groups such as blind and elderly people
- Public entities that manage the accessibility of the built urban environment.

2.3 Methodology

Three work phases are established for the development of the project:

2.3.1 Phase I: Definition of indicators

In this first phase, the definition of specific accessibility indicators for urban pavements is proposed. Thus, in this stage the following tasks will have special relevance:

- Technical study of the characteristics of urban pavements in relation to accessibility, identifying which are the most determining variables.
- Study of users' needs and their level of satisfaction with respect to existing solutions (workshops with visually impaired and elderly people)
- Study with the companies related to urban pavements and pedestrian surfaces of the weak points and opportunities for improvement of the commercial products currently on the market
- Identification and specification of all the results in evaluable indicators.

2.3.2 Phase II: Validation of indicators

The second phase will have an eminently practical character, where the indicators obtained will be tested, in a specific urban space (or several, depending on the extension of the project). A field validation by different user groups will be carried out, as well as a technical analysis and assessment (before and after the validation). Depending on the development of the project, participation may be opened for new technical contributions and validations to entities (of technicians, companies and users) from other countries.

2.3.3 Phase III: Development possibilities

In this conclusion phase, the results obtained in the previous phase will be reviewed and possible improvements to be made will be studied. Working groups will be held with companies and users to find out and compare points of view and guidelines will be established to be considered for future product developments.

3. DEVELOPMENT OF PHASE I:

3.1 Initial Technical Study

For this initial study by technicians and experts in the field, two initial sources will be taken as a basis for work:

- The DALCO criteria (Spanish acronym for Moving, Grasping, Location and Communication; MGLC in English) developed by UNE-170001-1, and their application to the different types of pavements and different situations existing on the surface of urban pedestrian routes will be analysed.
- The different ergonomic and human behaviour factors that result in a diversity of use of pavements and surfaces on urban pedestrian routes.

3.2 Participation workshops

In parallel with the initial technical analyses, various participation workshops will be organised in order to collect contributions from both manufacturers and users: their difficulties, suggestions for improvement, as well as any other observations that may be of interest.

At least the following groups will have a relevant role in the workshops

- Blind or visually impaired people: as a group that is particularly vulnerable in urban public space in terms of location and orientation needs
- Elderly people: as an increasingly majority group in the population, with a general reduction in functional capacities: mobility, grip, location and orientation
- Companies related to the manufacture and marketing of pavements and elements that make up urban pedestrian surfaces.

Depending on the development of the project, the form of realization (number of workshops and participants) may be different.

3.3 Creating indicators

With the comparison of both analyses and the results of the participation workshops, it is expected that the initial specific indicators will be obtained for validation and implementation in later phases.

Initially the following groups are established to structure the Pavement and Pedestrian Surface Accessibility Indicators (PPSAI) in:

- PPSAI in transit areas
- PPSAI in leisure and rest areas
- PPSAI on signalling elements (warning or guidance)
- PPSAI in special complementary or transitional elements

4. RESULTS

4.1 Expected results

The purpose of this communication corresponds to the initial presentation of the project, the definition of the general methodology to be followed, as well as the development of the methodology of phase I of the Definition of Indicators of Accessibility in Pavements. As a result, it is expected to obtain a collection of specific and evaluable accessibility indicators, grouped in families, depending on the different functions they perform in the urban space.

4.2 Conclusions

By way of conclusion, the initiative of the project and the obtaining of accessibility indicators for pavements is very positively valued. Its definition opens the possibility of both validation and development of new analyses with the aim of implementing the accessibility characteristics of the pavements in later phases

In addition, they may serve as an initial reference for other studies on accessibility (e.g. on indoor pavements, on other urban elements...).

TECHNICAL SESSIONS (II)
Measurement Principles and Technology

LOOKING FOR A COMPREHENSIVE SCALE FOR SLIP RESISTANCE

Gonzalo Silva[1], Adoración Muñoz[1], Rebeca Domínguez[1], Ana Torró[2], Cristina Llobell[2], Gloria Lillo[2]

[1] Instituto de Tecnología Cerámica (ITC). Asociación de Investigación de las Industrias Cerámicas (AICE). Universitat Jaume I. Castellón. Spain.

[2] Instituto Tecnológico del Calzado y Conexas (INESCOP). Elda. Spain.

gonzalo.silva@itc.uji.es

ABSTRACT

The magnitude of the available friction depends on many variables, such as the gait and speed, topography and roughness of the floor, type of contaminant and footwear sole material and design, so that a wide variety of actual situations are to be found. But standards need for a proper definition to ensure their reproducibility, so floors and footwear are often tested under conditions that are not representative of their expected use. Moreover, although there is a unique standard method for measuring slip resistance on footwear, there are currently four test methods included in CEN/TS 16165 for flooring testing, but no clear guide for using them in the evaluation of floors performance in actual conditions.

In this context, the coherence between the testing conditions of both products is critical for the proper selection of a suitable combination of flooring and footwear. In the present study, a comparison between the available standard reference surfaces and the different sliding devices (sliders and footwear) has been carried out to check the comparability between the scales from the different test conditions (CEN/TS 16165 Annex B and C, ANSI A326.3 and EN ISO 13287).

In addition, it has been studied the changes on the results obtained with the different test methods over abraded standard surfaces, using a linear washability tester. The results confirm a lack of equivalence between flooring slip resistance specifications related to each testing methodology.

Keywords: slip resistance, friction, footwear, standard surfaces, wear

Topic: Measurement Principles and Technology

1. INTRODUCTION

The legislation in force in the European Union clearly establishes the safety requirements of protective footwear (Regulation (EU) 2016/425), one of them being the footwear's slip resistance property, and according to the Regulation (EU) No. 305/2001, floorings must also include the declaration of their slip resistance in the CE marking. However, there is still a high number of occupational accidents, many of them related to slips or trips.

Despite the shared need of footwear and flooring manufacturers, there is not a common approach in these sectors about the assessment of slip resistance, who use different test methods, reference materials and establish requirements without considering the influence of the other relevant variables. There have been several previous initiatives on this subject, but only the European ULTRAGRIP project (FP7-SME-2010-1.262413) promoted the collaboration between the flooring and the footwear sectors to jointly addressing the problem of slip resistance. Its conclusions regarding friction processes between footwear and flooring products, and the results from their combinations with contaminants, confirmed the need for application-based standards, with different test conditions depending on the expected use.

The present work analyses the coherence between the scales from the different test methods.

2. SLIP RESISTANCE TEST METHODS

Within the scope of standardization of professional footwear (ISO/TC 94-Personal Safety, Protective clothing and equipment and CEN/TC 161- Foot and leg protectors), EN ISO 13287:2019 establishes the test method for slip resistance of footwear and its requirements are defined at EN ISO 20345-6-7 standards. This test method includes two combinations of reference surfaces and contaminants (Table), and three sole-floor contact modes (heel, flat and forepart) for coefficient of friction (CoF) measurements, as detailed in Figure 1.

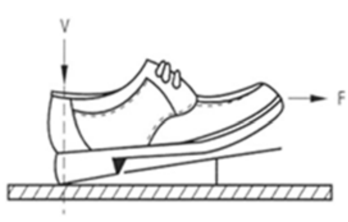
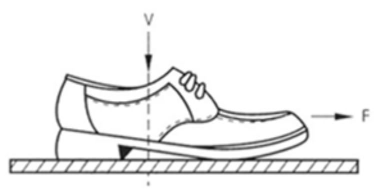
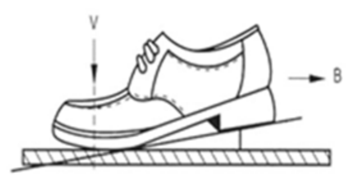
		
Forward heel slip	Forward flat slip	Backward forepart slip

Figure 1: Contact modes for footwear testing

In contrast, many different methods are used for evaluating the slip resistance of floorings, which usually give contradicting results on the same surfaces. Because of the lack of agreement at European level on a single test method for this purpose, CEN/TC 339 is currently developing a standard for slip resistance of pedestrian surfaces (prEN 16165), including three testing approaches: walking on an inclined ramp (annexes A-B), pendulum test method (annex C) and the use of a tribometer (annex D) for the measurement of dynamic coefficient of friction. Besides, there are also other national standards which introduce different reference surfaces (STD-P in UNE 41901 EX) or measuring devices (BOT 3000 in ANSI A326.3).

For the comparative analysis, it was decided to test reference surfaces using four methods (footwear, ramp, pendulum and ANSI tribometer) and two test conditions (water and glycerine/oil). Footwear tests according ISO 13287 were carried out with heel and flat contact modes on different commercial shoes, which were used for the ramp tests too.

Table 1: Slip resistance test methods

Standard	Product	Counterbody	Contaminant	Counterbody verification
ISO 13287	Footwear	Eurotile Polished steel	Water+0.5% SLS Glycerine	Slider 96 - 7° - 500N R_z =1.6 - 2.5 µm
TS 16165 A	Flooring	Barefoot	Water+0.1% SLS	St-A, St-B and St-C
TS 16165 B	Flooring	Reference sole	Oil 10W30	St-I, St-II and St-IIIA
TS 16165 C	Flooring	Slider 57 or 96	Water/dry	Float glass, Eurotile, Lapping film
TS 16165 D	Flooring	SBR-leather	Water+0.1% SLS	Float glass, HPL plate, Eurotile
UNE 41901	Flooring	Slider 57	Water	Ceramic tile STD-P, Lapping film
ANSI A326.3	Flooring	SBR rubber	Water+0.05% SLS	Standard tile

3. SELECTION OF TEST SURFACES

As detailed in Table 1, each of the test methods uses different methodologies to verify the counterbody to be used in the test. Footwear is tested for water contamination conditions using Eurotile 2, a flat medium rough ceramic surface. This surface shall get a calibration test value (CTV 96) in the range 0.20 to 0.26 when tested with a 25 mm wide IRHD 96 rubber slider (vertical force of 500N and contact angle of 7°). For glycerine contamination tests, a polished steel plate shall be conditioned using abrasive paper till a specific average roughness.

Shod ramp test establishes a validation of the test persons wearing a reference footwear with a specific sole design (Figure 2) on three standard test surfaces, one flat high rough (St-I) and two profiled ceramic surfaces.

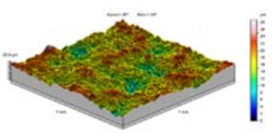
			
ISO 13287- Eurotile 2	prEN16165 B - sole	prEN16165 C - slider	ANSI A326.3 – SBR slider

Figure 2: Counterbodies for footwear and flooring tests

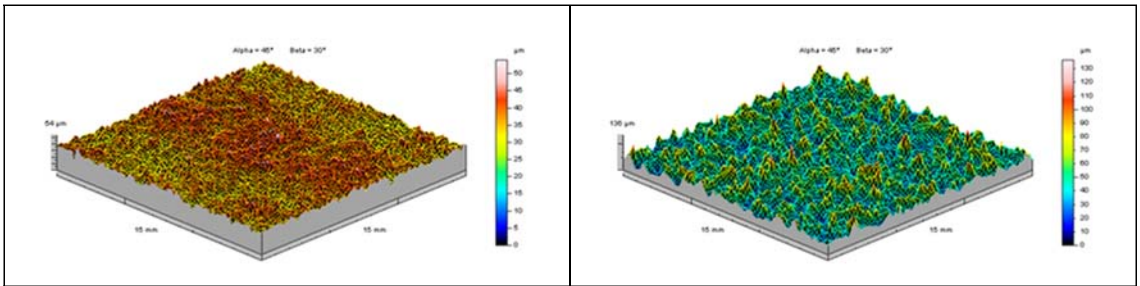
Pendulum and tribometers standards use reference surfaces for the verification of their different sliders. Both annexes C and D of prEN 16165 include Eurotile 2 (also known as Portuguese tile) within the three surfaces used for the verification of the test device. The Spanish pendulum test (UNE 41901) established a low roughness textured surface (STD-P), which was designed to correct the lack of durability of the Portuguese tile, and the SBR slider for the

American tribometer is verified with a smooth ceramic surface. ANSI standard tile was discarded due to its low CoF values (Table 2), and Eurotile 2 and STD-P were selected for the collaborative tests with the footwear research centre (INESCOP).

Although these ceramic surfaces get similar values when using these flooring tests methods, both were included in the study due to their differences in surface topography (Figure 3).

Table 2: Coefficient of friction of reference test surfaces in water contamination conditions

Standard	Surface	Pendulum S57	Pendulum S96	BOT 3000 SBR
TS 16165 C	Eurotile 2	0.28	0.40	0.63
UNE 41901	STD-P	0.25	0.41	0.65
ANSI A326.3	BOT reference tile	0.10	0.17	0.27



Flat medium rough - Eurotile 2 | Low roughness textured - STD-P

Figure 3: Surfaces topographies

4. TESTING WITH TEST METHOD FOR FOOTWEAR

Several shoes were tested according ISO 13287 with heel and flat contact modes on both reference surfaces. Unlike the apparent similarity between both reference surfaces shown by flooring tests methods, Eurotile 2 provides higher CoF than textured STD-P when tested with actual footwear and water+0.5% SLS, for both flat and heel contact modes (Figure 4). But in contamination with glycerine, both surfaces show similar values, except for the results with PURcom and PURcel shoes.

Previous studies [1] had confirmed that the friction mechanisms are very different depending on the surface geometry and type of contaminant present. In water contamination conditions, contact area and roughness of the surface are the main variables [2] that contribute to increase the CoF, which explains lower values obtained with low roughness textured surface of STD-P.

Conversely, surfaces with an embossed texture usually allow higher interlocking with the shoe sole in greasy liquid contamination conditions, whilst roughness contributes less to friction. Therefore, the STD-P reference surface achieves CoF values equal to or greater than Eurotile 2 for some of the tested footwear.

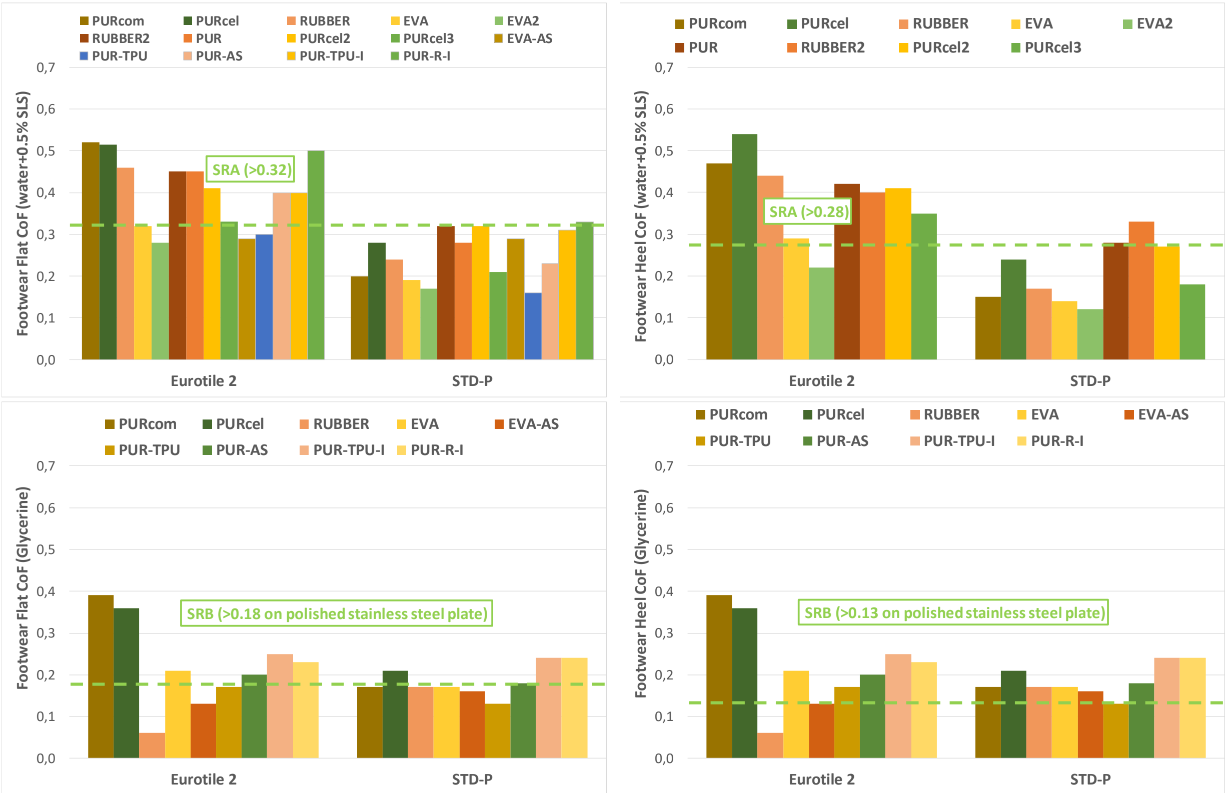


Figure 4: ISO 13287 – Water (up) and Glycerine (down) tests. Flat (left) and Heel (right) contact modes.

5. COMPARISON BETWEEN FOOTWEAR TRIBOMETER AND RAMP TEST METHOD

The test method for footwear evaluates the coefficient of friction as the ratio between the friction force (parallel to the surface) and the vertical force (400-500 N), while the footwear is displaced linearly over a reference surface at a speed of 0.3 m/s (Figure 5). The ramp method, based on the German standard DIN 51130, uses an adjustable inclining platform on which qualified technicians walk wearing reference boots with a specific sole design. Both the platform and the boot soles are previously covered with SAE 10 W-30 oil. The inclination of the ramp is increased at a rate of approximately 1°/s until a risk of slipping is detected and the maximum angle is recorded as test result.

Figure 5: Footwear and ramp test methods

To enable comparison of the CoF values from tribometer tests in flat contact mode with the critical angle results obtained using the ramp method, it was assumed that the CoF could be calculated as the tangent of the critical angle.

The comparative analysis of the test results using an aqueous solution of sodium lauryl sulphate (SLS) shows that the values obtained with the ramp were slightly higher than with the footwear tribometer (Figure 6), in some cases even exceeding the scale limit (0.8) in the ramp test. This could probably be related to the gait adjustment ability of technicians in a hazard prevention situation [3]. Regarding glycerine/oil tests, ramp test results confirm that STD-P surface performs better than Eurotile 2 for this contamination condition, with DIN 51130 reference sole too. As shown in red in the graph for glycerine/oil tests, the reference boot from shod ramp tests gets lower CoF results on Eurotile 2 than commercial footwear, even on a flat high rough ceramic tile, but reaches higher CoF values for STD-P and the profiled rough surface. This means that its sole design allows better interlocking with surface profile, and therefore, it is not very representative of most of protective footwear available in the market.

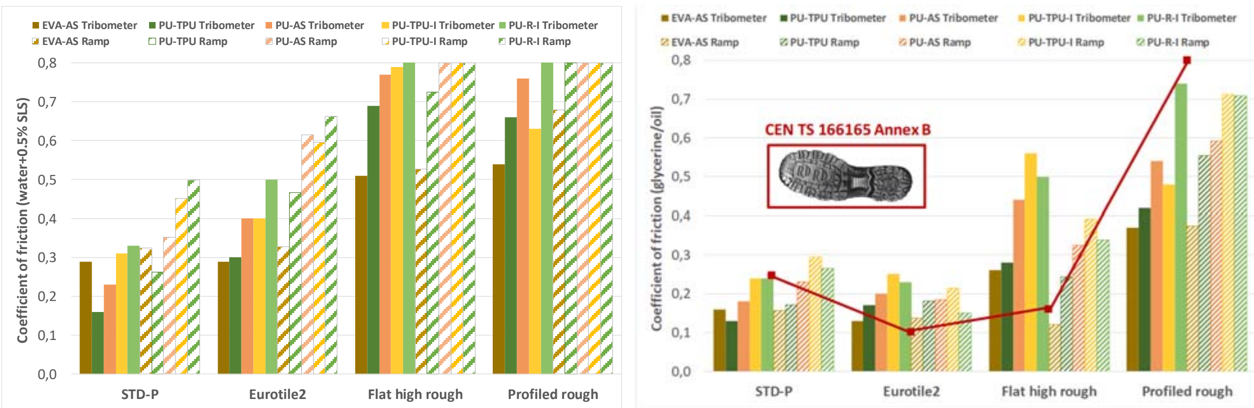


Figure 6: Tribometer and ramp results using same footwear. Water (left) and Glycerine/Oil (right)

6. COMPARISON WITH OTHER FLOORING TEST METHODS

Besides the shod ramp test, the most widely used test method for flooring materials is the pendulum friction tester, which is based on the British standard BS 7976-2. There are also different types of tribometers for measuring coefficient of friction at constant speed along a linear path (Tortus, GMG, BOT 3000), which differ in the type of slider used (Figure 2). For the tests, it was selected the ANSI A326.3 tribometer that uses a curved SBR rubber slider, allowing the reduction of the stick-slip phenomenon which usually produces unreliable CoF measurements with these kinds of devices.

Both reference surfaces were calibrated with footwear tribometer (CTV 96) and measured with pendulum (sliders 57 and 96) and BOT 3000. Figure 7 shows a comparison of the results with footwear testing (heel contact mode), where PTV57 and PTV 96 are divided by 100.

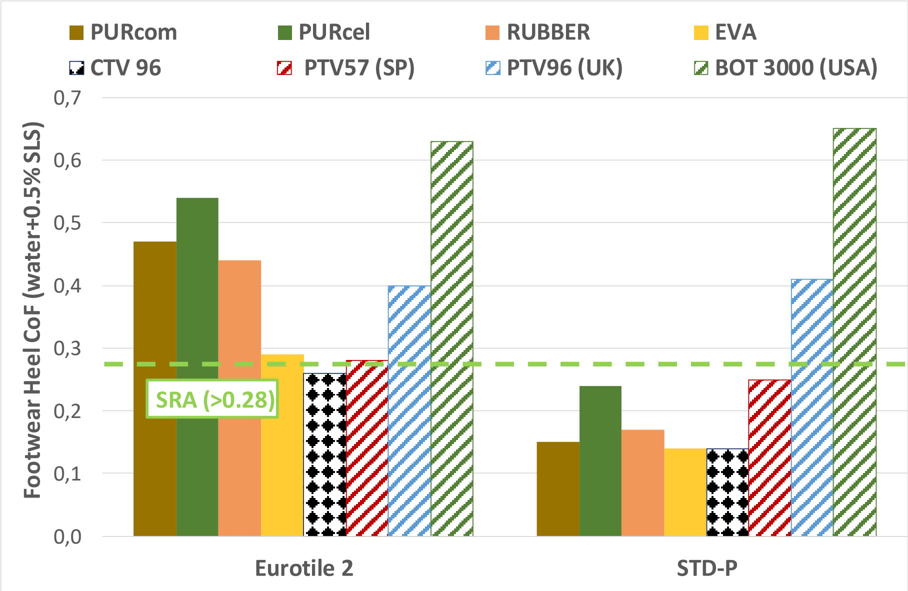


Figure 7: Comparison of footwear testing, calibration test value and flooring test methods

Calibration test values (CTV 96), measured according ISO 13287, are very different in both reference surfaces and almost equal to CoF of the least slip resistant footwear (EVA). Conversely, pendulum and BOT 3000 measurements for both reference surfaces are very similar. It should be noted that contact surface with the edge of pendulum sliders is around 1 cm^2, much lower than that allowed when testing with actual heel footwear (Figure 8). So, higher PTV on STD-P could be due to better interlocking of sliders edges with textured surfaces, which cannot be achieved on larger flat heel surfaces. Regarding BOT 3000 results, it should be clarified that such high values are due to averaging measurements along the path, which includes low and very high values generated by slip-stick phenomenon.

			
PURcom	PURcel	RUBBER	EVA

Figure 8: Footwear flat heels

After the initial characterization, both reference surfaces were abraded using a Gardco linear motion washability and wear tester [4], measuring the progressive changes on slip resistance with pendulum method. Eurotile 2 showed a higher decrease than STD-P, achieving friction stabilization on both surfaces after 500 cycles (Figure 9).

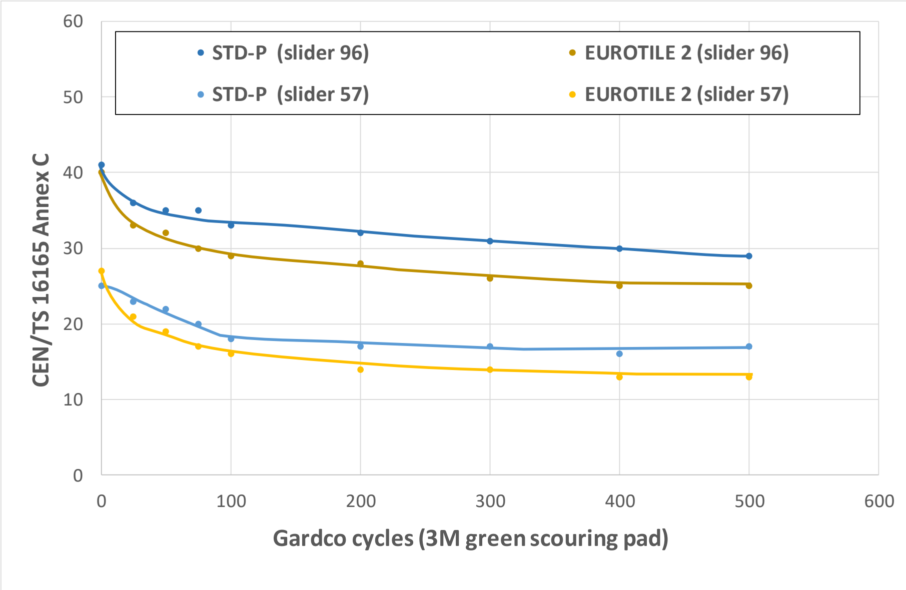


Figure 9: Evolution of Pendulum tests value with abrasion

Additionally, measurements with the footwear method and the American tribometer were carried out at the intermediate stage of 50 cycles and after 500 cycles (Figure 10). For Eurotile 2 surface, CTV 96 measurements according ISO 13287 and all flooring test method showed a similar decreasing trend, with approximately the same absolute reduction in CoF value.

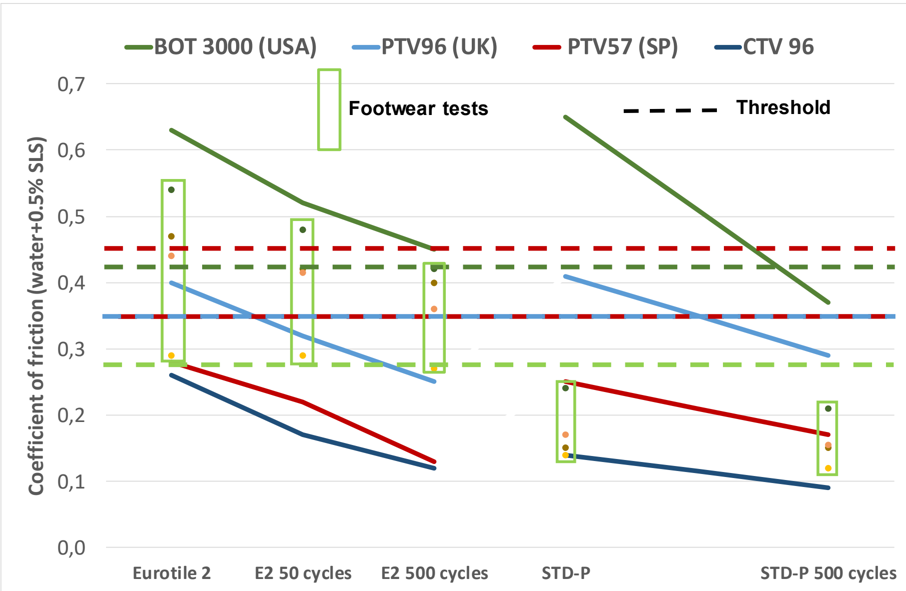


Figure 10: Changes on friction due to wear process

In contrast, for textured surface STD-P each method showed a different trend, with the lowest reduction for footwear tribometer (CTV 96) and the highest for BOT 3000 tribometer. Regarding footwear testing, CoF reduction due to abrasion was significantly lower in both reference surfaces, and almost negligible for the least slip resistant footwear (EVA).

But when comparing test results with their respective regulated or recommended thresholds (horizontal dotted lines), an evident lack of coherence between footwear and flooring assessment can be observed, particularly on textured surfaces. Considering that flooring test methods do not take in account the contribution to friction of shoe sole design, and even if both testing approaches will use the same reference surfaces, current recommendations and regulations for the different floorings test methods should be revised to get an equilibrated criterion for slip resistance classification of flooring with different methods.

Likewise, it should also be considered that most flooring test methods are excessively conservative in the evaluation of changes of roughness, whilst the changes in the coefficient of friction when testing with actual shoes seems to be much less relevant for safety purposes.

7. CONCLUSIONS

- Footwear and flooring test methods should share counterbodies, reference floors and shoes respectively, to allow a higher coherence between their own slip resistance classifications. It should be promoted the development of application-based standards, for water and greasy liquids contamination conditions, using common reference floors and shoe soles which should be representative of actual products in each environment.
- In water contamination in actual conditions, both the design of the sole of the footwear and the adjusting gait ability of users can contribute to friction in the same order of magnitude than surface topography of flooring. Therefore, slip resistance thresholds should be established considering all the contributions, and preferably based on common reference counterbodies.
- Flooring testing methods are excessively conservative in the evaluation of changes in friction due to wear, which appear to be much less relevant when wearing footwear.
- Requirements and recommendations for flooring should be revised to allow a closer slip resistance classification independently of the test method used, applying the approach of ASTM F2508 – 16 for the validation of walkway tribometers.

8. REFERENCES

[1] Silva; G., Beltrán; A., Muñoz; A., Escrig; A., Llobell; C., Sanchís; M., Lillo, G. Optimised combinations of ceramic flooring and footwear for work environments. XV QUALICER Congreso mundial de la calidad del azulejo y del pavimento cerámico. Castellón 12 y 13 febrero, 2018. ISBN: 978-84-95931-39-9

[2] Muñoz-Lázaro, A. PROBLEMÁTICA DEL RESBALAMIENTO EN PAVIMENTOS CERÁMICOS [PhD Thesis]. Castellón (Spain). Universitat Jaume I (UJI), 2019

[3] W.R Chang, W.R, M.F. Lesch, C.C. Chang, and S. Matz (2015). “Contribution of gait parameters and available coefficient of friction to perceptions of slipperiness”. Gait & Posture, 41, 288–290

[4] Strautins, C., Sustainable slip resistance: An opportunity for innovation, (2008) 10th World Congress on Ceramic Tile Quality, Castellon, Spain, Vol. 3, P.BC 381.

THE IMPORTANCE OF SURFACE CHARACTERIZATION FOR SLIP RESISTANCE: AN OVERVIEW

Ir. Marcel Engels

Forschungsinstitut für Anorganische Werkstoffe-Glas-Keramik-GmbH, Heinrich-Meister-Straße 2, 56203 Höhr-Grenzhausen

Marcel.engels@fgk-keramik.de

ABSTRACT

In the system of factors influencing slip risk the surface characteristics, the surface profile defines how a surface behaves under different circumstances. Objectively measuring the surface using state of the art topography analysis can support the estimation of the functional performance of a floor, interpreted by different measurement methods. The dos and don’ts of topography measurements in the laboratory and on site, their interpretation and implications, as well as the drawbacks of the method are addressed, advocating the essential importance of adequate surface characterization to support slip risk estimation for all relevant stakeholders.

Keywords: surface characterization, topography, slip risk, measurements, Slip STD

Topic: Measurement Principles and Technology

INTRODUCTION

In the system of factors influencing slip risk, the surface characteristics, especially for hard floorings, the surface profile or "roughness" defines significantly how a surface behaves under different circumstances regarding contamination, cleaning procedures and control measures.

The assessment of this surface aspect as a basis for the estimation of the slip risk was the subject of the European collective research project "SlipSTD", performed by a consortium consisting of tile manufacturers, tile manufacturers associations, architects, health & safety associations and leading European Research Centres from Germany, Italy, Spain, Portugal, Finland and Sweden [1]. While the aim of the project was to objectively measure the relevant aspects of a surface as the basis for the evaluation of its functional performance using state of the art topography analysis, using the slip measurement methods as now implemented in the DIN EN 16165 Standard (The ramp method, the coefficient of friction measurement and the pendulum test) [2] it was found that any slip measurement is an interpretation of these aspects, leading to possibly different risk estimations, depending on the measurement method used.

It highlighted, that these differences in interpretation are significantly dependent on the surface, which, using profile parameters as identified in the investigations, can be differentiated in specific surface topography groups, from smooth to highly profile. This has significant implications on the possible correlations of the methods as well as influences the performance of different measurement methods depending on the surface. As the discussion on the comparability and applicability of the methods is complicated, this can help to create an understanding of measurement effects and difficulties, often encountered assessing slip resistance in the laboratory and on site.

The aim of this paper is to highlight the do and don'ts of the surface characterisation and advocate its use and potential in interpretation issues and discussions as encountered in the field.

1. THE DO AND DON'TS OF SURFACE CHARACTERISATION

For the measurement of the surface parameters, relevant for slip resistance, it is necessary to utilize methods with a large measurement area (10 cm x 10 cm up to 20 cm x 20 cm) to capture the relevant aspects of the most floorings. This requirement was met by optical topography measurements using the method of chromatic aberration, which uses the spectral shift of the maximum reflection peak of a focused white light beam to calculate the surface parameters while scanning the surface.

The mentioned topography measurement provides the possibility to measure the mentioned surfaces (up to 20 x 20 cm) with a relevant horizontal resolution in an acceptable timeframe (from 40 minutes up to 2 hours, dependent on the resolution). In this case it is important not to measure as accurate as possible (as provided by other methods like interferometry) but to cover a surface capable of catching the slip relevant surface characteristics. The available large measurement area deletes the need for "stitching" of smaller surface patches, necessary with interferometry and laser scanning microscopy. The results are based upon a 3D-based evaluation (based upon ISO 4287, ISO 428 and ISO 135658).

The investigations recommend the use of primary profile parameters (Indicated as P): It has to be noted that these provide better correlations to the actual functional performance as the (wavelength-based) filtered and widely used R-Roughness values, often derived from 2D tactile measurements. In this case it has to be noted that R-values as such can only be compared if the filter settings are comparable (simplified: small wavelengths incorporate micro-roughness, while large wavelength filtering incorporates waviness). These have to be adjusted according to the actual measured roughness (as specified in DIN 4288), which is not always possible on the equipment used in the market. This can significantly influence the actual results.

Furthermore these single profile based tactile 2D measurements are insufficient to represent the relevant variations in the surface area measured, even when multiple profiles are summarized to create a “semi” 3D measurement. In this regard the often used single profile based Rz value has to be interpreted with care, when used to compare different surfaces. It can be used to indicate surface changes, but is not sufficient to evaluate actual slip relevant changes.

2. INTERPRETING SURFACE CHARACTERISATION

An important aspect to be considered is that the relevant surfaces characteristics cannot be represented by a single parameter. Besides the parameters peak height Pp (providing grip of the surface) and the core roughness Pk (significant for the friction of the surface) (figure 1) , specified in the SlipSTD project as relevant for slip resistance, ongoing investigations identified also the skewness, the shape of the profile height distribution has proven to be of significant influence (figure 2). As the 3D based calculation of peak distances is complex and intensive, it helps to represent a “density” of peaks in the surface.

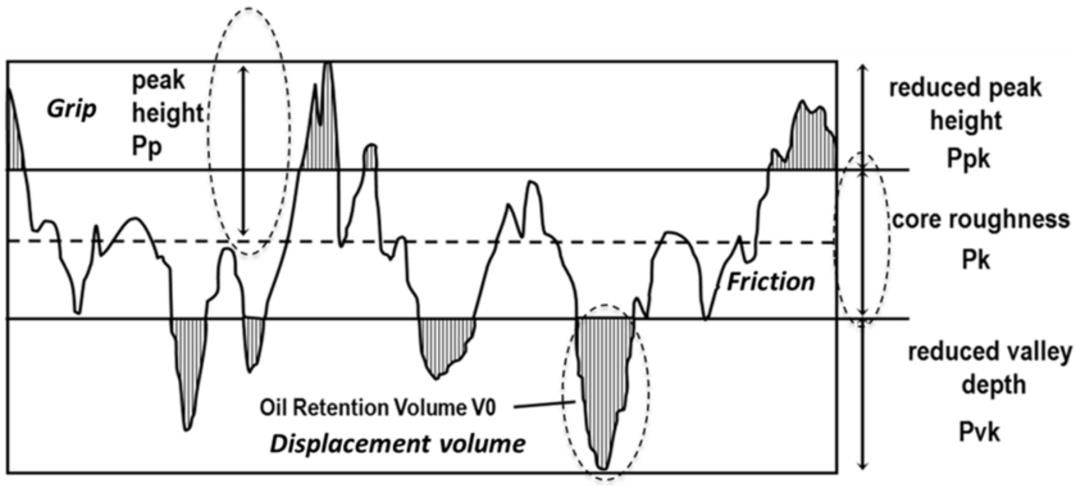


Figure 1: Surface parameters (acc. to ISO 4287 and EN ISO 13565) and their significance for slip resistance

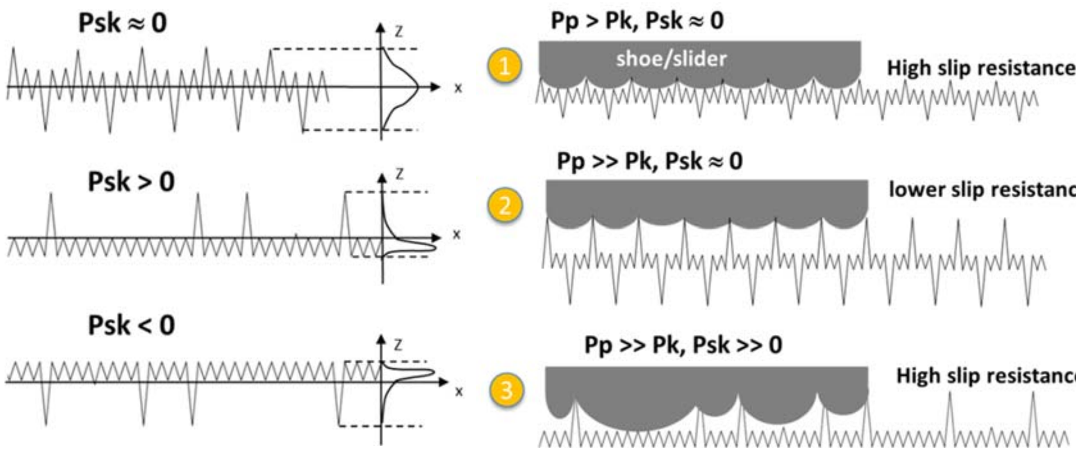


Figure 2: The influence of the Skewness Psk (left) on the slip resistance (right). At high Pp values with a regular peak pattern ("2"), the friction contact is reduced, leading to a lower slip resistance. High friction contact ("1") or irregular peak distributions ("3") increase slip resistance.

The practical influences are illustrated in figure 3, where a significant difference at comparable Pp and Pk values is illustrated.

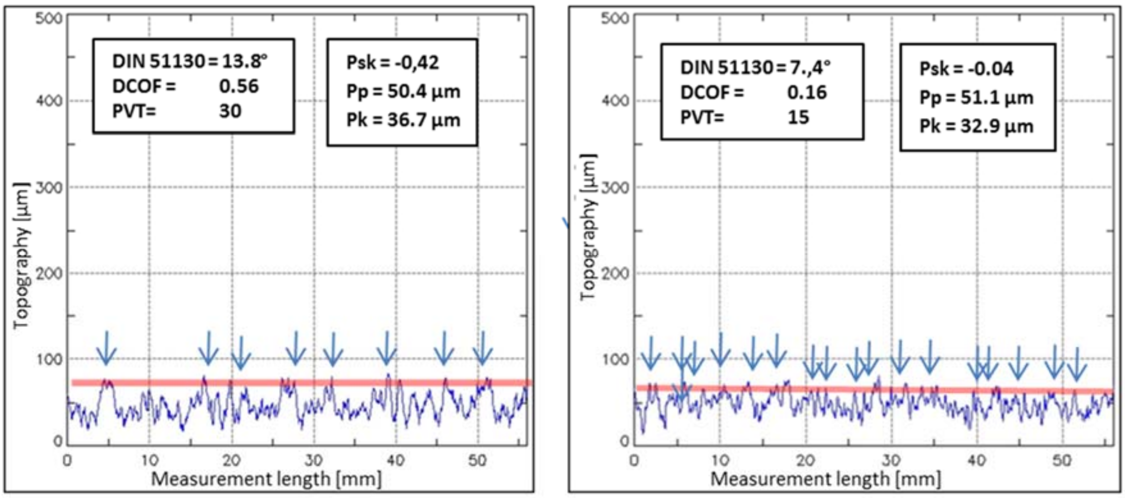


Figure 3: The practical influence of the Skewness Psk

The results of a topography and slip resistance survey of about 60 surfaces with a value of Pk between 45 and 85 and a Pp between 80 and 190 (non-profiled with micro roughness, "gritty touch") are presented in figure 4, which indicates some significant implications:

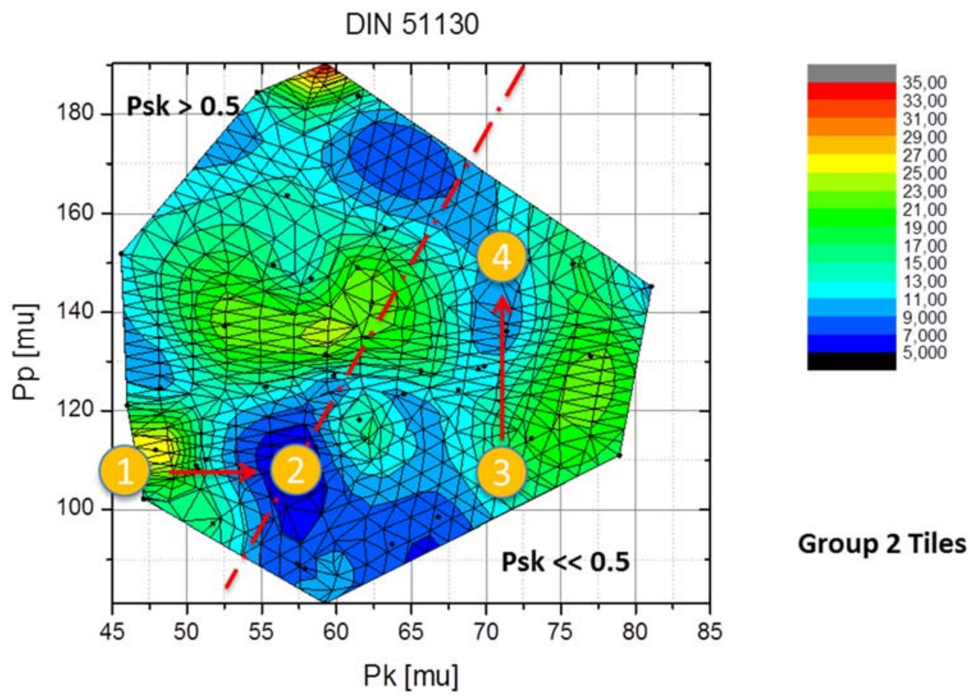


Figure 4: The correlation of slip resistance (here: acceptance angles according to DIN 51130 Ramp) with surface parameters: left of the red division line the Psk value is above 0.5, right of the line Psk is below 0.5.

- There are no linear correlations between surface parameters and slip resistance. Slip resistance is built up as a result from the combination of the settings of Pp, Pk and Psk values.
- It can be seen that for these surfaces slip resistance can be reached with different combinations of surface settings, as to be expected from figure 2.
- The highest slip resistance is limited to a very narrow surface range, indicating that this situation might be strongly influenced by production variations or wear of the surface.
- It shows that if the Pk value is increased, and so nears the Pp value, grip can be lost in a regular distribution of peaks (“1” to “2”).
- It confirms that if peaks are increased by design (higher Pp values, going from “3” to “4”), in contrary to the expectation, this may lead to loss of slip resistance (see figure 2).

3. THE IMPLICATION OF USING SURFACE CHARACTERISATION

The results presented in figure 4 are a selection of the surfaces (group 2, see figure 5), which, mentioned before, can be grouped in 4 surface categories, which have shown different behaviour with different measurement methods. This implies that there are differences in the interpretation of slip resistance depending on the actual surface profiles measured with different methods (figure 5).

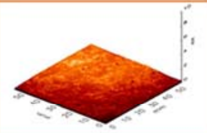
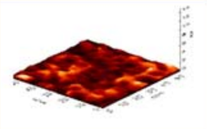
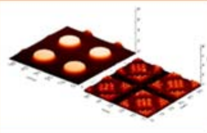
Surface topography groups	Examples	Surface influences		Measurement suitability
Group 1 Non profiled, mainly smooth surface, Pk <50 µm		hydrodynamic film effects, different measurement methods and settings influence results		tribometer and pendulum can overestimate actual slip resistance due to stiction effects
Group 2 micro rough, „gritty touch“, Pk to 100 µm, Pp up to 200 µm		topography is significant: correlations between surface and slip and different methods		ramp, tribometer and pendulum can be applied
Group 3 Structured and textured: „macro rough“, Pk above 100, Pp above 200 µm		topography and geometry (shape) are significant. Loss of contact area		Ramp and pendulum applicable, tribometer impaired by loss of contact surface (low) or irregular traction (high)
Upper Group 3 geometrically profiled with Pk above 300, Pp above 700 µm		geometry (shape) is significant, different for each surface. Loss of contact area		Ramp and Pendulum applicable, impact variation on profile with Pendulum needs attention

Figure 5: The specified surface groups [1, 3] and their implications on the measurement suitability.

This means that, when interpreting slip measurements, the surface has to be taken into account. The measurement of smooth surfaces (group 1) is prone to have a higher influence of the actual measurement setting (and differences): velocity, medium and slider surface (for instance slider preparation) can be more significant than the actual surface differences, and can lead to misinterpretations, also based upon measurement effects like sticking (in some cases the values in wet conditions are higher than in dry conditions). In figure 6 the differences between the measurement methods on surfaces of group 1 are shown. As the surface roughness increases (group 3 and higher) the hardness of the slider used can strongly influence the result, as contact surface might be lost.

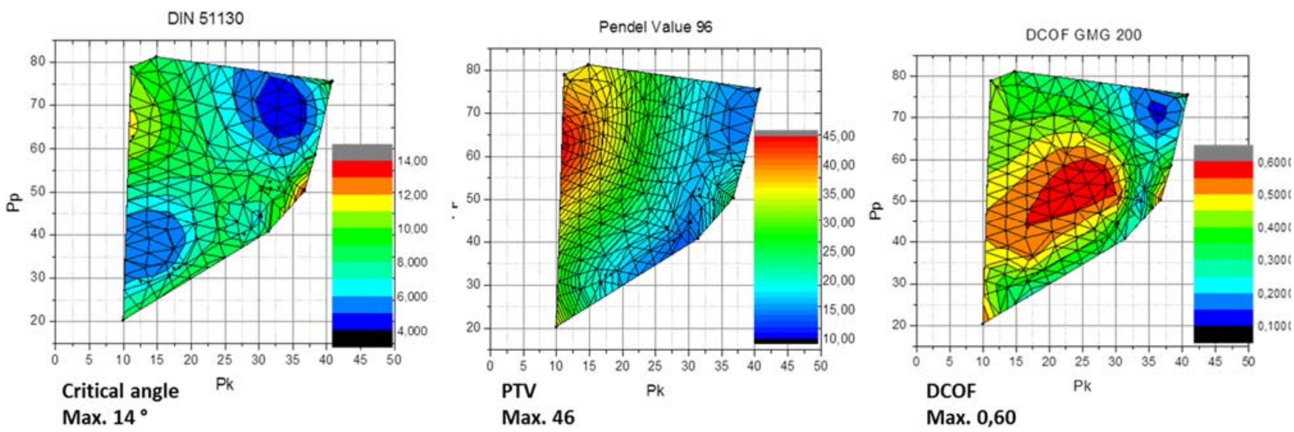


Figure 6: The differences in ramp (critical acceptance angle), pendulum (PTV) and coefficient of Friction (DCOF) measurements are highlighted.

This also has implications for correlation studies of the different methods: It explains one of the most and repeatedly made errors, when trying to evaluate the correlations between measurement methods over a broad range of surfaces, from smooth to profiled, mostly only visually or haptic specified. As the surface influences from the specified groups make it impossible to find an overall correlation. When assessing performance and comparability of measurement methods, the surface aspect is essential.

4. THE RESTRICTIONS OF SURFACE CHARACTERIZATION

Although the current situation regarding the surface characterisation can provide the mentioned innovative possibilities, there are aspects which still impede its implementation.

There are drawbacks to use the method. Up to now there is no possibility to measure these aspects directly on site. The equipment used for the investigations is not mobile and expensive, although portable alternatives are being developed. Here an increase in demand for surface characterisation to be used to support slip risk evaluation from different stakeholders might speed up the process. For the moment on site duplication techniques are used with a satisfactory accuracy to establish the required surface characterisation in laboratory. This has supported the implementation of this method in on site assessments, surface development and durability studies.

Besides the mentioned still to be developed availability of the technology for the stakeholders, it requires an new and open discussion regarding the approach of surfaces and their slip measurements, as well the limitations of these methods, which have to be addressed to understand and deal with discrepancies in interpretation, the lack of correlations and optimization possibilities of the measurement methods. It will put an extra complexity into the slip resistance measurement discussion, but it might support a scientifically approach to generate practicable measures.

5. THE POTENTIAL OF SURFACE CHARACTERIZATION

The use of the presented surface characterization opens many new and innovative possibilities, which already have been investigated and implemented with success. It has proven to be an important aspect to explain slip effects on different floorings and to evaluate the significance of the measurements. Besides the support of the redesign as well new development of slip resistant surfaces, taking into account influences from the precursor (pressed tile) to the end products (fired, sealed tiles) it has also been a valuable tool to assess the actual wear of floorings. This is and will be an important requirement for the development of practical, application oriented wear simulations and eventually the development of new standards in regards of the increasing important discussion on duality and declarations of performance of flooring materials. It will also remain a necessary aspect to support the ongoing discussions on the development and use of slip resistance measurement methods.

6. REFERENCES

1. Tari, G, Engels, M., 'The SlipSTD European Collective Research Project: Development of slip resistant standard surfaces', Qualicer 2008, Xth World Congress on Ceramic Tile Quality, Castellon Spain, Vol.3, pp. Pos. 135 – Pos. 137.
2. CEN/TS 16165 (12-2016) Determination of slip resistance of pedestrian surfaces – Methods of evaluation.
3. Engels, M 'The correlation of slip resistance and durability with surface topography', Qualicer 2018, XVth World Congress on Ceramic Tile Quality, Castellon Spain.

HYDRODYNAMIC LUBRICATION AND THE MEASUREMENT OF PEDESTRIAN SLIP RESISTANCE

Malcolm Bailey PhD(Eng), MSc(Eng), DIC, ACGI, MICE, CEng

Head of UK delegation on CEN TC339

drmalcolmbailey@aol.com

ABSTRACT

In the author's experience, most slipping experts do not understand how the film of water trapped between the floor surface and the heel of a pedestrian or test machine slider actually works. Most experts are only too well aware that whereas test machines give comparable values of slip resistance for a particular floor surface in dry conditions, in water wet conditions the results for different types of test machine can be significantly different. Some test machines will suggest that the floor surface is "safe" whereas others will suggest that it is "dangerous". This paper provides an answer as to why this occurs, and that when fully understood it is possible to design a test machine that gives similar readings to another type of test machine, even though the machines are completely different in the way that they measure slip resistance, for example using different vertical forces on the slider and different areas of contact. Based on this it is thus possible to ensure that the test machine replicates the characteristics of the film generated under the slipping heel of a pedestrian, and thus a truly realistic value of the slip resistance of the floor surface.

Keywords: Slip, measurement, hydrodynamic, lubrication

Introduction

Most researchers into pedestrian slipping are aware that machines designed to measure slip resistance will generally give reasonably close agreement in terms of the result for any particular dry surface. If the surface is wet however the results can vary significantly, and since most slipping accidents tend to occur in wet situations, this has led to an unsatisfactory situation. Those who market flooring products tend to favour those devices which give high values of slip resistance in the wet as it makes their product look safe or safer, whereas others question this, as such an approach does not correlate with actual slipping accidents.

The problem was partly solved in the UK back in the 1980s when it was realised that the crux of the matter was that the water on the floor was acting as a lubricant. Although this was generally accepted in the UK, the precise way that the water acted was not understood in a clear and unambiguous manner. It was thus simply described as 'Hydrodynamic lubrication' as if this explained everything. In practice the term 'Hydrodynamic lubrication' is itself misleading as it implies full lubrication whereas in practice in pedestrian slipping it should correctly be referred to as 'Partial hydrodynamic lubrication' as will be evident from this paper.

It will also become clear that using these principles, not only can one deliberately design a machine to give similar results in the wet as another machine, even though they may use different approaches to measurement, but also to ensure or check that they replicate the lubrication conditions which occur when a pedestrian's heel slides across the floor in a slip.

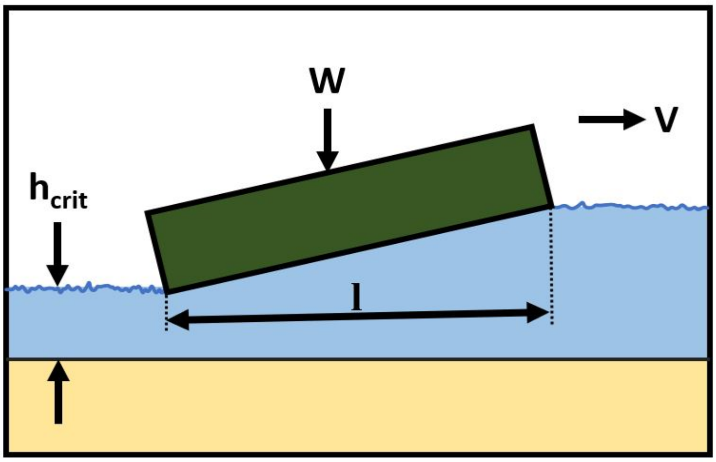
Lubrication

Full lubrication occurs when a film of liquid exists between two surfaces. The film needs to be continuous and such that it prevents one surface contacting the other. Such a film can exist under certain special circumstances when there is no movement between the surfaces but generally movement is involved; it is this movement which creates the film and keeps the two surfaces apart.

The fundamental factors which cause this to happen are …

i) Liquid is forced into the gap between the two surfaces at the 'leading edge' of the sliding surface due to the relative movement.
ii) It can only escape around the sides and rear edge of the slider.
iii) Because the escape route is very limited, it needs pressure in the liquid to cause the liquid to flow from the leading edge to the sides or rear. This pressure is caused and maintained by the movement between the two surfaces and as a result of the liquid being forced into the gap at the leading edge.
iv) In full lubrication this pressure fully supports the weight of the sliding object, and the film thickness will adjust itself in relation to the weight imposed, the velocity of the slider, and the dimensions of the slider in contact with the film.

The following diagram and equations are taken from traditional lubrication theory.



$h = ((6\eta l v K_e K_p)/P_{av})^{½}$ or $h = ((6\eta l^2 b v K_e K_p)/U)^{½}$

which, when U = W becomes $h_{crit} = ((6\eta l^2 b v K_e K_p)/W)^{½}$

Where
- η is the viscosity of the liquid in the lubricating layer
- l is the length of the slider in the direction of motion
- b is the width of the slider
- v is the relative velocity of the slider relative to the floor
- K_e is a constant relating to the b/l ratio of the slider
- K_p is a constant relating to the geometry of the film wedge
- P_{av} is the average pressure in the film
- U is the Uplift force provided by the film
- W is the downwards force exerted by the slider

In practice the angle of the slider is often only a degree or so – it is shown here with a much larger angle for clarity.

Partial lubrication

In pedestrian slipping, the only time where one is likely to get full lubrication is on a very smooth surface such as glass. The value of h_{crit} in pedestrian slipping is around 2μm (2 microns). In almost all other floorings the roughness of the floor itself is greater than 2 microns and there is no continuous film separating the floor and slider (or heel).

However the film of water still exists but is contained in a myriad of tiny passages or tunnels which are formed between the slider and the floor. The forward movement of the slider or heel still forces the liquid to enter the system at the leading edge and the liquid is forced through the labyrinth of passages and out at the rear or sides. On very rough floors the passages are large, the liquid flows easily and requires very little pressure to do so. On more shiny floors, the passages are small, the liquid does not flow easily and requires much larger pressures to do so.

Full lubrication is self regulating and the thickness of the film adjusts itself to ensure that the pressure generated in the film exactly equals that necessary to support the full weight of the slider. In partial lubrication, the value of h is determined by the characteristics of the floor surface. Hence, whereas in full lubrication the film thickness will vary in response to variations in the forward velocity, in partial lubrication the value of h stays roughly constant and the pressure in the film varies in relation to the forward velocity.

The same basic equation as used in full lubrication applies to partial lubrication except that two further constants are required. The first, K_r, is similar to the Reynolds number used in fluid mechanics and aerodynamics and relates to the ease/difficulty with which the water can flow through the tunnels and escape along the sides and rear of the slider. The harder it is for the water to flow, the greater the pressure which will be generated in the film.

The second constant, K_a, relates to the proportion of surface area which is available on the slider (or heel) on which the pressure in the film can act. For instance, a soft rubber will not only sit lower onto the asperities on the floor surface, thus reducing h, but will also cloak the asperities to a greater extent leaving less free area in contact with the water film.

It is worth noting that it is these two constants and particularly K_r which upset the hypothesis that one could measure slip resistance by measuring surface roughness. Certainly surface roughness is a guide (and only a guide) to the value that h (the average height of the passages) might be, but that is only one of the parameters which determine the upward pressure on the slider and hence the slip resistance to be measured.

In Partial Lubrication, the equation becomes…

$$h = ((6\eta l^2 bvK_eK_pK_rK_a)/U)^{½} \quad \text{or} \quad U = 6\eta l^2 bvK_eK_pK_rK_a/h^2$$

Where *h* is the average height of the passages between the floor and slider

Effect on μ

The effect of this pressure in the partial lubrication film is to support a proportion of the weight of the slider (or heel) leaving the remainder of the weight to generate friction. It is this reduced value of friction which is thus used to calculate the wet slip resistance and is based on the full value of *W*. Hence any uplift caused by the film will register as a lower value of *μ* than that found in dry conditions.

The frictional force (F) which will be developed by the slider will be …

$F = (W-U)\mu$ and from this the value of μ_{wet} will be calculated thus

$\mu_{wet} = (W-U)\mu / W$ By replacing U and W in terms of the equations previously mentioned gives…

$$\mu_{wet} = (1 - (h_{crit}/h)^2 K_rK_a)\mu$$

This equation is critical in relation to both comparing one machine with another and with a slipping pedestrian. For a given floor surface K_r will be the same as it relates to the ease/difficulty with which liquid flows through the passages formed by its inherent roughness. Similarly h is a function of the surface roughness and the available height of the passages, and K_a will likewise remain at a particular value; these are all dictated by the floor surface and/or the slider/heel material rather than the test machine itself or the sliding dynamics of the pedestrian.

The only other component which dictates the proportion of weight supported by the film, and thus μ_{wet} , is the value of h_{crit} for the measuring machine (or the slipping pedestrian).

Hence, whereas in the UK it was correct to postulate in the 1980s that the measuring device should have the same value of h_{crit} as a slipping pedestrian, it was based on a less than full analysis of what really takes place during lubrication.

The slipping pedestrian

Because all the parameters in the equation for h_{crit} relate to physical dimensions and/or characteristics of the test machines (eg. speed of travel) it is possible to calculate the h_{crit} for the machine itself. This is the thickness of the water film that the machine would develop on a perfectly smooth surface to fully support the slider and thus give full lubrication.

The calculation for h_{crit} for a pedestrian is based on work in the early 1980's by Christer Bring at the UK's Building Research Station whilst on a sabbatical. His experiments with slipping using real slips showed that the average velocity of a slip was around 1.5m/sec that is, starting at a relatively low velocity and rising to between 2.4 to 3.0m/sec at the end of the slip path which on average was around 600mm in length..

Based on this and average weight of pedestrians and heel contact dimensions an h_{crit} of 2 microns can be calculated using the formula.

Likewise if one calculates h_{crit} for the TRL Pendulum, a figure of 2 to 2.2 microns can be found depending on what one takes as the mean velocity and value of *l.*

The Ramp Trolley method as detailed in BS 8204 aka SlipAlert was designed specifically to have an h_{crit} of 2 microns.

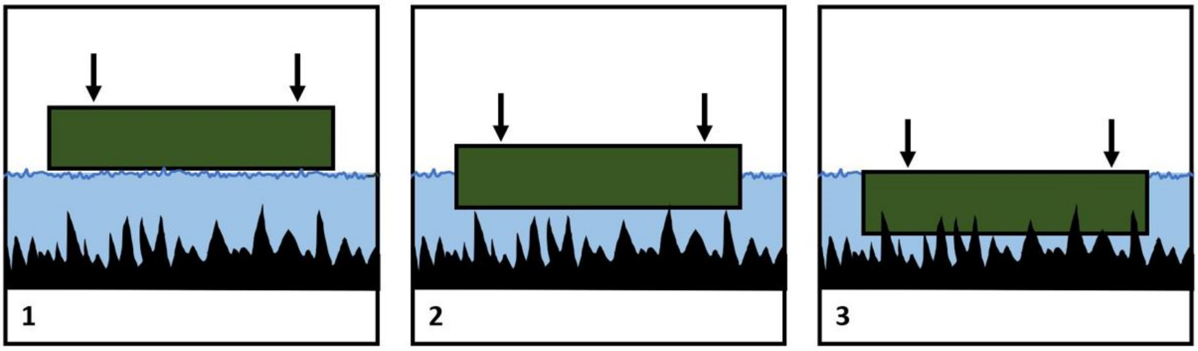
It was thus not surprising that SlipAlert and the Pendulum show good correlation (0.95 correlation coefficient). The main reason for the differences is that the Pendulum measures over a 125 mm path length whereas SlipAlert measures over a much larger path length. Tests have shown that slip resistance as measured by the Pendulum can vary over the typical SlipAlert path length.

The importance of designing the test machine around h_{crit} can be seen from the equation. If a device has an h_{crit} of say 1 micron the proportional uplift it will experience is only 25% of that of a machine with an h_{crit} of 2 microns. As a result the wet coefficient of friction will be significantly greater for the 1 micron machine than the machine with the 2 microns h_{crit}. It is thus critical that the machine h_{crit} is as close to the average person's h_{crit} as possible.

Some devices when used on wet floors indicate a slightly higher value of μ_{wet} than in the dry or a very similar value. The problem is almost certainly due to the velocity of the slider which is insufficient to force the liquid under the slider and it is simply pushed around the slider on the surface. If one calculates the value of h_{crit} for those machines it will be found that it is significantly less than the 2 microns found from a slipping pedestrian.

Start of the slip

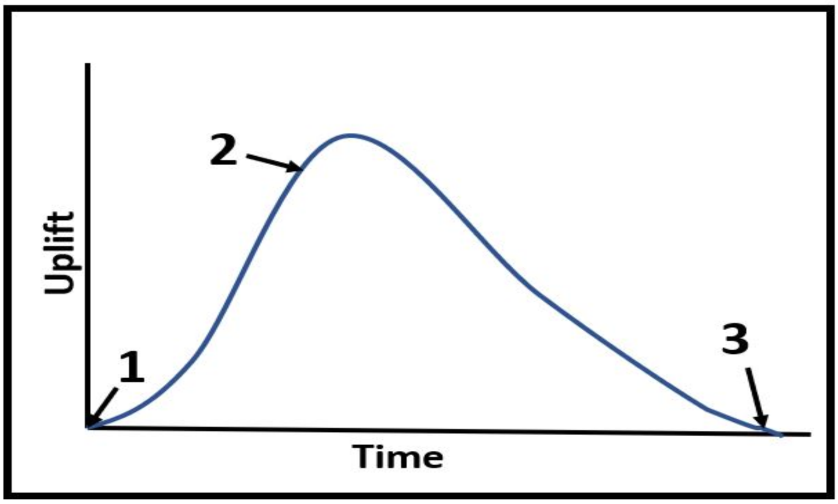
it may be argued that when a pedestrians heel first contacts the ground, that there is no or little forward velocity. In practice high-speed filming carried out in the 1960s showed that there is generally forward velocity at the moment of impact. Indeed this accounts for the wear on the back of the heel that most people find on their shoes. Also as the heel lands on a wet surface the water under the contact area has to be displaced before the heel surface first contacts the asperities in the surface and then for it to settle fully onto those asperities in order that the surface can support the full weight of the heel.



1 – The heel first encounters the wetness on the floor

2 – The heel first encounters the asperities of the floors roughness

3 – The surface now fully supports the heel



Diagramatic representation of the variation in uplift as the heel settles onto the floor in the situation described in the three drawings shown. It assumes no horizontal movement of the heel.

It is during this time that friction is being sought by the pedestrian, and it is not until Point 3 in the diagrams above that the full extent of the friction that might be available can be realised. The potential danger zone between Points 2 and 3 is exacerbated by the pressure increase in the film caused by forward movement. A full analysis of the pressures and uplift during that period when the two systems interact is complex and is not part of the analysis in this paper. It will depend on the height of the liquid layer on the floor and the range of velocities, both vertical and horizontal, which pedestrians employ when lowering their heel onto the floor. The author is not aware of any published research which has established the ranges of these velocities in normal pedestrian activity.

In the UK it is generally accepted that a floor can only be regarded as safe if it can prevent a slip which has started to take place from developing into one which is uncontrollable. Hence h_{crit} for a pedestrian is calculated using the velocity halfway along the slip rather than at the start or end. This approach would appear to be vindicated by the GLC work which in the 1960s tested some 3500 floors in London and found good correlation between the pendulum and the known slip history of the floor concerned. Such a correlation would be impossible if the actual film thickness generated by the pendulum was not similar to that which is generated by a slipping pedestrian. In other words the pendulum would have suggested many more floors were at risk than their slip history suggested; this was clearly not the case.

Conclusions

Lubrication theory is by no means new. It is clear how it works with the fluid film providing sufficient pressure to keep two sliding surfaces separate. Partial lubrication is a relatively straightforward extension of that theory and explains why the apparent coefficient of friction in the wet is generally less than the dry coefficient and can vary significantly depending on how it is measured. It is important that the uplift which is exerted on the test machine slider by the partial lubricating film relative to the downward force on the slider (proportional uplift) is the same as experienced by a slipping pedestrian. Unless this occurs, the value of μ_{wet} indicated by the test machine is of little intrinsic value in relation to pedestrian slipping.

Whereas certain authorities consider that the most important factors of a test are its repeatability and reproducibility regardless of the intrinsic value of the measurement it gives during the wet test, most responsible authorities would wish to have a test method whose wet slip resistance values correlate with the known slip potential characteristics of a wide range of floorings. In that respect, the Greater London Council in the 1950s and 1960s tested some 3,500 floors in London where the accident history was known and found a good correlation with the Pendulum wet readings. Their results and the criteria they were thus able to set out showed agreement with research at the UK's Building Research Station into the level of forces that people need when walking.

References

American Standard for Testing and Materials (1983), *Standard Method for Measuring Surface Frictional properties using the British pendulum test*, (ASTM Designation: E303 – 83), 595-599

Bailey, M. (1988), *The measurement of slip resistance of floor surfaces*, Construction and Building Materials, Bailey, M. (2005), The *TRL pendulum slip resistance tester, the reasoning for its acceptance in the UK*, Proceedings of the Annual Conference of the Ergonomics Society, April 2005

Bring, C. (1964), *Friktion och Halkning*, Rapport 112, Byggforskningen, Stockholm

Bring. C. (1982), *Testing of Slipperiness*, Swedish Council for Building Research, Stockholm

British Standard BS8204, (2011), *In-situ Flooring*, BSI, London

British Standard BS7976, (2002), *Pendulum Testers*, BSI, London

Fuller, D. D. (1956), *Theory and practice of lubrication engineers*, John Wiley and Sons, New York.

Giles, C.G., Sabey, B.E., Cardew, K.H.F. (1964), *Development and performance of the portable skid resistance tester*, HMSO Road Research Technical Paper No 66, (HMSO, London)

GLC (1971), Bulletin 43 (Second series) Item 5*, Slip resistance of floors, stairs and pavings*, GLC Department of architecture and civil design

GLC (1985), Bulletin 145, Item 2*, Sheet safety surfaces for floors, methods for evaluation*, Building Technical File No 9, 916-922

Harper, F. C., Warlow. W. J., Clarke, B. L. (1961), *The forces applied to the floor by the foot in walking*, National Building Studies Research Paper32 (HMSO, London)

Proctor, T.D., Coleman, V. (1986), *Slipping tripping and falling accidents in Great Britain – the present and future*. HSE (UK)

Sigler, P. A. (1943), *Relative slipperiness of floor and deck surfaces*, US Department of commerce, National Bureau of Standards, Building materials and structures, Report BMS100, (US Government Printing Office, Washington)

Sigler, P. A., Geib, M. N., Boone, T. H. (1948), *Measurement of the slipperiness of walkway surfaces*, Journal of Research of the National Bureau of Standards, Research Paper RP1879, 40, (US Government Printing Office, Washington), 339-346

SLIPPERINESS: CONTRIBUTION OF TESTING MATERIALS LABORATORIES

Joaquim Valente de Almeida[1]

[1] 1 CTCV – Centro Tecnológico da Cerâmica e do Vidro, Coimbra, Portugal

valmeida@ctcv.pt

ABSTRACT

The search for a "Sustainable and Safe Building" necessarily leads to the growing need for "Sustainable and Safe Products" and therefore their performance assessment from these points of view. The new Construction Products Regulation, Regulation (EU) No 305/2011, has a basic requirement regarding "Safety and Accessibility in use" and will require the revision and adaptation of the existing standards, in order to address this aspect in the CE marking of the different products. This paper presents the contribution of a Laboratory dedicated to Building Product Testing, by presenting a range of tests currently developed and directly related to safety theme, applied to different Construction Products. The main tests were performed according to European and International Standards, and are related to evaluation of the slipperiness characteristics of the products.

Keywords: Safety, Laboratories, Tests, Slipperiness, CE Marking

1. INTRODUCTION

CTCV is an Entity of the Scientific and Technological System, certified by CERTIF according to NP EN ISO 9001 and with laboratories accredited by IPAC according to the standard NP EN ISO / IEC 17025, for the performance of analysis and tests. It is also a Sectorial Standardization Body recognized by IPQ, with an active participation in National, European (CEN) and International (ISO) Standardization Technical Committees.

It is composed of a multidisciplinary team with solid scientific and technical skills in different knowledge areas, which are the result of its 30 years of accumulated experience and specialized training.

With a R & D culture oriented towards results and value for industry, CTCV offers its business partners a set of integrated solutions ranging from specialized consulting and auditing, professional training, measurement and testing and RTD solutions. The CTCV services are oriented towards Ceramics and Glass and the whole cluster of habitat.

CTCV's performance is essentially based on the partnership developed with clients, other entities of the Scientific and Technological System and Sectorial and Regional Associations, as well as rigor and credibility, allied to the strong innovation and technology transfer component.

CTCV is organized into Competence Centers: Testing (Essay), Consulting and Technical Support, Training and Innovation.

Figure 1 shows the organizational structure of CTCV with all its services and competence centers.

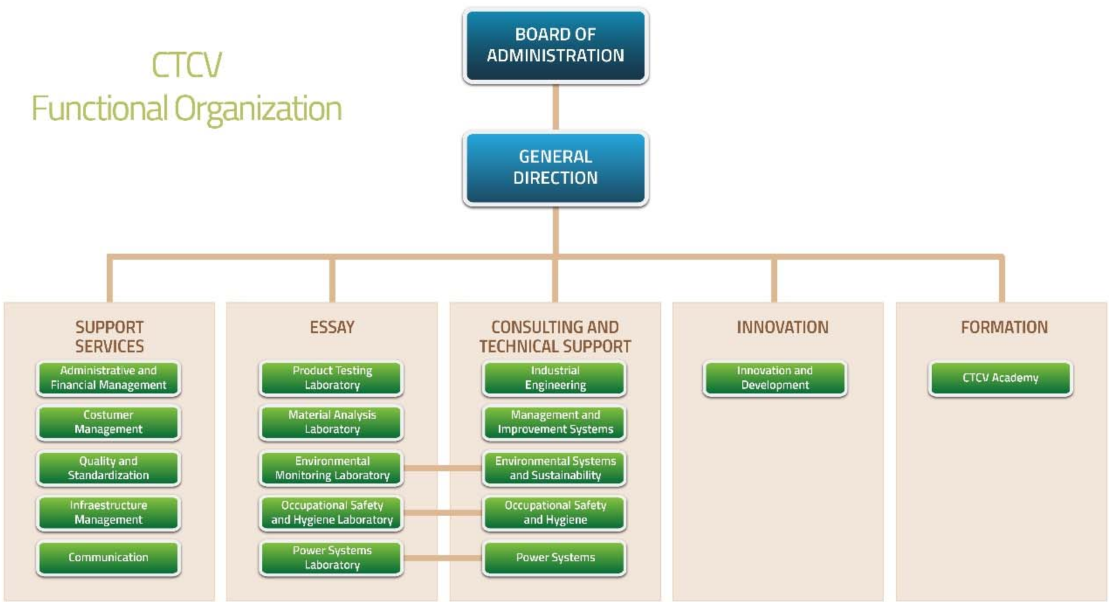


Figure 1: CTCV Functional Organization

In the Testing Competence Center we have 5 laboratories with different areas of expertise summarized below:

- Product Testing Laboratory - Testing of construction products and materials, building equipments and glass.
- Material Analysis Laboratory - Physical-chemical analysis of mineral raw materials and non-metallic inorganic materials and other industrial materials.
- Environmental Monitoring Laboratory - Monitoring and characterization of pollutants in indoor and outdoor environments. Stationary source emissions.
- Occupational Safety and Hygiene Laboratory - Monitoring of risk parameters for health and safety of workers. Occupational hygiene sampling and measurements.
- Power Systems Laboratory - Technical support for decision related to the efficient use of energy. Tests of solar energy systems (solar thermal collectors and photovoltaic solar modules).

In this article the activity carried out by CTCV in slipperiness tests will be developed by presenting the standardization applicable to each intervention sectors of the laboratory and their relationship with CE marking.

2. FRAMEWORK

2.1 Regulation

Regulation (EU) No 305/2011 [1] laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106 / EEC defines as basic requirements for construction works:

- Mechanical strength and stability
- Fire safety
- Hygiene, health and environment
- Safety and accessibility in use
- Noise protection
- Energy saving and thermal insulation
- Sustainable use of natural resources

Construction work shall, be fit for its intended use as a whole and in its separate parts, , taking into account in particular the health and safety of the persons involved in them throughout the life cycle of the building. Construction work shall meet, under normal maintenance conditions, the basic requirements of construction work for an economically reasonable period of life.

The basic requirements of the established construction works form the basis for the preparation of standardization mandates and harmonized technical specifications.

These basic requirements will define the essential characteristics of construction products to be laid down in the harmonized technical specifications.

The basic requirement with impact on the theme of this article is “Safety and accessibility in use”. Under this requirement, construction works shall be designed and constructed in such a way that they do not present unacceptable risk of accident or damage during use and operation, such as risk of slipping, falling, colliding, burning, electrocution and injury, by explosion and theft. In particular, construction works shall be designed and carried out with regard to accessibility and use by persons with disabilities.

2.2 Product Testing Laboratory

The Product Testing Laboratory is accredited by IPAC (Technical Annex No. L0151) according to the reference standard EN ISO / IEC 17025: 2005 (at this moment we are in a transition phase for new edition), since 12-05-1990 for several technical tests.

Product Testing Laboratory's activities include testing of products and materials covered by the CE marking in the context of Regulation (EU) 305, namely:

- Ceramic
- Glass
- Stone and aggregates
- Concrete
- Mortars
- Adhesives

Skid / slip tests were always performed in the laboratory, due to the high export rate of the Portuguese ceramic industry, in particular, the ceramic floor industry. In this context, the national industry has always required CTCV to carry out tests to evaluate the anti-slip characteristics of ceramic floors in order to meet companies customers' requirements.

The involvement of the laboratory manager in the various CEN and ISO Technical Committees - CEN TC 339 and ISO TC 189 WG 10, assists and furthers the development of laboratory skills in these matters, as well as a member (President) of the Portuguese Mirror Group CT189. , in the dissemination and exchange of knowledge with the Portuguese ceramics industry, specifically the ceramic tiles and floors industry.

Faced with the constant search for approach to the Construction Industry in general, CTCV has extended its activity to other branches of Habitat, often motivating to close tissue gaps. Portuguese and also derived from the implementation of the CE marking in these sectors.

2.3 Legislation

In Portugal, there is no specific legislation on the slipperiness unlike in other European countries.

National Industry is confronted with the requirements of the Countries to which they export, and because a country has its own legislation, manufacturers are required to have their products / materials tested according to a range of standards and requirements.

This process, besides being expensive, raises questions for manufacturers of results interpretation regarding the non-comparison between test methods used, as well as a complete dispersion of ideas about skid / slip of materials.

Harmonization of legislation and related requirements should be carried out in such a way as to facilitate the work of both manufacturers and consumers who often do not understand this diversity of test methods and their non-correlation.

At European level there is an attempt to standardize the slip test through CEN TC 339, materialized in the attempt to approve the European standard of CEN / TS 16615 [2]. At the global international level, within the ISO framework, and following the eventual approval of the European standard, there is a possibility of international adoption, which would be of added value for the covered industry as well as consumers.

3. STANDARDIZATION OF SKID/SLIP TESTS

The materials / products covered by the Product Testing Laboratory, for which where skidding / slipping is an essential characteristic of the CE marking are: ceramic floor tiles, concrete floor tiles (pavers and slabs), natural stone floor tiles and aggregates.

Table 1 shows the harmonized European standards which in their Annex ZA show skid / slip as an essential characteristic and which requires the performance of slip tests for further declaration of the performance of their products / materials.

Table 1: Harmonized standards

Product	Standard
Ceramic floor tiles	EN 14411
Concrete floor tiles	EN 1338 EN 1339 EN 1340
Natural stone floor tiles	EN 1341 EN 1342 EN 1468 EN 12057 EN 12058

The main test standards for performing the skid / slip tests are given in Table 2. The table lists the different products / materials with the most demanded standards as well as a brief description of the test methodology (principle) and respective rating / evaluation.

Table 2: Standards versus products/materials

Product	Standard	Test method (principle)	Classification/Evaluation at Standard
Ceramic floor tiles	DIN 51097	Ramp, barefoot	A, B and C
	DIN 51130	Ramp, shoed foot	R 9 to R13
	ENV 12633	Pendulum, slider 57	No class, PTV
	BS 7976-2	Pendulum, slider 57/ 96	No class, PTV
	CEN/TS 16165	Ramp, barefoot	No class, º
		Ramp, shoed foot	No class, º
		Pendulum, slider 57/ 96	No class, PTV
		Tribometer	No class, value
	NF XP P 05-010	Ramp, barefoot	PN 6 to PN 24
		Ramp, shoed foot	PC 6 to PC 35
	AS 4586	Pendulum, slider 57/ 96	P1 to P5
			P0 to P5
	ANSI A 326:3	DCOF, BOT3000	No class, value
	ASTM C 1028	SCOF, Pull-off	No class, value
Concrete floor tiles	EN 1338	Pendulum, slider 57	No class, PTV
	EN 1339	Pendulum, slider 57	No class, PTV
	EN 1340	Pendulum, slider 57	No class, PTV
Natural stone floor tiles	EN 14231	Pendulum, slider 57	No class, PTV
	EN 1341	Pendulum, slider 57	No class, PTV
	EN 1342	Pendulum, slider 57	No class, PTV
Aggregates	EN 1097-8	Pendulum, slider 57 (polished)	No class, PSV

Figure 2 : Ramp test equipment

Figure 3 : Pendulum test equipment

Figure 4 : BOT 3000 (DCOF) test equipment

Figure 5 : Pull-off (SCOF) test equipment

From the analysis of Table 2 we can conclude that the two main test equipment used in European standardization are the ramp and the pendulum. The test methods are all very similar with minor differences related to the year of edition of the standards - the latest one has more explicit methodology details such as calibration / verification of the pendulum and rubbers.

In the case of the USA, the methodology of ASTM and ANSI standards is quite different from the European one, except for the method on Annex D of CEN / TS 16165. This makes it difficult to interconnect manufacturers / consumers on both sides of the two main trading blocks for this typology of products.

4. CONCLUSIONS

Slipperiness test laboratories play a key role in several aspects, namely to ensure the quality of their results in society in general, and in particular with the most direct players (manufacturers and consumers). The accreditation of laboratories is a decisive step in the pursuit of these objectives and serves as a statement of trust between the "players".

The biggest difficulties for laboratories are the excessive amount of existing methodologies and the existence (or absence) of appropriate and reliable reference materials over time.

As a final conclusion, it can be stated that testing laboratories on the product / material evaluation / characterization have a remarkable role and of major importance.

5. REFERENCES

[1] – REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, March 2011

[2] - CEN/TS 16615:2016 - DETERMINATION OF SLIP RESISTANCE OF PEDESTRIAN SURFACES - METHODS OF EVALUATION

FOOTWAY EVALUATION

Tim Massart[1], Luc Goubert[2]

[1] BRRC

[2] BRRC

t.massart@brrc.be

ABSTRACT

Walking and cycling are green transport modes which should be given more attention in future. The quality of footways is not always very good. The problem is the lack of a complete evaluation method. We have developed an evaluation method for footways.

Our approach is based on a network analysis with a wheelchair, which is the most “sensitive” type of footway user. This wheelchair is equipped with sensors and a skid resistance measuring device. Three parameters (comfort/longitudinal unevenness in the direction of travel, gradient in the direction of travel, and crossfall) can be measured in one run, and a skid resistance measurement is made in each section of the network.

We would like to present this measuring equipment with results maintained untill now. Furthermore we would like to promote this approach and show the good relation between the objective measuring device and the subjective rating of the testpanel.

The concept what will be presented, has been tested in actual practice.

With this complete evaluation method administrators will be able to manage this asset in a more efficient way and with a well determined approach.

After this inspection, the administrator will have a good overview of the quality of his footway network. He will easily find those footways who need a maintenance. On the other hand, experience will be gained for different types of pavements for footways. With this experience, the administrator will be able to decide wich type of pavement is suitable for wich footway.

Keywords: Footway, comfort, skid resistance, network approach

Topic: Footway evaluation

1. INTRODUCTION

Since the beginning of the 21st century, accessibility of public spaces has become a growing priority for both regional and municipal road authorities. The needs of road users are choice criteria that are of great importance in the design of a new road layout.

Pedestrian accessibility depends on, among other things, the availability of high quality pavements that meet the needs of both disabled and disabled pedestrians: flatness, stability, skid resistance, obstacle, water drainage, visibility and cleanliness. Pavements meeting these needs offer high user quality, which is more likely to move in the public space concerned.

At the national and international level, there is currently no objective tool to determine this quality of pedestrian pavements continuously, quickly and cost-effectively. The concept is all too often approached subjectively, on the basis of the feeling that we get as a traffic participant in a public space. That is why the Belgian Road Research Center decided in 2015 to develop a measuring instrument to assess pavements on three criteria that are fundamental for pedestrians: flatness (comfort), skid resistance (resistance to slipping) and slope (transverse and longitudinal).

2. EVALUATION CRITERIA

Relevant technical parameters to be collected for footway evaluation are the following:

- footway width;
- longitudinal unevenness / comfort;
- crossfall / gradient;
- skid resistance / coefficient of friction;

2.1 Footway width

Different users need different footway widths. In this concept we use a wheelchair. We assume that people with impaired mobility are the most “sensitive” users of a footway. If people with a wheelchair, baby car or other vehicle can travel in an acceptable way, the criterion is met.

2.2 Longitudinal unevenness / comfort

The feeling of comfort on a footway varies widely with the type of user. In the concept proposed in this article, we will measure comfort with a wheelchair equipped with an accelerometer. This evaluation is objective and stringent, because a wheelchair user suffers the most from lack of comfort on a footway.

2.3 Crossfall / gradient

Crossfall should normally be lower than 2 %. This parameter will be measured continuously in the concept proposed below.

3. CONCEPT

3.1 Basic concept (V0)

After analysing the available tools and the way inspections are made in other countries, we found that no existing device can measure all the relevant characteristics at an affordable price. That is why we are suggesting the concept described below. (This measurement method remains to be refined and the measuring equipment still needs to be developed.)

The basic component of the method is a wheelchair. We propose to convert it into a measuring vehicle. The chassis of the wheelchair as well as the wheels and the load (weight in the wheelchair) will be determined experimentally, as a first step. It seems interesting to choose the chassis and wheels so as to minimize suspension and damping, with a view to obtaining a highly sensitive measuring device.

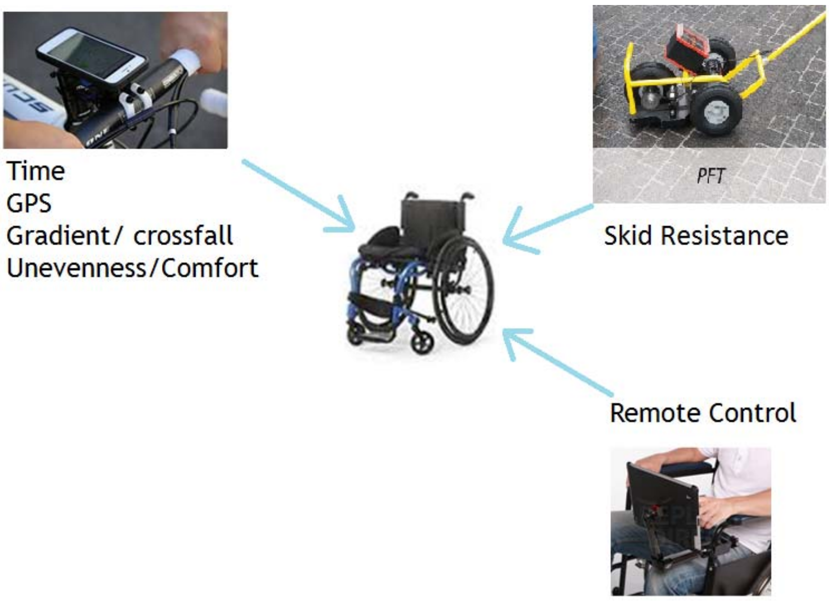


Fig.1. Prototype 1 equipped with two smartphones (with optional a camera for taking pictures).
Source: BRRC

A smartphone is fixed onto the chassis and the following parameters can be measured:

- time;
- GPS;
- orientation with respect to the north (compass);
- speed;
- crossfall / gradient;
- longitudinal unevenness / comfort (with accelerometer).

In 2016, a first prototype (V0) was developed by the CRR. This was materialized by a wheelchair on which smartphones containing a GPS and an accelerometer had been fixed (equipment integrated by default in all smartphones). This equipment provided figures concerning the comfort of the coating (rating out of 10). This comfort is evaluated via the accelerometer which will measure the vertical accelerations generated by the surface of the coating on the wheelchair and therefore in fine on the user. In order to measure also the adhesion of the coating, a complementary tool available to the BRRC has been used: the Portable Friction Tester (PFT - more information available on www.brrc.be/fr/article/f1301_06 and www.vti.se/en/Publications/Publication / road-marking-friction_669533).

At the end of 2016, surveys were carried out with this prototype and the PFT tool on eleven "test" sites located in the city center of Brussels, each with a different coating: two asphalt, two concrete and seven natural stone .

In April 2017 and in collaboration with Brussels Mobility, the adherence and flatness of these eleven sites were then evaluated by different users during a morning organized by the CRR. The objective of this approach was to verify if the results obtained by the measuring equipment, reflected the feeling of pedestrians. In total, twenty-eight participants took part in this field exercise: eighteen valid pedestrians and ten people with reduced mobility (people in wheelchairs, people walking with difficulty, people with visual impairments). A test sheet was completed by each participant and for each site.

Fig.2. Users' assessment of the comfort and adhesion of different coatings. Source: BRRC

At the end of the analysis and as illustrated in the graph of FIG. 3, a classification of the sites according to the comfort of the coating perceived by the users was carried out. The classification obtained from the subjective data collected by the twenty-eight users (light blue on the graph), compared to that obtained with the encrypted data collected by the prototype (dark blue), shows that a correlation exists on this notion of comfort.

Encouraged by this encouraging observation, the BRRC decided during the summer of 2017 to develop a second prototype (V1) with several objectives:

- also measure the transverse and longitudinal slopes of the pedestrian zones;
- measuring the speed of movement to eliminate the disturbances generated by different survey speeds;
- remove as much as possible the possible disturbances related to the quality of the accelerometer used (variable depending on the smartphone);
- develop a single system with which all the components communicate;
- Automatically centralize all the data collected in a single database.

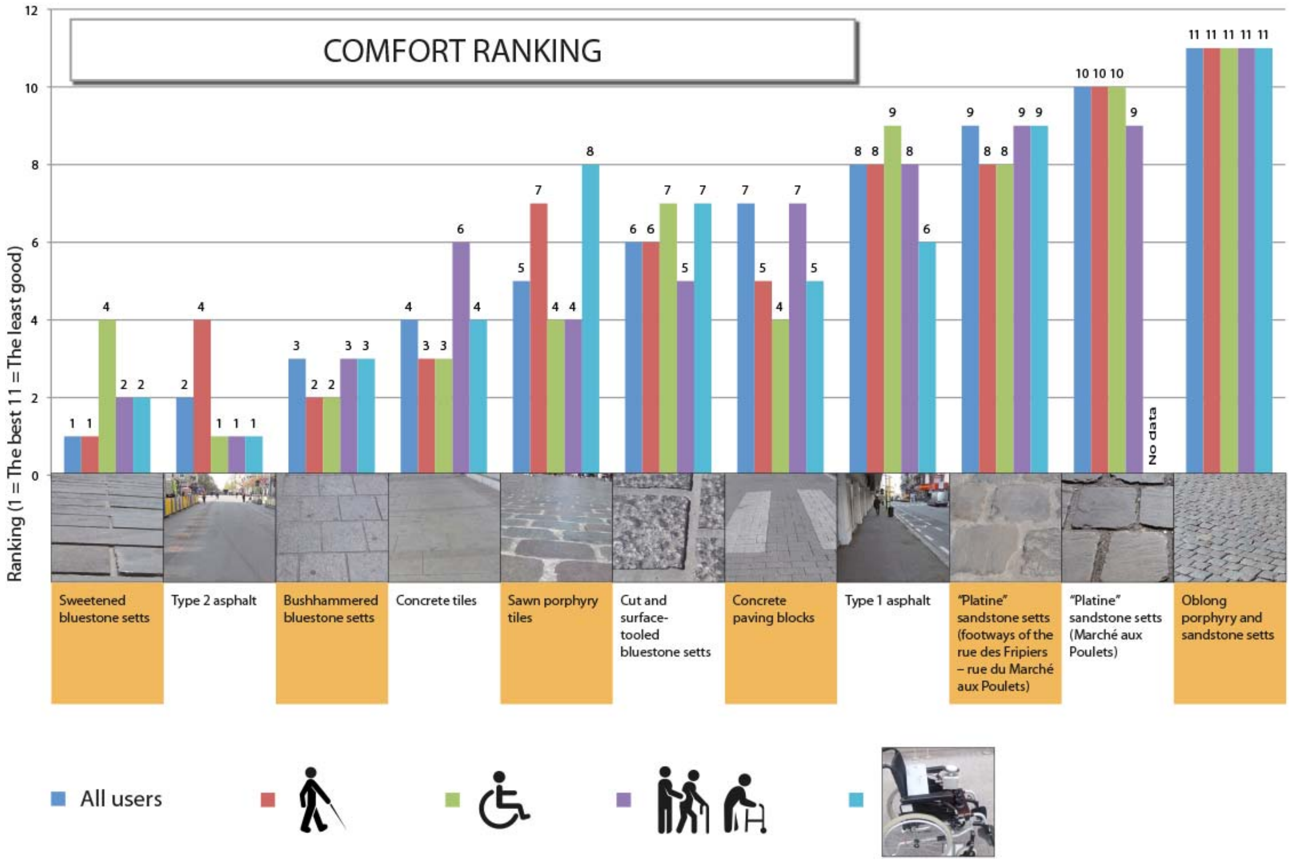


Fig.3. Classification of the different sites tested by the users and by the prototype 1.
Source: BRRC

4. RESULTS AND PERSPECTIVES

Presented in preview on the stand of the BRRC at the Belgian Road Congress in Brussels at the beginning of October 2017, this equipment allows to measure continuously and in a "geolocated" way the comfort and the longitudinal and transversal slopes of the sidewalks and other pedestrian spaces. The measurement of adhesion can currently not be performed by this equipment and always requires the use of additional equipment (PFT tool for continuous measurement (tests in progress), SRT pendulum (Skid Resistance Tester for point measurement). This second prototype and the sensors that compose it are shown in Figure 4.

Currently, the CRR is finalizing equipment calibration (survey speed, total equipment mass) based on the results collected by pedestrian users as a reference value in terms of comfort.

As soon as this calibration step is complete, the development of this equipment will continue with the completion of new comfort and adhesion measurements of pedestrian coatings. At the same time, users will also be invited to evaluate these different coatings. A comparison similar to that made with the previous prototype will be proposed to confirm the correlation already observed and thus validate the tool.

At the end of this development, this functional equipment should then integrate the family of roadside inspection equipment available to the BRRC. It can then be used to respond to external technical assistance specifically oriented to the quality of use of pedestrian coatings.

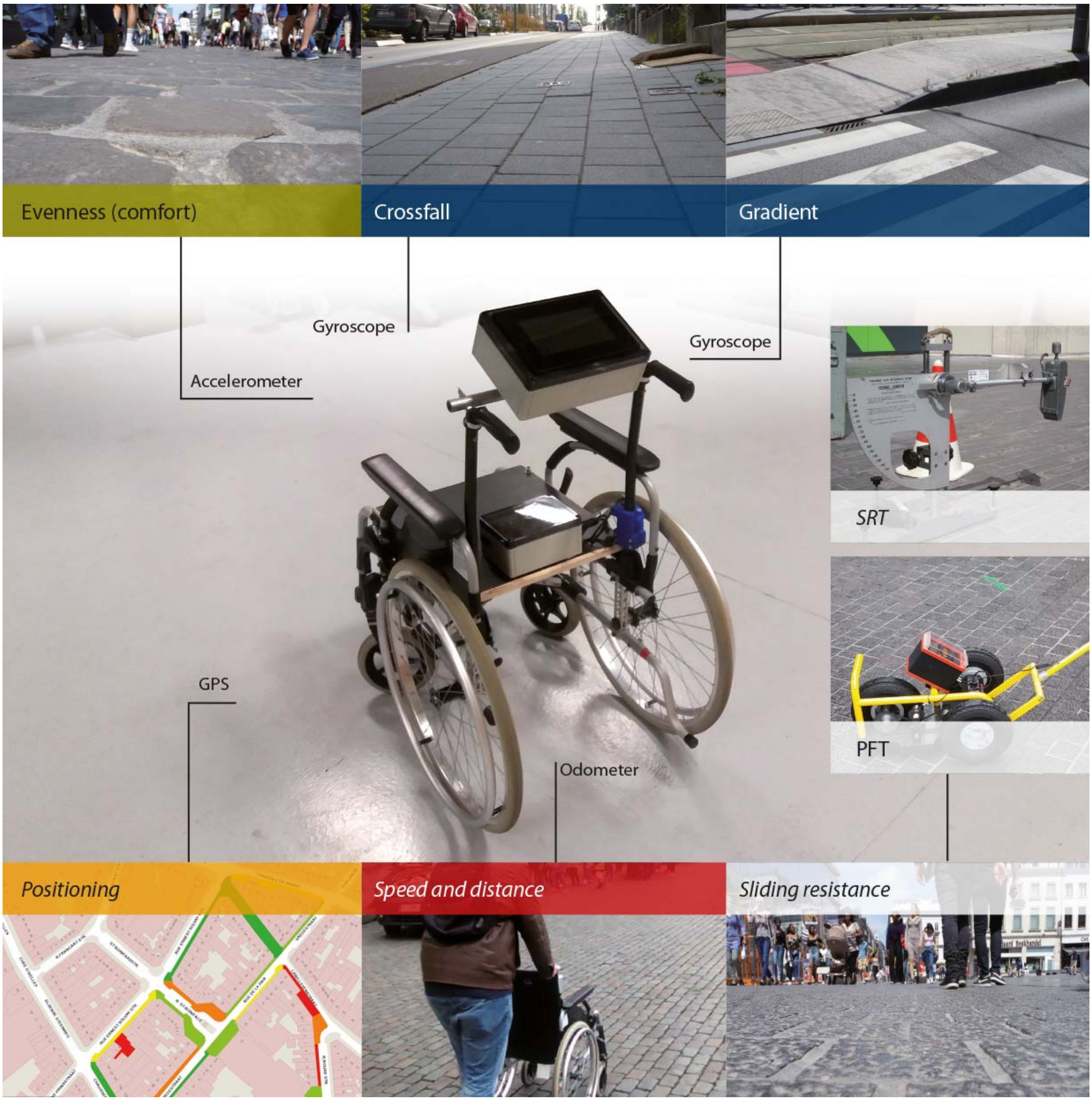


Fig.4. Tool for measuring the quality of use of pedestrian coatings under development (prototype 2)
Source: BRRC

The road administrator will be able to categorize different pedestrian coatings based on comfort and adhesion measurements. The following figure shows a decision grid that can be used to trigger an intervention. In the green area (VG Very Good) we have a pedestrian coating with very good scores on comfort and adhesion. In the red zones we have at least one problem (adhesion or comfort). Based on this we can choose a substantiated measure.

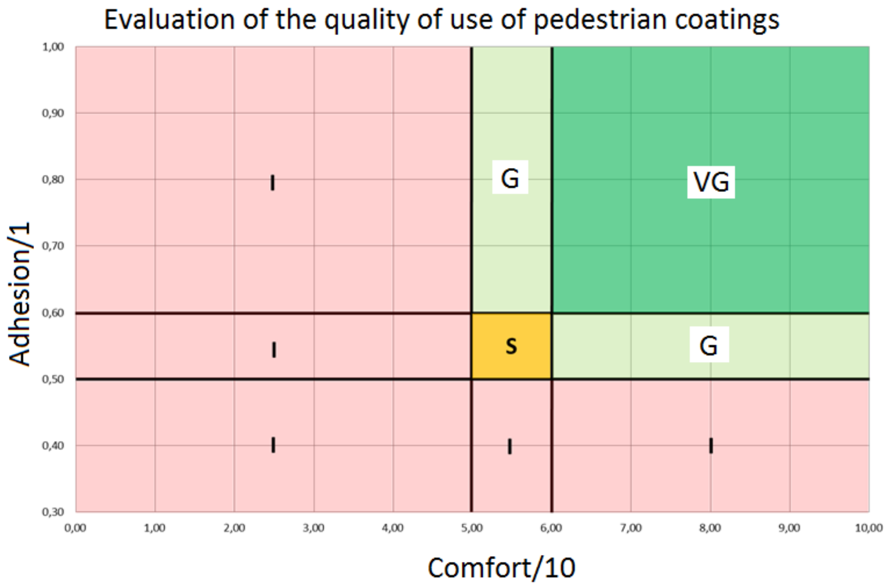


Fig.5. Evaluation of the quality of use of pedestrian coatings.
Source: BRRC

5. WHAT STILL REMAINS TO BE DONE

The concept presented above has been tested in actual practice. We will explore different strategies to get this equipment on the market.

- the wheelchair community has shown interest and we will explore posssibilities how to encourage them to measure their network;
- Explore possibilities to use applications (app) on smartphone / tablet and correlate wheelchair users with the prototype;
- Establish a measurement method so we obtain repeatable and reproducable measurements.

6. CONCLUSSION

Walking and cycling are green transport modes which will get more attention in future. The quality of footways is not always very good. In most cities, road managers have difficulties in estimating the quality level of their footway network. Maintenance planning and budgeting are mostly based on ad hoc repairs. With this complete evaluation method administrators will be able to manage this asset in a more efficient way and with a well determined approach.

After this inspection, the administrator will have a good overview of the quality of his footway network. He will easily find those footways who need a maintenance. On the other hand, experience will be gained for different types of pavements for footways. With this experience, the administrator will be able to decide wich type of pavement is suitable for wich footway.

IDENTIFICATION OF APPROPRIATE TRIBOMETER VALIDATION SURFACES

Russell J. Kendzior, WACH, RAS

National Floor Safety Institute (NFSI)

russk@nfsi.org

ABSTRACT

For many years the direct comparison of various walkway tribometers data has been elusive in part because there has not been a precise method of validating tribometers as to ensure that they produce accurate and reproducible data. Also, different devices measure slip resistance in different ways and produce different results even when testing the same surface only to create uncertainty and confusion as to the surfaces “true” slip resistance value. Unlike other countries, The U.S. experiences a significantly high number of slip and fall lawsuits which tribometer data is often entered as evidence and can influence verdicts. Identifying a more consistent validation/calibration reference surface(s) will: (a.) allow tribometer users to validate that their device is functioning within the manufactures engineering guidelines/controls and, (b.) will permit a more precise means of direct comparison between various tribometer COF test results.

In an effort to identify a more suitable method of validating the accuracy and precision of tribometers, five (5) factory trained technicians (operators) measured the wet SCOF and DCOF of twenty (20) hard surface materials using five different (5) tribometers. Testing was performed per the ANSI/NFSI B101.1-2009 wet SCOF and ANSI/NFSI B101.3-2012 wet DCOF standards. Test surfaces included polymer-based sheet materials, engineered printed glass, and industry specified ceramic reference tiles.

Keywords: Tribometer, Validation, Calibration, Reference Surface,

Topic: Measurement Principles and Technology

PENDULUM FRICTION TEST: IMPROVING THE METHOD IN DRY CONDITIONS

Juan Queipo de Llano Moya[1], Elena Frías López[1]

[1]Eduardo Torroja Institute for Construction Sciences - CSIC

jqueipo@ietcc.csic.es

ABSTRACT

In 2014, an alternative method to the National Building Code for testing the slip resistance in dry conditions was defined. The test methodology was based on the regulatory method, the pendulum friction test in wet conditions, but avoiding wet surfaces and determining new limit values.

Problems related to the variability of the results tested with the 57 rubber slider, have made it necessary to develop a Spanish standard, based on the CEN/TS 16165, for the pendulum friction test in dry conditions, using the 96 rubber slider. However, limit values have to be changed.

Data of the last “EILA”plan, about the pendulum test variability in dry conditions, the detection and control of the common laboratory errors and the validation of a verification tile, could improve the National standard. Additionally, limit values could be proposed.

This paper is part of the research related to the “Spanish Interlaboratory Tests Plan” (EILA), an annual and national control planning, with the collaboration of the different test laboratories and coordinated by the Regional Administrations/Governments, in order to improve and verify the results of these laboratories.

Keywords: slip resistance, pendulum friction test, safety limit values, variability of test results, pattern.

Topic: Falls prevention

1. INTRODUCTION

The Spanish Building Code (CTE) was published on March 2006 (1). The approval of the CTE meant significant changes in the regulatory framework with a new performance-based approach. It was also the first time Slip Resistance was included in the Code.

At that time, in most European Standards, the test methods depended on the "floor surface" and were different from each other. The lack of a reliable correlation between these test methods made necessary to choose a general test, regardless of the material tested. For that reason, the friction pendulum test in Annex A of ENV 12633:2003 was chosen (2,3).

Even today, in the European Union there is a disagreement on the test method to be used so that the Standard CEN/TS 16165 establishes 3 different methods: the pendulum, the ramp and a tribometer (4).

Moreover, in 2014 the standard ENV 12633:2003 was withdrawn. The Spanish Technical Committee of Standardisation has been working on a Spanish standard since then. Finally, UNE 41901:2017 EX for surface testing in wet conditions (5) and UNE 41902:2017 EX in dry conditions (6) have been published in Spain. These standards include the pendulum friction test described in CEN/TS 16165 but defining those clauses where the standard is still open, such as the type of slider, the verification tile and the laboratory and on-site test protocol.

To complete the Spanish Building Code and help in its interpretation, the Ministry of Public Works publishes supporting documents. One of them (DA DB SUA/3) has as its objective to clarify some aspects related to the risk of slipping and the test method in dry conditions (7). Currently, the test method is based on the standard ENV 12633:2003, withdrawn.

Now, the objective is to include the new standard UNE 41902:2017 EX, that uses the slider 96, instead of the standard ENV 12633:2003, that uses the slider 57. For this reason, this paper presents the results of an annual and national interlaboratory test (Plan EILA, coordinated by the Regional Governments to improve and verify the results of laboratories) conducted in 2017 and 2019 in order to validate the safe limit value, currently set at 40 and 65 PTV values. Additionally, improvements in the friction pendulum test performance carried out by each laboratory will also be compared.

2. RESULTS OF TEST METHOD IN DRY CONDITIONS

2.1 EILA 2017

2.1.1 Methods

The interlaboratory test EILA 2017, undertaken in laboratory, was aimed at the following objectives:

- To evaluate the performance of EILA participanting laboratories in the wet friction pendulum test according to the UNE ENV 12633 standard, included in the Spanish Building Code. This test is performed with the pendulum slider IRHD 57 (soft rubber), as indicated in the standard.

- To develop specific Spanish test standards, based on the incomplete European CEN/TS16165, that included the two test modalities (test in dry and wet conditions). This test is performed with the pendulum slider IRHD 57 (soft rubber) in wet conditions and with the IRHD 96 (hard rubber), which presents less dispersion than 57 alternative in dry conditions (2). A slider 96 of the same batch and a specific dry testing protocol were provided to each laboratory. This objective was part of an Eduardo Torroja Institute research study.

Six ceramic tile samples were tested by each laboratory. 72 laboratories participated, but not all of them gave useful results for the analysis (only 67 in wet conditions and 66 in dry conditions).

2.1.2 Results and discussion

In Figure 1, the test results in dry conditions show a high dispersion. If outliers are removed by successive steps with Mandel statistic test, too many of them are removed, barely getting valid results for a real study, which seems unacceptable.

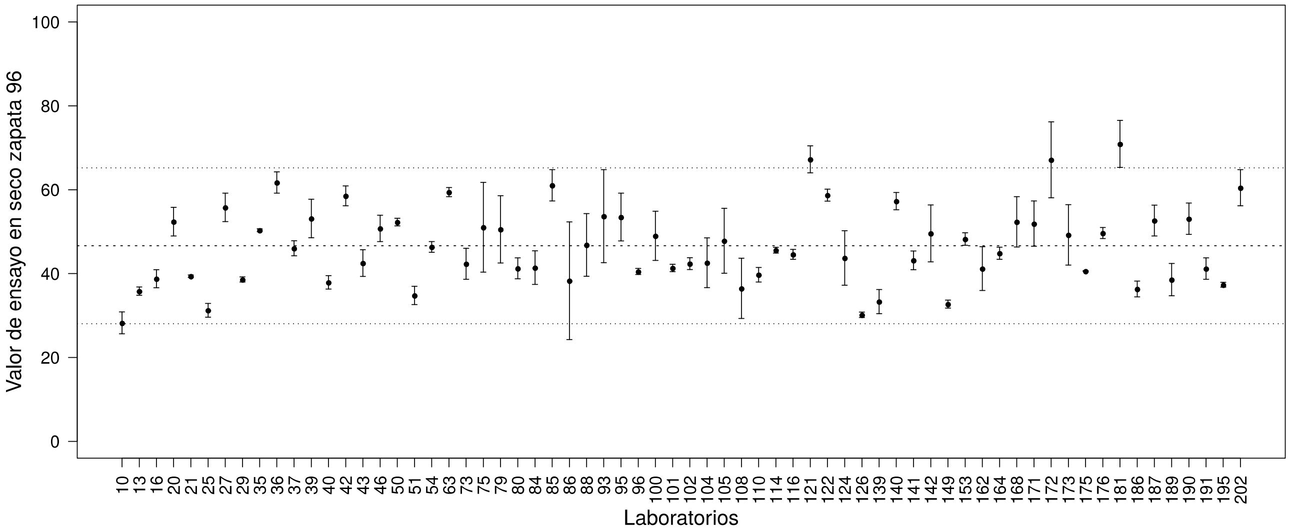


Figure 1: Results in dry conditions. All laboratories.

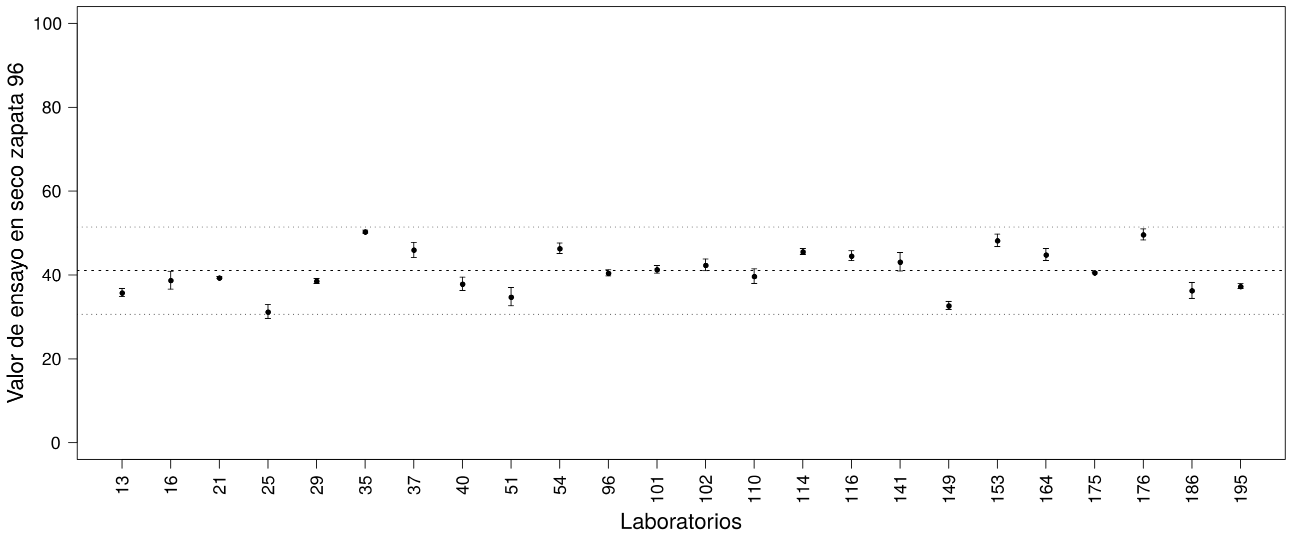


Figure 2: Test in dry conditions. Filtered laboratories with successive Mandel test.

Results before and after filtering outliers are shown in Table 1.

Table 1: Test accuracy before and after outliers filtering. EILA 2017 test in dry conditions.

Variable	All laboratories	Filtered laboratories
Total of laboratories	66	24
Mean	46.64	41.05
Interlaboratory standard deviation	9.32	5.20
Repeatability standard deviation	2.30	0.69
Reproducibility standard deviation	9.60	5.25
Repeatability value (r)	6.39	1.92
Reproducibility value (R)	26.60	14.55

Each entity tested in its own laboratory without any external control. Some procedural errors were detected, indicating that laboratories may not be performing well, for example: using non-conditioned or out of date rubbers, using non-calibrated pendulums, testing without slider preparation or without initial pendulum preparation, etc.

By way of comparison, the results of these same laboratories for the same tiles in wet conditions, gave repeatability value r and reproducibility value R of 2.89 and 9.19 respectively (before removing outliers).

2.2 EILA 2019

2.2.1 Methods

The interlaboratory test EILA 2019, undertaken on site at different locations, was aimed at the following objectives:

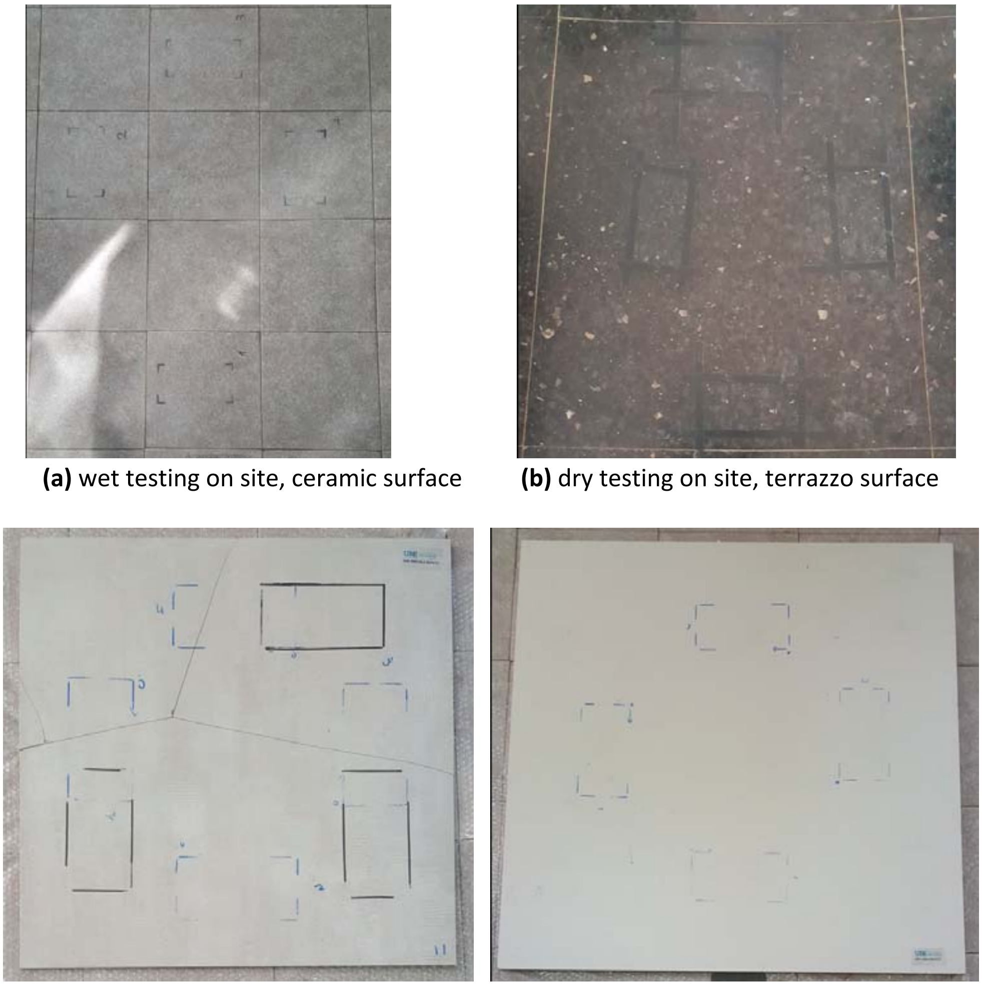
- To evaluate the performance of EILA participating laboratories in the friction pendulum test on site according to the new UNE 41902:2017 EX in dry conditions and UNE 41901:2017 EX in wet conditions Spanish standards. This time the tests were controlled by experts, so that laboratories carried out the test carefully. This test is performed with the pendulum slider IRHD 57 in wet conditions and with the IRHD 96 in dry conditions, as indicated in these standards.
- To validate the safe limit value in dry conditions, currently set at 40 and 65 PTV values with the 57 slider, and to improve the test performance of the new Spanish standards, if necessary. This objective is part of an Eduardo Torroja Institute research study.

Currently, UNE 41902:2017 EX and UNE 41901:2017 EX have replaced UNE ENV 12633 withdrawn standard in the Spanish Building Code.

A specific protocol was prepared to monitor the test performance of the different laboratories by an expert, in some cases, correcting the way of operating.

A location for the wet (Figure 3.a) and another for the dry test on site (Figure 3.b) were selected in each region (11 regions in total, see Figure 4). Additionally, 2 large format tiles (Figure 3.c and

3.d) were provided to each region to simulate a location on site and to allow a national scale comparison. The tests were conducted in 4 areas per location.



(a) wet testing on site, ceramic surface **(b)** dry testing on site, terrazzo surface

(c) wet testing on site, ceramic tile sent **(d)** dry testing on site, ceramic tile sent

Figure 3: Madrid samples.

The slider 96, provided to each laboratory in the EILA 2017 interlaboratory, was also used in the test in dry conditions. On the other hand, each laboratory used their own slider 57 in wet condition testing. STD-P verification tiles and some pink films of the same batch were also sent to each region.

68 laboratories participated in wet conditions and 56 in dry conditions. UNE 41902:2017 EX in dry conditions gives only reference surface value for the pink lapping film (70 ± 8 in dry conditions) for pendulum verification. This value was obtained after an interlaboratory study carried out in the development of the Spanish standard (2).

2.2.2 Results and discussion

2.2.2.1 On-site testing. Regionally

Figure 4 shows all results per region. Because floors are different in each selected region, it is not possible to obtain general dispersion values for the on-site testing. For each location, mean, repeatability and reproducibility values are given in the graph and reproduced in Table 2 for better reading. Prior and posterior verification is pointed out at the bottom of the graph. Red values are not available or out of range.

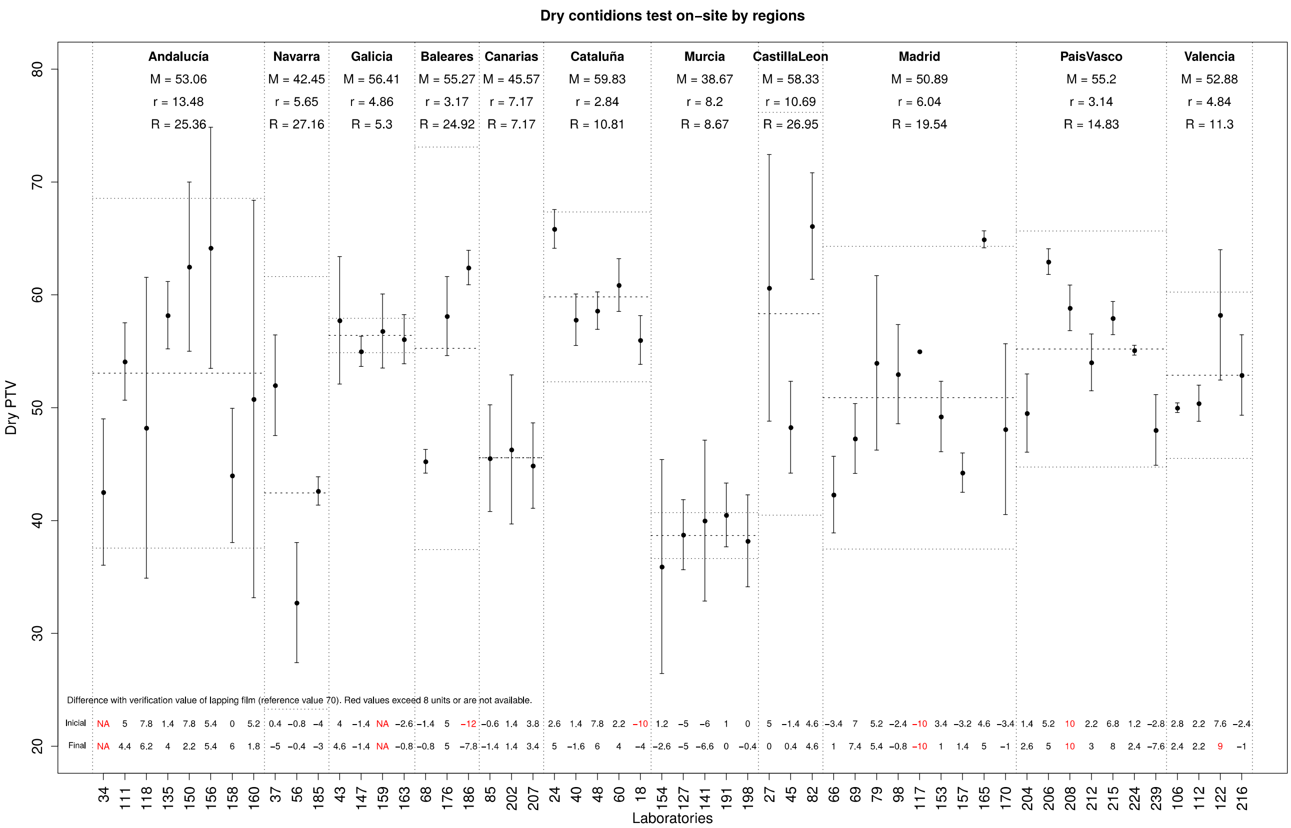


Figure 4: Results for testing in dry conditions on-site EILA 19

Table 2: Test accuracy. EILA 2019 test in dry conditions on-site.

Location	Laboratories	Mean	Repeat.Value (r)	Reprod. Value (R)
Andalucía	8	53.06	13.48	25.36
Navarra	3	42.45	5.65	27.16
Galicia	4	56.41	4.86	5.3
Baleares	3	55.27	3.17	24.92
Canarias	3	45.57	7.17	7.17
Cataluña	5	59.83	2.84	10.81
Murcia	5	38.67	8.2	8.67
Castilla y León	3	58.33	10.69	26.95
Madrid (see surface in Figure 3.b)	9	50.89	6.04	19.54
País Vasco	7	55.2	3.14	14.83
Valencia	4	52.88	4.84	11.3
GLOBAL MEAN			**6.37**	**16.55**

As there are so few laboratories in each location, Mandel's diagnostic is not able to detect outliers. Laboratories 34, 159, 186, 18, 117, 208 and 122 have not passed the verification or do not give verification data.

2.2.2.2 On-site testing. Ceramic tile sample

Figure 5 shows the results for the tile testing (Figure 3.d). In this case, repeatability and reproducibility values are obtained for all laboratories (r = 3.96 and R = 12.55) and improve the results of EILA 2017 (Table 1). They are also better than the average values obtained on-site (Section 2.2.2.1). Removing Mandel detected outliers and laboratories out of verification range, results even improve a little bit (r = 3.10 and R = 10.18), as Figure 6 shows.

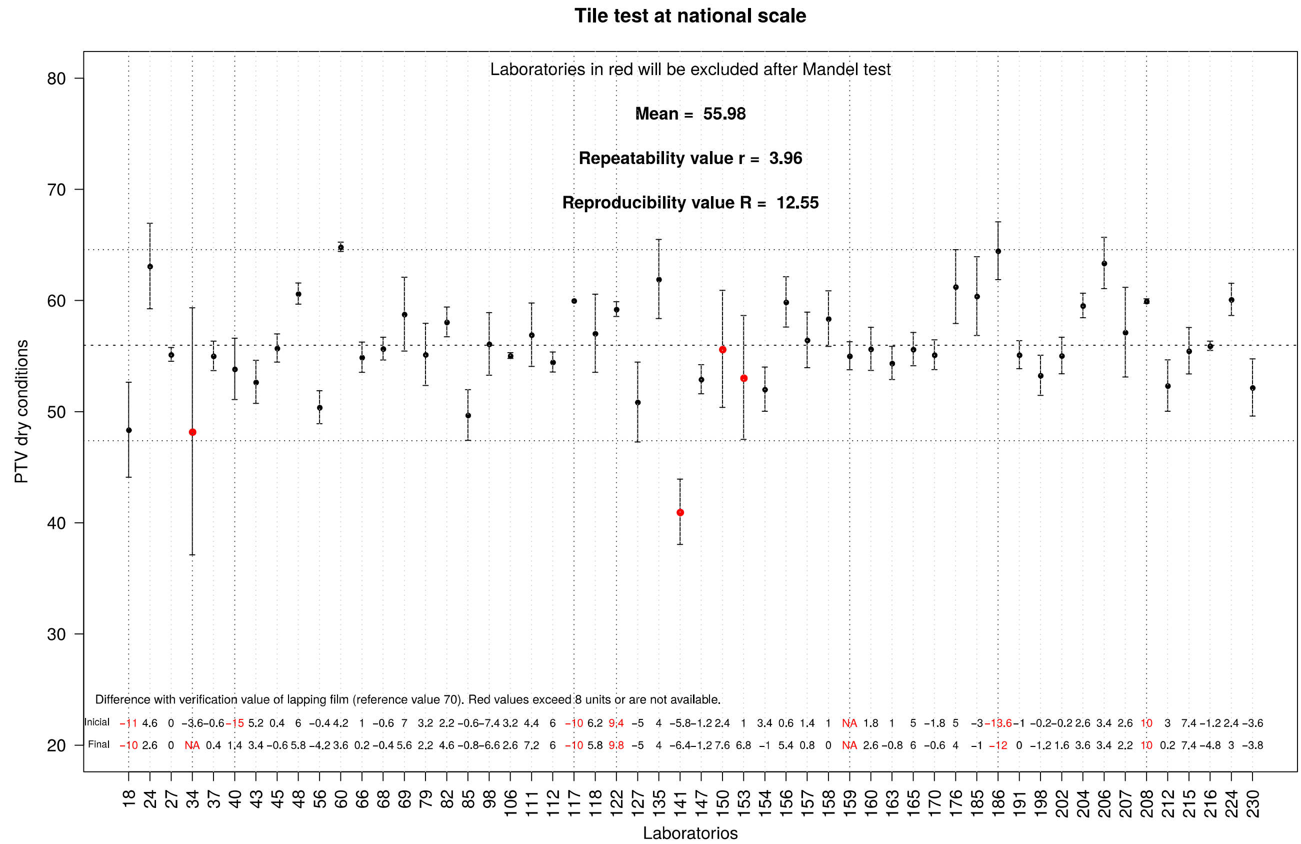


Figure 5: Results for tile on-site testing in dry conditions. EILA 2019 (all laboratories)

2.3 Conclusions. Comparison between EILA 2017 and 2019

In EILA 2017, the results of test in dry and laboratory conditions showed a much greater dispersion than the wet test. Although it is known that there is a greater dispersion in dry testing, these results evidenced another problem, probably related to deficiencies carrying out the test. It must be taken into account that these laboratories, although they are not reference laboratories, show the reality of what was being tested. The main conclusion drawn was that it is very important to improve the training of laboratories to improve the quality of the results. Consequently, it was proposed to repeat the test, this time on-site, in order to better control the laboratory test procedure and pendulum calibration and verification.

In EILA 2019, the dry test has shown an important improvement in accuracy, which may be due to the following factors:

- Use of the same verification surfaces (pink paper) for all laboratories
- Presence of the regional expert coordinators, which may have induced many laboratories to send to calibrate their pendulums before the test.
- Improvement in the test methodology itself, thanks to the explanatory documents sent, the experience gained by laboratories since EILA 2017, 2 years before, and the work of the regional coordinators during the tests.

EILA 2019 has shown that when the device is well calibrated and the test is carried out following the standard specifications, the results are reliable.

Finally, EILA 2019 opens the possibility of studying if the ceramic sample (Figure 3.d) could be used as a verification tile, due to accuracy results could be considered acceptable.

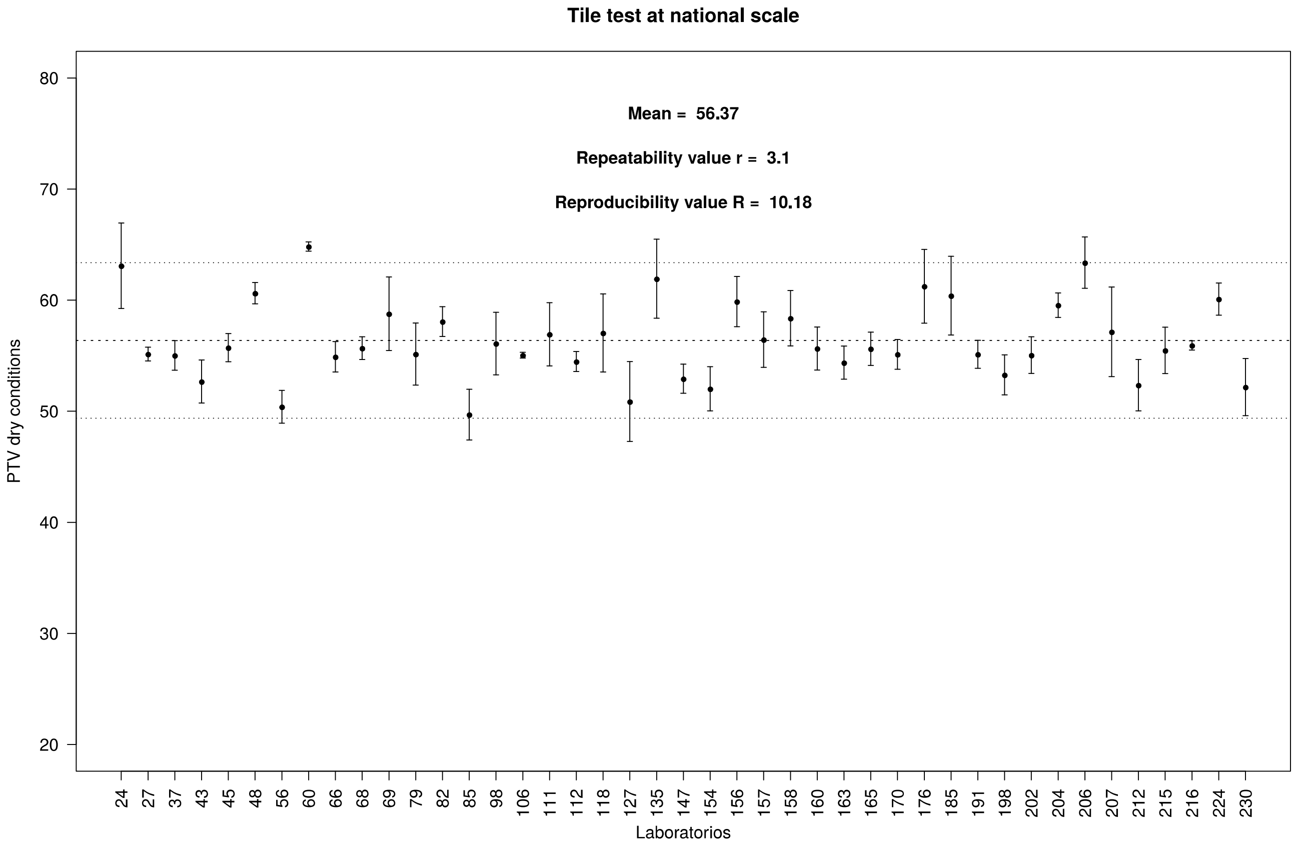


Figure 6: Results for tile on-site testing in dry conditions. EILA 2019 (filtered laboratories)

3. SAFE LIMIT VALUE

The limit values for the dry test recommended in the supporting document DA DB-SUA/3 (7) correspond to the slider 57. However, this kind of slider presented more dispersion than 96 alternative in dry conditions (2). Consequently, changing the slider implies the need to re-evaluate the safe limit values. It has been found that, although slider 96 gives values higher than slider 57 for the same floors (Figure 7.a), the behaviour in dry conditions is the opposite (Figure 7.b) (8). Slider 96 obtains lower values for the same surfaces, which would allow in principle to establish a lower limit value. This change requires an in-depth and larger study, so that the current values, which are on the safety side, has been maintained for the moment in DA DB SUA/3.

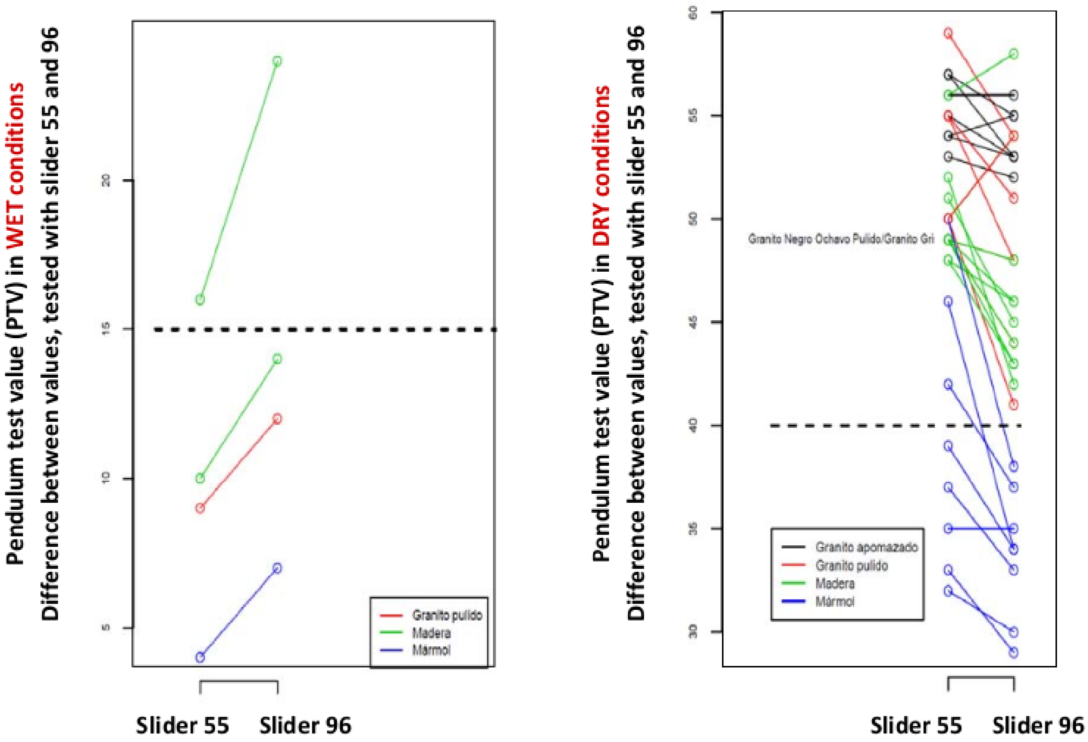


Figure 7: Difference between slider 57 and 96 test values, **(a)** in wet conditions **(b)** in dry conditions

4. REFERENCES

(1) Spanish Building Code, Real Decreto 314/2006 de 17 de marzo (BOE 28 de marzo de 2006) (2006). Código Técnico de la Edificación. Ministerio de Vivienda.

(2) Juan Queipo de Llano Moya and Elena Frías López (2016). Spanish Pre-regulatory Research in Slip Resistance. In: Slips, Trips and Falls 2016. The Way Forward. London, 2016

(3) UNE ENV 12633:2003 Method of determination of unpolished and polished slip/skid resistance value. AENOR, 2003.

(4) CEN/ TS 16165:2016 Determination of slip resistance of pedestrian surfaces Methods of evaluation. CEN, 2016

(5) UNE 41901:2017 EX Surfaces for pedestrian transit. Determination of the slip resistance by pendulum friction method. Wet test. AENOR, 2017

(6) UNE 41902:2017 EX Surfaces for pedestrian transit. Determination of the slip resistance by pendulum friction method . Dry test. AENOR, 2017

(7) DA DB SUA/3 Safety in use and Accessibility supporting document: Slipperiness. Ministerio de Fomento. https://www.codigotecnico.org/index.php/menu-seguridad-utilizacion-accesibilidad.html

(8) Queipo de Llano Moya (2015). Optimization of the friction pendulum test method for the evaluation of the risk of slipping on polished floors. Thesis. Universidad Politécnica de Madrid.

PENDULUM CALIBRATION, METROLOGICAL TRACEABILITY AND REFERENCE MATERIAL

Carl Strautins

Safe Environments Pty Limited

Carl@SafeEnvironments.com.au

ABSTRACT

A major source of measurement uncertainty for the pendulum friction tester is attributed to calibration. Two methods of calibrating a pendulum are presented in this paper, the first being a direct calibration of the pendulum specification, such as the arm mass, centre of gravity from the axis of rotation and the slider force (the input variables); the second being an indirect calibration by comparison of reference material. This paper outlines the collaborative efforts of laboratories from Australia, Netherlands, Spain, Slovenia and the United Kingdom over the past two years. The result of this work includes the development of a mathematical model to correct for systematic instrument bias and establish sensitivity coefficients for input variables. This characterisation process yields metrological traceability using an operationally defined method through the realisation of the quantity values supported by SI units and their associated uncertainties. This study validates the various calibration standards of the pendulum (BS 7976-3, CEN TS 16165, EN 13036-4 and ASTM E303) being consistent as calibration defined within JCGM 200:2012 *International vocabulary of metrology – Basic and general concepts and associated terms* (VIM). The focus of the study turned to the development of reference material in support of an indirect calibration using the framework outlined within ISO Guide 35 *Reference materials — Guidance for characterization and assessment of homogeneity and stability*. This method developed seeks to improve Calibration and Measurement Capabilities (CMC) to 1 PTV and facilitates more accurate proficiency testing activities by reducing bias in the assigned value that occurs from consensus values.

Keywords: calibration, metrological traceability, reference material, tribometer

Topic: Pendulum calibration and metrological traceability

1. INTRODUCTION AND BACKGROUND

In some countries, pendulum calibrations have been accepted as being a test method rather than a calibration. This paper challenges this view and outlines a pathway for metrological traceability via calibration of the pendulum friction tester specifications as defined by the measurement method CEN TS 16165 *Determination of slip resistance of pedestrian surfaces — Methods of evaluation Annex C Pendulum test*[1] with the apparatus specifications (input quantities) traceable to the SI units for mass (kg) and dimensions (m) through international/national standards. The measurement result(s) of these calibrated equipment may be used to characterise property values and their associated uncertainties for reference material. This facilitates an artefact (float glass, reference tile, verification film or other suitable material) to be realised on the measurement scale and be used as a calibrant[2].

1.1 Calibration standard

The calibration procedure outlined within CEN 16165 Annex C.10 requires individual components (or input quantities) that define the operational method are to be calibrated. These components include:

- Mass of the pendulum arm
- Distance of centre of gravity to centre of rotation
- Spring force tension
- Levelness of the frame

The calibration of the input quantities is supported by the force and length measurements in SI units to establish metrological traceability via the operationally defined method. Communicability of the input values to the measurand is governed by the laws of classical Newtonian rotation and friction. The result of the calibration and the associated uncertainty are defined by the instrument specifications and tolerances (Table9). A final calibration by indirect measurement against reference surfaces are then performed to verify that the instrument is providing an indication on the measurement scale (Pendulum Test Value or PTV) that is within the acceptable uncertainty of the method. These estimates of uncertainty for the calibration may be achieved through an understanding of the theoretical principles or practical experience of the performance of the method[3].

1.2 Limit values of the verification surfaces (theoretical estimate of uncertainty)

The *a priori* estimate of uncertainty may be achieved by calculating the expanded uncertainty as tabled through the verification limits of the sliders within the Calibration Standard by following the Guide to the GUM[4]. This method indicates a minimum Calibration and Measurement Capability (CMC) is approximately 3 PTV for the float glass and up to 6 PTV for the reference tile, expressed as an expanded uncertainty at the 95% confidence interval with coverage factor K = 2.

Table1: Estimated uncertainty via limit values of the verification surfaces (slider 96)

Verification surface	**Limit value** (PTV)	**Semi-range** (a)	**Probability Distribution**	**Divisor** (ki)	**Sensitivity coefficient** (ci)	**Standard uncertainty** (uc)	**Expanded uncertainty** (Uc)
Float glass	5 to 10	2.5	Rectangular	$\sqrt{3}$	1	1.44	2.9
Reference tile	5	5	Rectangular	$\sqrt{3}$	1	2.89	5.9
Verification film (PLF)	5	3	Rectangular	$\sqrt{3}$	1	1.73	3.5

1. The expanded uncertainty Uc is calculated at the 95 % confidence limit, vi = 30 and a coverage factor K = 2

The decision rule for the limit values of the verification surfaces are unclear as to whether this includes tolerance of the value of the reference surface, the acceptable uncertainty and/or a combination thereof. It would assist accreditation bodies and calibration laboratories if the limits of the verification surfaces were specified with an acceptable tolerance of the target property value for the reference surface and an associated uncertainty.

For example, the reference tile shall be a Certified Reference Material (CRM) with a property value of between 30 and 40 PTV and an associated expanded uncertainty of no more than 3 PTV at the 95 % confidence limit. This should also not limit the type or form of material that may be used, however it would be beneficial to provide guidance as to material that has been found to be acceptable. The property value and associated uncertainty should ideally be CRM produced by an organisation accredited to ISO 17034[5]. This method establishes metrological traceability as required under ISO 17025 clause 6.5 for accredited calibration facilities, reduces effort required for validation and verification and provides unequivocal evidence of the Standard being a *'true'* calibration as defined in VIM 200[6].

Table2: Suggested format for the limit values of the verification surfaces

Pendulum Reference Surface (PRS)[3]	**Tolerance of the Reference Surface Certified Value (PTV)**[2]	**Acceptance Criteria between Certified Value and Measured Value for Pendulum under Calibration (PTV)**[3]
PRS-1	0 to 10	± 3
PRS-2	30 to 40	± 3
PRS-3	60 to 80	± 3

1. PRS-1 has traditionally been float glass; PRS-2 a reference tile such as a preconditioned Portuguese tile known as *'Pavigres'* characterised by the UK Slip Resistance Group (UKSRG); PRS-3, a single use pink Lapping Film for fibre optic connector polishing comprising graded aluminium oxide particles coated on a 3-mil polyester film produced by 3M (product code: 261X 3 MIC - 8 1/2" X 11")
2. The property value and associated uncertainty shall be calculated according to ISO Guide 35 at the 95% confidence limit.
3. The uncertainty of the CRM should be no greater than 1 PTV, otherwise this must be considered in the acceptance criteria.

1.3 Guide to expression of uncertainty in measurement (theoretical estimate of uncertainty)

In measurement, the GUM provides an a-priori estimate of uncertainty by modelling the measurement and identifying the input quantities, assessing the uncertainty distribution function through scientific judgement, converting to a standard uncertainty and then finally calculating to an expanded uncertainty with a stated confidence limit. Scientific judgement may include previous measurement data, general knowledge of the behaviour e.g. classical rotational motion, information within calibration certificates.

The GUM provides a method to compartmentalise each of the input quantities and determine their relative influence in the overall contribution to uncertainty. This provides facilities an opportunity to effectively reduce the overall uncertainty by first reducing the uncertainty of the most influential components. This may be depicted graphically to provide a quick comparison through the use of an uncertainty budget. The derived uncertainty budget identifies calibration and drift components as the most significant in the overall uncertainty of measurement; minimising components with less than 30 percent of the overall uncertainty will have negligible influence on the overall uncertainty[7] .

Table3: Realisation of uncertainty components via GUM method

Component	Units	Distribution	Ui	ki	ui=Ui	Ci	(cixui)	Vi
Drift	PTV	Rectangular	-3	1.73	-1.73	1	1.73	10
Calibration	PTV	Normal	3	2.0	1.50	1	1.50	30
Resolution	PTV	Triangular	1	2.45	0.41	1	0.41	30
Repeatability	PTV	Normal	0.4	1	0.42	1	0.42	9
Rounding	PTV	Rectangular	1	1.73	0.58	1	0.58	100

1. Ui = expanded uncertainty; ki = divisor of the probability distribution function to convert into a standard uncertainty (Uc); Ci = sensitivity coefficient; vi = effective degrees of freedom.

The calibration uncertainty was characterised by the most commonly reported CMC of 3 PTV by accredited facilities undertaking pendulum calibrations. Drift was characterised by the limit values of 3 PTV for control tiles outlined within Australian Standard AS 4586[8] and AS 4663[9] and the reported drift by Hiti and Ducman[10]. In consideration of the uncertainty budget, the most effective way to improve measurement uncertainty for the pendulum is to reduce the effects of calibration and drift.

Table4: Summary of measurement uncertainty via GUM method

Standard uncertainty (u_c)	Effective degrees of freedom (V_{eff})	Coverage factor (k)	Expanded uncertainty (U_{95})
2.4 PTV	32.7	2.04	5.0 PTV

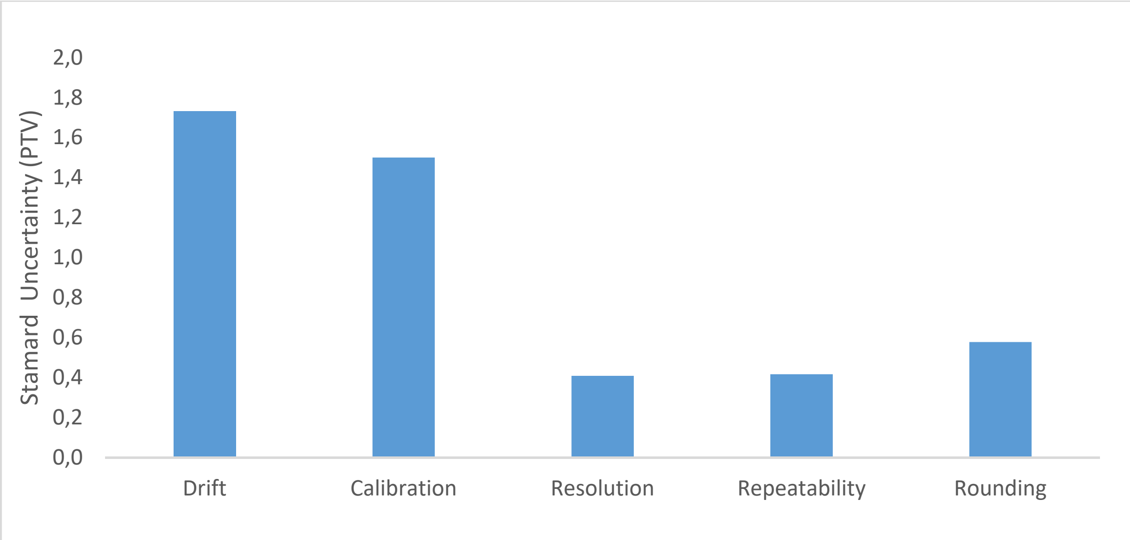


Figure1: Graphical representation of a typical measurement uncertainty budget

1.4 Precision and Bias Study to ASTM E691 (practical estimate of uncertainty)

Facilitated by the UK Slip Resistance Group in September 2017 at Lucideon, Stoke on Trent UK , a precision and bias study was conducted to ASTM E691[11]. The reference surfaces used included float glass, verification film (3M 261 grade 3MIC; pink lapping film (PLF) and five additional reference tiles manufactured by Porcelanosa with an engineered slip resistant surface which was worn down using an accelerated wear procedure[12],[13] from an initial PTV of approximately 70). A combination of six pendulums and six operators were used during the study for the seven different surfaces across the expected measurement range.

Table5: Bias and precision study via ASTM E691

Format	FG	T1	T2	T3	T4	T5	PLF
x	5.5	24.8	32.9	40.7	45.8	52.9	61.8
s_{x^-}	0.44	0.41	1.27	0.94	1.98	1.61	1.43
s_r	0.44	0.31	0.50	0.72	0.78	0.43	1.16
S_L	0.41	0.39	1.25	0.89	1.95	1.60	1.35
S_R	0.60	0.50	1.34	1.14	2.10	1.66	1.78
$r_{95\%}$	1.2	0.9	1.4	2.0	2.2	1.2	3.2
$R_{95\%}$	1.7	1.4	3.8	3.2	5.9	4.6	5.0

The bias and precision study indicate reproducibility estimates at the 95 % confidence limit may be between 1.5 to 5 PT, with repeatability (precision) being the dominant component of uncertainty at low PTV and bias high at high PTV; bias appears to become a significant contributing factor to the overall uncertainty for PTV greater than 30.

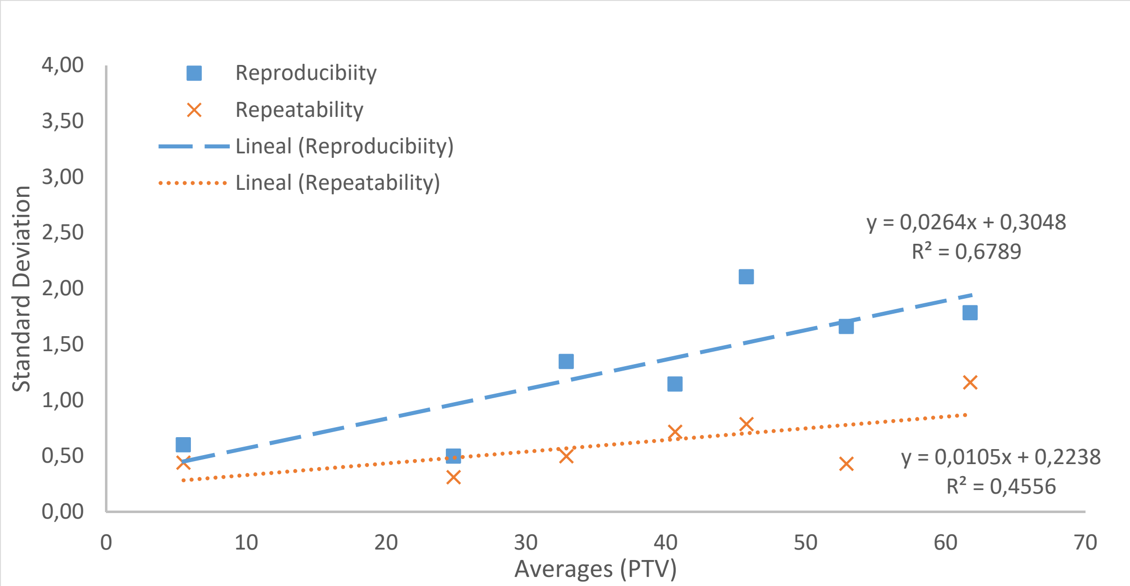


Figure2: Standard deviations of reproducibility (S_R) and repeatability (S_r) versus average PTV (x)

1.5 Proficiency testing to ISO 17043 & ISO 13528 (practical estimate of uncertainty)

A simultaneous proficiency program (PT) was conducted throughout September and October 2018 in accordance with ISO 17043[14]. The PT program included eight countries (Australia, Germany, Netherlands, New Zealand, Slovenia, Spain, Turkey, United Kingdom). The measurement results were analysed according to Algorithm A as per ISO 13528 with five different surfaces comprising values from about 8 to 87 PTV:

- Surface A: White glazed ceramic tile
- Surface B: Structured / Profiled grey / blue ceramic tile
- Surface C: Brown ceramic tile
- PLF: 3µm Pink Lapping Film
- P400: P400 grade abrasive paper

Three specimens of each surface type were provided as replicates to reduce the effects of homogeneity. In all cases, the standard uncertainty of the assigned values (uX) in calculating z-scores and En values were negligible, being calculated as less than 0.3 times the robust standard deviation (uX ≤ 0.3σˆ).

Table6: Summary statistics of proficiency testing to ISO 17043 & ISO 13528 algorithm A

Format	Surface A	Surface B	Surface C	PLF	P400
Number of facilities	35	36	36	28	28
Robust Average (x*)	7.8	38.6	63.3	61.6	87.1
Robust Standard Deviation (s*)	2.57	2.45	2.39	2.22	3.16
2σˆ	5.1	4.9	4.8	4.4	6.3

Based on the results of proficiency testing, the global performance in the use of the pendulum test method is estimated to be a standard robust deviation of about 2.5 PTV. The variance in results are likely due to clustering of different geographical regions and an increase in the number of facilities that are not accredited to ISO 17025 through the International Laboratory Accreditation Cooperation (ILAC) scheme.

Proficiency testing programs will benefit from the use of certified reference material (compared with participant consensus values) through the reduction of bias error arising because of drift or the incorrect settings of spring tension. This also increases confidence in the results, reduces the confidence interval for acceptable values and reduces false signals. Where the expanded calibration and/or certified reference material uncertainty is reduced to 1 PTV (U95), then the maximum permissible error of about 3 PTV may be achieved when setting action levels within proficiency testing programs.

1.6 Summary of estimate of uncertainty for the operationally defined method CEN 16165

The current estimated uncertainty in using the pendulum is about 3 – 5 PTV. Based on the current specifications for the pendulum calibration and measurement procedures, the expanded uncertainty at the 95 % confidence limit, a calibration CMC is practically 3 PTV with a practical measurement uncertainty of between 3 to 5 PTV for values between 5 to 70 PTV.

The assigned value for the PLF was assessed for each of these studies and upon investigation there were significant differences. Because the value of 61 is published, there may be either a conscious or unconscious bias to allow instruments to drift to this value and falsely consider the result as acceptable. Further analysis of the PT program revealed on average a difference of 2 PTV between calibration laboratories and testing facilities; the hypothesis being reduced spring tension over time. The effect of spring tension was the impetus for further study.

Table7: Assigned value for the Pink Lapping Film (PLF) across different studies

Reference / Study	Assigned value for PLF
BS 7976[15]	61
UKSRG Precision and Bias Study to ASTM E691	61.8
Safe Environments PT Program (all facilities)	61.6
Safe Environments PT Program (calibration facilities)	64.0

2. CORRECTING FOR BIAS

2.1 Adjustment via slider force/deflection integral referenced to an *'ideal pendulum'*

Hiti and Ducman (2014) characterised the slider force/deflection characteristics and identified that pretension of the lift handle will reduce the measured value on PLF, causing a negative bias. PLF is a verification film used in the calibration of pendulum friction testers with a reported PTV of 58 for slider 57 according to CEN 16165. The nominal spring tension in the pendulum is set at 24.5 Newtons (N) at a deflection of 4.5 mm. This is problematic in the case of BS 7976-3 as this is a single point that is outside the deflection that the pendulum will normally operate. Consequently, the 'true' force is unknown unless the effective spring tension complies with the force-deflection limits specified within CEN 16165.

Precision and bias studies indicate reproducibility may be in the range of 3 to 5 PTV where a significant component may be bias in the form of the effective spring tension. It was hypothesised that bias from spring tension could be corrected via the force-deflection curve. With the normal force acting on the surface due to the effective spring tension being the variable under study, the coefficient of friction (expressed as PTV) and the horizontal force effectively become a constant, the correction for bias being a function of the PTV following the classical laws of friction:

$$F_H = \mu . F_N \tag{1}$$

Where,

μ =	Coefficient of Friction (CoF)
F_N =	Vertical compression force in Newtons (N) when the slider is deflected
F_H =	Frictional force in Newtons (N) exerted opposing motion between the two surfaces

For a surface with a known coefficient of friction or PTV and a specified normal force, an adjustment factor (α_{Fh}) is then applied on the above relationship e.g. the correction factor α_{Fh} for PLF is calculated to be 2.37; where F_N = 24.5 N is the nominal vertical compression force when the slider is deflected at 4.5 mm and the assigned value for PLF is 58 PTV using slider 57 per CEN 16165. This adjustment factor was then applied to the difference of the integral of the force deflection curve between an *'ideal pendulum'* and that of a pendulum under calibration.

$$Corr_{PTV} = \alpha_{Fh}.\left(F_{ref} - F_{eff}\right) \tag{2}$$

Where,

$Corr_{PTV}$ =	Correction applied to the instrument under calibration (PTV)
α_{Fh}=	Bias correction factor determined as F_H at the corresponding CoF for the reference / verification surface
F_{ref}=	Effective force of the slider averaged over the path length/time of an *'ideal pendulum'* via an association with the mid-point of the force-deflection limits per CEN 16165 C.10.6.2 and Figure C.8 (N.mm)
F_{eff}=	Effective force of the slider averaged over the path length/time of the pendulum under calibration via an association with the force-deflection curve derived from CEN 16165 C.10.6.3 (N.mm)

The simple integration of the force-deflection curve requires further consideration in the use of this calculation. This is because the deflection of the slider (and subsequent force), is a function of the path length. As the pendulum foot follows a circular path of 514 mm, the path length is characterised as a 126 mm chord with the slider deflection being the distance between the 126 mm chord and the 514 mm radius of swinging foot. The procedure at CEN 16165 C.10.6.3 allows this to be calculated at 1.5 mm, 3.0 mm and 4.0 mm slider deflections on the force-deflection curve.

The integral at 1.5 mm deflection will account for approximately 20% of the path length, between 1.5 and 3 mm about 30% of the path length and between 3 and 3.9 mm about 50 % of the path length. For practical purposes, the deflection along the path length. It is slightly asymmetrical due the 10 mm height drop from horizontal and the effect of the de-acceleration (change in velocity/time of the slider over the path length) can be considered negligible. The effective force over the path length can be calculated by the integral of the force-deflection by the relationship:

$$F_{eff} = 0.2 \times \int_{0.0}^{1.5} F \cdot D + 0.3 \times \int_{1.5}^{3.0} F \cdot D + 0.5 \times \int_{3.0}^{3.9} F \cdot D \quad (3)$$

Where,

F_{eff} = Effective force of the slider averaged over the path length/time (N.mm)

F = Force of the slider acting on the surface in Newtons (N)

D = Deflection of the slider in millimetres (mm)

The effective force that an *'ideal pendulum'* exerts on the surface over the slider path length can then be calculated, based on the assumption that this is defined by the mid-point of the force-deflection envelope:

$$F_{ref} = 0.2 \times 24.1 + 0.3 \times 36.1 + 0.5 \times 22.3 \quad (4)$$
$$F_{ref} = 26.8 \, N.mm$$

These formulas were then applied to the raw data by Hiti and Ducman (2014) to calculate the correction for bias resulting from the force-deflection curve deviating from the mid-point of the limit envelope and provided at Table1. Each series represents a pendulum with different effective spring tension(s) and force deflection curves by adjusting the lever pre-tension. Pendulum test values were obtained using Slider 57 on PLF with each series meeting the force deflection requirements of 24.5 N when the slider was deflected 4.5 mm.

Table7: Calculations to correct for bias due to the effective spring tension

Series		1	2	3	4	5	6	7	8
F_{eff}	N.mm	28.1	27.5	26.7	25.9	24.3	22.7	21.7	26.4
$F_{ref} - F_{eff}$	N.mm	1.27	0.73	-0.05	-0.92	-2.52	-4.12	-5.08	-0.39
$Corr_{PTV}$	PTV	-3.0	-1.7	0.1	2.2	6.0	9.8	12.0	0.9
Measured value	PTV	60.0	60.2	59.0	55.2	51.6	49.0	43.6	58.0
Adjusted value	PTV	57.0	58.5	59.1	57.4	57.6	58.8	55.6	58.9
Δ (Adj – PLF)	PTV	-1.0	0.5	1.1	-0.6	-0.4	0.8	-2.4	0.9

1. The *'true value'* of PLF was assumed to be 58 PTV for slider 57 as reported in CEN 16165
2. F_{ref} = 26.8 N.mm
3. α_{Fh} = 2.37

Table8: Assigned value and standard deviation as measured and corrected for bias

Method	Average PTV	Average bias (range)	Standard deviation
Measured	54.6	-3.4 (-14.4 – 2.2)	6.0
Corrected	57.9	-0.1 (-2.4 – 1.1)	1.2

1. The *'true value'* of PLF was assumed to be 58.0 PTV for slider 57 as reported in CEN 16165

The measured values present a bias of between -14.4 and 2.2 PTV and a standard deviation of 6.0. When corrected via the model, the bias was reduced to -2.4 to 1.1 and the standard deviation reduced to 1.2 PTV. The outcome of this investigation was that a pendulum that does not meet the force-deflection limits may be corrected for bias within an acceptable level of accuracy e.g. ± 3 PTV expanded uncertainty. It also reinforces the work by Hiti and Ducman (2014) in the importance of characterising the effective spring tension through the use of the slider force-deflection curve within the range of normal deflection that the slider will experience along the path length.

2.2 Adjustment via predictive model realised through pendulum calibration input quantities

In November 2018, a pendulum characterisation study took place at LOEMCO laboratories Madrid Spain with participants from Australia, Slovenia, Spain and the United Kingdom. The aim was to identify and characterise the input quantities that are specified within the pendulum calibration procedure. Metrological traceability was established by way of the involvement of equipment and personnel from five organisations that are accredited to ISO 17025 as part of the ILAC MRA of testing and/or calibration of the Pendulum along with two manufacturers (KSS & Munro) from the UK. Other personnel involved were experienced and competent technicians supervised throughout the study which was conducted over a two-day workshop.

The methodology followed ISO 5725-2 *Basic method for the determination of repeatability and reproducibility of a standard measurement method*[16]. Six pendulums were characterised by six experienced pendulum operators. Measurements were performed on the three verification surfaces outlined in CEN 161665, float glass, Pavigres tile and PLF. The input quantities of the operationally defined method were measured; these included the effective spring tension, pendulum arm mass, centre of gravity of the pendulum arm to the axis of rotation, length of axis of rotation to the slider edge.

The three verification surfaces were tested in accordance with CEN 16165 Annex C and then the test was performed again for repeatability assessment. This was then repeated after interchanging pendulums and operators. Following this, the spring tension was adjusted to nominal values of 19.0, 21.5, 23.5, 24.5, 25.5 N at 4.5 mm deflection. The force was measured using a *'direct force method'* with a balance rather than the use of *'hanging weights method'*. The *'direct force method'* eliminates the uncertainty that is associated with the unknown weight of the lever arm when inverted through the *'hanging weights method'*. A total of 124 verifications of each surface were performed in characterising the effective spring tension.

Multi-variate regression analysis was performed using STATA (version 15). Linearity of the explanatory variables were checked with no departures observed. All input quantities were statistically significant in the model, (P<0.001). Co-linearity was expected between the input quantities due to the theoretical Newtonian model of rotational motion and force. The baseline multivariate model was constructed where significant co-linearity was observed between the input quantities of the pendulum arm mass and the centre of gravity from the axis of rotation. This effect was ameliorated by combining these input quantities within the multivariate model.

The predicted value for the PLF was a PTV of 65.1 using the multivariate regression model with an expanded uncertainty of 3.0 (coverage factor k=2; see Table9). One method to reduce the uncertainty is to constrain the tolerance limits of the input quantities increasing the number of replicate measurements. By restricting the tolerance limits for the input quantities (effective spring tension ± 0.3 N, pendulum arm mass ± 10 g, distance of centre of gravity to centre of rotation to ± 3 mm and performing five replicate measurements) the expanded uncertainty may be reduced by 50 %. This equates to an expanded uncertainty of 1 PTV for float glass and the reference tile, and 1.5 PTV for PLF. The practicability of reducing the force deflection envelope should be considered, particularly the effects of hysteresis within the system and the decision rule with respect to uncertainty. e.g. whether the rising, lowering or average force deflection need all need comply with the tolerance. For practical purposes, reference to the *'accuracy method'* as outlined within BIPM JCGM106 clause 8.2.4 should be considered as the decision rule when determining conformity with within CEN 16165 e.g. Limit of Performance (LOP) requirements for the balance used to measure mass and/or force.

Table9: Regression coefficients via the predictive model realised through pendulum calibration input quantities

Input quantities	Units	Specification values	Tolerance	Regression coefficient (β)	PTV range	Standard uncertainty
Force (F) @ 4.5 mm deflection	(N)	24.5	0.5	2.64	2.6	0.76
Arm mass (W)	(g)	1500	30	-	0.0	0.00
CoG (L)	(mm)	410	5	-	0.0	0.00
W*L	(g.mm)	615000	19650	-0.000102	4.0	1.16
Arm length (Al)	(mm)	514	1	0.123	0.2	0.07
Repeatability	(PTV)	-	-	-	-	0.62

Table10: Summary of assigned value, associated uncertainty and input regression coefficients for CEN 16165 verification surfaces

Verification surface	Assigned value (PTV)	Expanded uncertainty (U95) (PTV)	Modified Tolerance (U95) (PTV)	β $F_{@4.5\,mm}$	β W*L	β Al
Float Glass	6.4	1.9	0.8	0.12	-0.000061	0.08
Pavigres	36.6	1.9	1.0	1.88	-0.000045	0.04
PLF	65.1	3.0	1.5	2.63	-0.000102	0.12

3. REFERENCE MATERIAL CHARACTERISATION

One method of calibration is via the use of certified reference material (CRM), or an artefact which provides a point in the measurement system that an instrument may be measured against. ISO Guide 35 defines CRM *'material characterised by a metrologically valid procedure for one or more specified properties, accompanied by a reference material certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability.* In this study, the metrologically valid procedure is CEN 16165 Annex C.

There is no holy grail for a universal tribometer or reference surface; it does not exist. This is because each test method defines its own measurement system with the property value dependent on the operationally defined procedure, its respective input quantities and effect on the measurand. Each test method for surface friction has the ability for the development of reference material when the input quantities, their association with the measurand and uncertainties are established and characterised. This forms part of a verification process, where CRM provides the realisation of a point in the specific measurement system.

CRM may be produced in large quantities where the property value and its associated uncertainties require to be characterised for the batch. The components of uncertainty arising from mass production of CRM includes homogeneity (variation within the batch) and stability (how the property value may change over time or use). Similar to an uncertainty for measurement, these components relating to reference material are provided in ISO Guide 35:

$$x_{CRM} = y_{Char} + \delta_{hom} + \delta_{lts} \quad (5)$$

Where,

x_{CRM}	=	Property value of the CRM
y_{Char}	=	Property value obtained by characterising the batch of material
δ_{hom}	=	Error due to homogeneity of the batch of material
δ_{lts}	=	Error due to stability of the material

3.1 Property value (y_{Char})

The property value of the candidate CRM may be obtained by following the statistical techniques outlined within ISO 5725-2. A suggested design is to perform at least six tests with a combination of 3 pendulums and 2 operators to reduce potential systemic bias. An adjustment using a predictive model, limiting uncertainty by restricting the tolerance of the pendulum input quantities, or a combination of both should be considered to reduce the effects of bias resulting from the predictive model. The calibration uncertainty of the input quantities for the pendulum should also be incorporated in the uncertainty associated with the property value y_{Char}.

3.2 Homogeneity assessment (δ_{hom})

Homogeneity quantifies the variation in PTV between surfaces within the batch and is conducted by testing a minimum of ten tiles. A number of repeat measurements may need to be undertaken because homogeneity may be masked by the repeatability error and is governed by the equation:

$$\frac{S_r}{\sqrt{n_{crm}}} \leq \frac{u_{trg}}{3} \quad (6)$$

Where,

s_r	=	Repeatability standard deviation
n_{crm}	=	Number of measurements
u_{trg}	=	Target standard uncertainty

Where this requirement cannot be met, then S_r / $\sqrt{n_{crm}}$ must not exceed the target standard deviation u_{trg}. Assuming the target expanded uncertainty is 1 PTV, the standard uncertainty

u_{trg} becomes 0.5 PTV. In evaluating the repeatability standard deviation from the precision and bias studies, no less than three tests on each of the ten individual units should be conducted to that $S_r\ /\ \sqrt{n_{crm}}$ does not exceed u_{trg}. The homogeneity component δ_{hom} may be characterised using ISO 5725-2 which may also be used to confirm repeatability error.

3.3 Stability assessment (δ_{lts})

The UK Slip Resistance Group established an informal procedure to assess the stability of verification tiles by swinging the pendulum over 800 times across the wetted surface that is held in the same position using a sample holder. The basic principle being that this represents about 100 verifications over a one-year period between calibrations. The acceptance criteria being a reduction of no more than 4 PTV over its intended use. The measured PTV will tend to reduce in use as the slider will 'polish' or wear the surface. As this uncertainty component will drift as a negative bias, the stability component can be split into a bias and uncertainty. For instance, the initial target property value for the *'Pavigres'* tile in the UK is 38 PTV, with a 4 PTV instability component can be then be expressed as 36 ± 2 PTV.

Following ISO Guide 35, instability of the candidate CRM can be characterised by following the UKSRG method and statistically analysis the reduction in PTV compared with the number of swings. The uncertainty component due to instability of the surface friction δ_{lts} is defined by the upper 95% confidence interval of the regression line. If this component is split to account for bias, then the average regression coefficient should be used. The target uncertainty of the CRM may be optimised by limiting the number of uses to restrict the uncertainty component associated with instability of the surface friction.

3.4 Uncertainty of CRM (y_{Char})

The total uncertainty of the CRM is then defined by vector addition sum of squares.

$$u_{CRM} = \sqrt{u_{char}^2 + u_{hom}^2 + u_{lts}^2} \tag{7}$$

The uncertainty u_{CRM} may be optimised depending on the nature and use of the material, such as a calibrant, reference material within for a proficiency testing scheme, or reference surface for quality control checks. For instance, material within a simultaneous proficiency testing scheme may eliminate stability uncertainty, however for a sequential proficiency testing scheme stability is essential and there will no uncertainty contribution for homogeneity.

CRM that is only used once, such as PLF does not require a stability assessment, however homogeneity then becomes the dominant contribution of uncertainty. For CRM that is to be used multiple times, it is essential that the stated number of uses be incorporated into the CRM documentation to ensure the validity of its use. The validity of use may be expressed as the number of swings or verifications. Where the CRM is limited by use, a detailed log is essential, or if time based its first use assuming that a verification is performed each working day.

3.4 Statement of metrological traceability of CRM

User of CRM require documentation to ensure its validity of use. This is usually provided in the form of a certificate which includes the property value and metrological traceability [17], [18], e.g.:

“The certified value is 64.1 Pendulum Test Value (PTV) ± 1.5 PTV and is traceable to the SI units for mass (kg) and dimensions (m) through European/national standards via calibration of the pendulum friction tester specifications defined by the measurement method CEN 16165 Determination of slip resistance of pedestrian surfaces — Methods of evaluation Annex C Pendulum test. The value was realised on the measurement scale by an adjustment via a model to the point estimate of the apparatus specifications. The uncertainty has been calculated according to ISO Guide 35 and is stated at the 95% confidence limit (k=2)”

4. SUMMARY

This paper supports CEN 16165 Annex C10 as a calibration as defined within VIM 200. This is because the relationship between the quantity values, their respective measurement uncertainties and sensitivity coefficients are established via the pathway of an operationally defined method supported by SI units. This information was used to establish a relationship in obtaining the Pendulum Test Value (PTV) and associated uncertainties.

The overall measurement uncertainty when determining the slip resistance of pedestrian surfaces is between 3 to 5 PTV by the method of CEN 16165 Annex C. The calibration component contributing to measurement uncertainty is significant which is estimated to be 2 PTV for values of less than approximately 35 PTV, and 3 PTV for values greater than approximately 35 PTV. Every effort should be made to reduce the calibration uncertainty to 1 PTV (one-third of the total measurement uncertainty) to ameliorate its contribution in measurement of pedestrian surfaces.

Repeatability error was identified as the dominant component of uncertainty where the PTV is less than 35 PTV and accounts on average about 1.5 PTV (expanded uncertainty, U_{95}). This effect can be reduced in the calibration procedure or for verification / control checks of the instrument by increasing the number of replicate specimens. The use of replicate specimens should be between 3 to 5 units. This will assist to balance increased precision with the extra effort in taking more measurements and ensure homogeneity is not masked by repeatability error when characterising CRM.

Bias error was identified as the dominant component of uncertainty where PTV is greater than approximately 35 PTV. After a pendulum is calibrated, the instrument may drift with a negative bias due to changes in spring tension. This is problematic in the analysis of proficiency test results and will likely present false action signals for calibration laboratories; the use of CRM will assist to overcome this issue.

Two methods were identified to calibrate and make an adjustment to correct for bias error via the following methods:

- Slider force-deflection integral referenced to an ‘ideal pendulum’; and
- Predictive model realised through pendulum calibration input quantities

Both methods were shown to reduce bias and uncertainty where a combination of these two methods will likely provide the greatest benefit. In addition to a combination of these models, the force slider force-deflection curve of an *‘ideal pendulum’* should be realised to remove ambiguity and allow continual improvement in refining accuracy of the calibration method. This realisation should be based on characterising a number of pendulums (rather than the mid-point of the deflection curve) to simulate pendulums that are used in practice. This would likely reduce the potential for over or under correction. Further to this, the method of hanging weights at 4.5 mm deflection to characterise the effective spring tension should be removed for the following reasons:

- The slider under normal deflection across the path of travel will not exceed 4 mm, consequently, the calibration point on the measurement scale is outside the range of the pendulums normal operation.
- The value of 2.3 in the equation to correct for the effective spring tension is an unknown variable as the weight of the lever arm is unknown.
- The force deflection curve as required within CEN 16165 renders the *'hanging weights method'* redundant as multiple points of deflection are measured to characterise the force acting between the slider and the surface within the sliders path of travel during normal operation.

Calibration uncertainty was shown to reduce to an expanded uncertainty of 1 PTV for float glass and reference tile and 1.5 PTV for the PLF by constraining the tolerance limits for the input quantities (effective spring tension ± 0.3 N, pendulum arm mass ± 10 g, distance of centre of gravity to centre of rotation to ± 3 mm and performing five replicate measurements). Poorly built and maintained pendulums will generally be more difficult to comply with these tighter tolerances; however, there may be an opportunity to provide a two tiered system where two levels of uncertainty could be provided within CEN 16165 to provide a simple estimate of the calibration uncertainty.

The development of CRM for surface friction using the pendulum has been contextualised using ISO Guide 35 to establish metrological traceability. This framework is applicable to all tribometers and reference material and should be considered in future method development and standardisation. The use of CRM then provides good practice in calibrating a pendulum through an indirect method of comparison with an artefact or reference material as outlined within ISO Guide33.

5. REFERENCES

[1] CEN TS 16165 *Determination of slip resistance of pedestrian surfaces — Methods of evaluation,* European Committee for Standardisation, Brussels, 2016

[2] ISO Guide 33*, Reference materials — Good practice in using reference materials*, International Organisation for Standardisation (ISO), Geneva, 2015

[3] ISO 17025, *General requirements for the competence of testing and calibration laboratories*, International Organisation for Standardisation (ISO), Geneva, 2017

[4] JCGM 100, *Guide to the expression of uncertainty in measurement*, Bureau International des Poids et Measures (BIPM), Paris, 2008

[5] ISO 17034, *General requirements for the competence of reference material producers*, International Organisation for Standardisation (ISO), Geneva, 2016

[6] VIM 200, *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms*, Bureau International des Poids et Measures (BIPM), Paris, 2017

[7] ISO Guide 35*, Reference materials – Guidance for characterisation and assessment of homogeneity and stability*, International Organisation for Standardisation (ISO), Geneva, 2015

[8] AS 4586*, Slip resistance classification of new pedestrian surface materials*, Standards Australia (AS), Sydney, 2013

[9] AS 4663*, Slip resistance measurement of existing pedestrian surfaces*, Standards Australia (AS), Sydney, 2013

[10] Hiti and Ducman (2014). *Analysis of the slider force calibration procedure for the British Pendulum Skid Resistance Tester*. Measurement Science and Technology, 25, 1–9

[11] ASTM E691, *Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method*, American Society for Testing and Materials International (ASTM), West Conshohocken, 2016

[12] Strautins, Carl J (2007). *Enhanced Test Method for Assessing Sustainable Slip Resistance*, International Ergonomics Society Conference on Slips, Trips & Falls 2007: From Research to Practice, Boston USA.

[13] Strautins, C., (2008) *Sustainable slip resistance: An opportunity for innovation*, 10th World Congress on Ceramic Tile Quality, Castellon, Spain, Vol. 3, P.BC 381.

[14] ISO/IEC 17043, *Conformity assessment — General requirements for proficiency testing*, International Organisation for Standardisation (ISO), Geneva, 2010

[15] BS 7976-3:2002+A1:2013, *Pendulum testers. Method of calibration*, British Standards Institution (BSI), London, 2013

[16] ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*, International Organisation for Standardisation (ISO), Geneva, 1994, pp. 42

[17] ISO Guide 31*, Reference materials — Contents of certificates, labels and accompanying documentation*, International Organisation for Standardisation (ISO), Geneva, 2015

[18] ISO/TR 16476, *Reference materials — Establishing and expressing metrological traceability of quantity values assigned to reference materials*, International Organisation for Standardisation (ISO), Geneva, 2016

DETERMINATION OF THE SLIP RESISTANCE OF FLOORINGS FOR BAREFOOT AREAS

Dr.-Ing. Christoph Wetzel [1]

[1] Expert Committee Trade and Logistics, German Social Accident Insurance, Germany

c.wetzel@bghw.de

ABSTRACT

Swimming pools, showers and bathrooms are lurking with special slipping hazards. Floors are usually wet and people walk barefoot. Slip accidents occur regularly, which can be prevented in particular by slip-resistance floorings. A new European draft standard prEN 16165 containing various test methods for determining slip resistance will be published for survey at the beginning of 2020. One is a test method on an inclining ramp for determining the slip resistance of floorings used usually barefoot. The advantage of this method, besides the testability of all kinds of floors, is that the test promises the highest validity because the barefoot test conditions are very similar to the practical conditions of use. However, foot skin is not the same as foot skin, which affects the reliability and repeatability between different testers. An effective calibration and correction procedure is required. In the last years the test procedure was further developed and tested in CEN TC 339 at European level. In comparison to the previous version of technical specification, the draft standard introduces a new calibration and correction procedure for the test persons, which brings testing and calibration closely together and thus meets the challenges of this test method.

Keywords: slip resistance, ramp test method, barefoot area, calibration method, prEN 16165

Topic: Slip resistance of floorings for barefoot areas

1. INTRODUCTION

Swimming pools, showers and bathrooms are lurking with special slipping hazards. Floors are usually wet and people walk barefoot. Slip accidents occur regularly, which can be prevented in particular by slip-resistance floorings.

To evaluate the slip resistance of floors, suitable measuring methods are necessary which can determine the desired properties as precisely and as practically as possible. Under real conditions, a combination of floor, dirt, shoe or barefoot must always apply the necessary friction under the given environmental conditions. The variations in the possible states and characteristics are so high that each measuring system ultimately always represents a compromise.

For floors that are walked on barefoot, a test procedure should also use barefoot test persons or use the measurement results determined by barefoot test persons as a reference. So far, no artificial materials are known that reflect the anti-slip properties of foot skin on a high level. Since the human skin of the foot shows variations between different persons, a suitable correction procedure is necessary for a measuring system. This paper deals with the development of a correction procedure for slip-resistance test using barefoot test persons.

2. A NEW EUROPEAN STANDARD FOR THE DETERMINATION OF SLIP RESISTANCE

A new European draft standard prEN 16165 containing various test methods for determining slip resistance will be published for survey at the beginning of 2020. When the CEN/TC 339 committee started its work, the idea was to standardize a single European test method that would serve as a reference method. However, since there is no "all-in-one" method, the committee decided to combine several methods used in Europe into one standard. Different requirements for the test methods are taken into account and different physical-technical principles are applied:

- Annex A | Ramp test with barefoot test person
- Annex B | Ramp test with shoed test person
- Annex C | Pendulum test
- Annex D | Tribometer test

The aim of the new testing standard is to offer individual product-related TCs a selection of test methods from which they can select and, if necessary, define product-related minimum requirements, as well as to provide national interests such as occupational health and safety with a uniform European test basis for their requirements. This reduces the testing effort and simplifies the implementation of requirements for all interested parties.

3. DEVELOPMENT OF THE BAREFOOT-RAMP-METHOD

The focal point of this paper is the barefoot ramp test method, which is described in the Annex A of CEN/TS 16165 and prEN 16165:2020. In the last years the test procedure was further developed and tested in CEN TC 339 at European level. In comparison to the previous version of technical specification, the draft standard introduces a new calibration- and correction procedure for the test persons which affects the reliability and repeatability between different test persons.

3.1 Overview previous standards and specifications

The barefoot ramp method was subject to some changes as the calibration- and correction procedure was continuously improved. Table 1 shows an overview of the German and European standards, technical specifications and draft standards.

Table1: Overview over previous standards / specifications for barefoot-ramp

standard / specification	Result	Included verification / calibration / correction procedure
DIN 51097 : 1992 + other Standards that adopted this method	Flooring-**classification** A | B | C	**Verification** procedure with standard surfaces on the classification-limits, the test-flooring was mounted and tested together with the standard surfaces. Example: If a test-person reaches a higher angle than on the standard surface A (and less on standard surface B), the test-flooring result is classification "A".
CEN/TS 16165 : 2012	**Angle of slip** without correction	**Calibration** of the test-person: The test-person have to be in a defined tolerance on the standard surfaces; there is no correction calculated
CEN/TS 16165 : 2016 similar to E DIN 51097 : 2016	**Angle of slip** with correction	Uses a **calibration- and correction procedure** analogue to the Ramp-test with shoes. Before the test the test-persons measure all three standard surfaces and have to be in a defined tolerance. The difference to the standard values is used for a calculation of a correction
prEN 16165 : 2020 similar to E DIN 51097 : 2019	**Angle of slip** with correction after "Live-calibration"	Uses a new developed **calibration- and correction procedure**: The measures for the correction-values are directly next to test-surfaces

3.2 Important development of the calibration- and correction procedure

There are two main reasons why the original process had to be further developed. First, the verification surfaces were no longer available and new ones had to be found. On the other hand, the result was a classification based on requirements in Germany. However, the measurement method should give a concrete value which can then be used as proof of compliance with different national requirements in Europe and can also be used by manufacturers for their product development.

3.2.1 New Standard surfaces

In a research project lasting several years, new standard surfaces were found (see Figure 1) which allow a three-point calibration and can be used for a correction. They were tested in a German and a European round robin test and the standard values were determined.

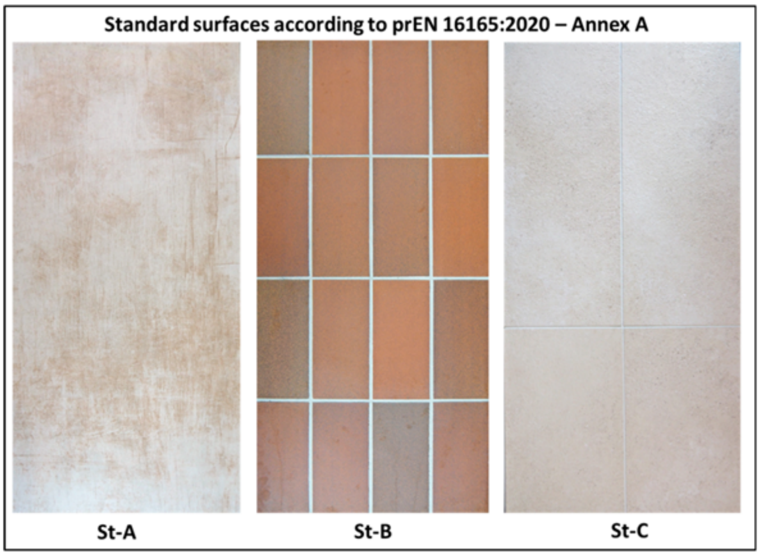


Figure 1: Standard surfaces St-A, St-B, St-C

3.2.2 New calibration procedure

The version of CEN/TS 16165 : 2016 introduced a three-point calibration and correction procedure analogous to the shoe test (Annex B). A test day in a test laboratory was carried out in such a way that first the three standard surfaces were tested and then the floors to be tested. The test sequence is shown schematically in Figure 2.

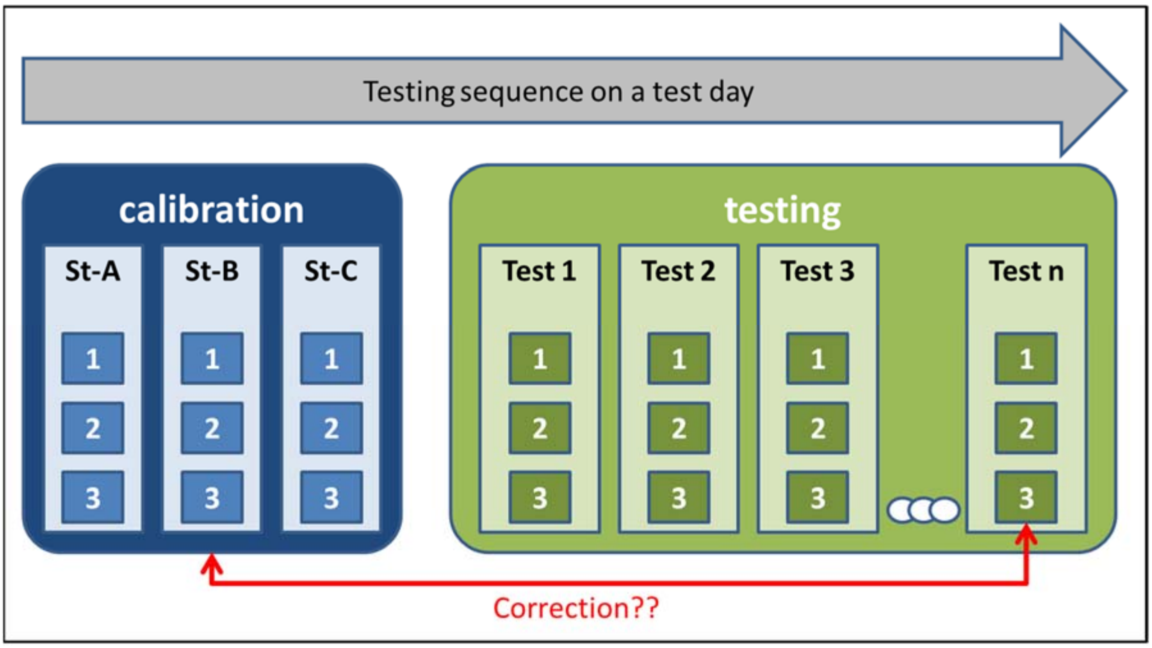


Figure 2: Test sequence according to CEN/TS 16165 : 2016

Experience with this method has shown that a time offset between calibration and test flooring can lead to falsifications. During the test the skin of the foot changes due to contact with water, which can lead to different measured values. As a result, it could happen that a measured value was corrected with a correction value based on a different condition of the foot skin.

For the conversion of CEN/TS 16165 into the European draft standard prEN 16165:2020, a new calibration and correction procedure was introduced which is divided into two parts: a check on general suitability or training, and a live calibration directly after a test floor.

Figure 3: Checking / Training of test persons, prEN 16165 : 2020

For training purposes, before the first test and at the latest every 2 months, the test person must prove his general suitability by lying within the normatively prescribed tolerance in the mean value over three measurements on the three standard surfaces (see Figure 3). This training or proof does not have to be carried out on every test day.

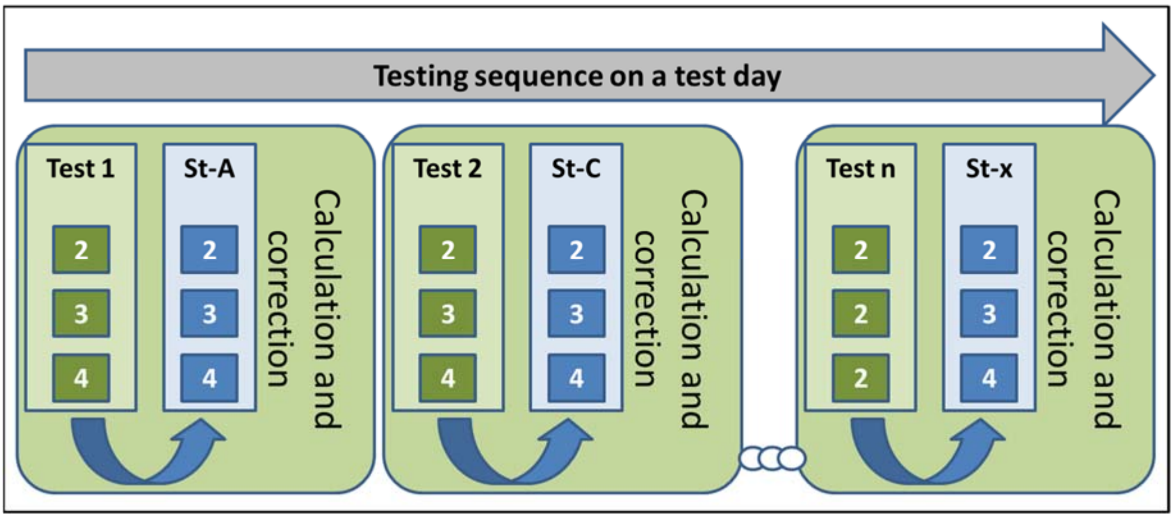


Figure 4: Live-Calibration and correction of values, prEN 16165 : 2020

On a test day, test floors and standard surfaces are used alternately (see Figure 4). A test sample to be tested is performed four times by the test person in accordance with the draft standard. The mean value is calculated from the last three measurements. Depending on the value range in which the mean value lies, one of the standard surfaces is mounted directly onto the inclinable ramp and also walked on four times. A correction value is calculated from the difference to the standard value in accordance with the draft standard and the result is calculated for a test person. This is followed by the next test sample with the corresponding standard surface depending on the result. It is possible that the same standard surface must be used several times in one day. This procedure minimizes the time lag between the test sample test and the calibration, so that the same status of the skin and the test person can be assumed. This reduces the measurement uncertainty and increases the comparability and reproducibility of the test method.

3.3 Further Improvements of Annex A in the new prEN 16165 : 2020

Some further points in the test procedure were further developed and incorporated, which will only be briefly mentioned here:

- The temperature of the test medium has been increased, so that on the one hand this corresponds more to the practical situations and on the other hand the ergonomics for the test persons can be increased and the feet can be more relaxed.
- Four measured values are determined and only the last three are evaluated, as experience has shown that the first value deviates statistically more often.
- The wetting agent was changed. The addition of a liquid wetting agent eliminates the risk of SDS dust when mixing the solution.
- The wetting agent is only used once and does not circulate, which avoids concentration due to evaporation.

4. DISCUSSION

The ramp barefoot test method has been continuously further developed in recent years. Experience has been gained which has been incorporated into new versions. After publication of EN 16165, an applicable standard will be available in 2021.

Bare-footed testing is certainly associated with increased measurement uncertainty and dispersion, which is not least shown by the relatively large tolerance ranges of the standard surfaces. Nevertheless, the validity is high, since this method depicts the real operating conditions, where other methods have to make much greater compromises.

The disadvantage is and remains that the process can only be used in the laboratory. Experience shows that cleaning agents and cleaning machines often change the anti-slip properties during the first cleaning after installation. Here the manufacturers are required to guarantee stable properties as well as the operators to maintain the floors properly. An additional mobile test method (tribometer, pendulum, or anything else) with a slider material that reproduces foot skin as well as possible would be desirable.

TECHNICAL SESSIONS (III)

Ergonomics, rehabilitation and assistance products.
Research & development of innovative products. Footwear

THE EFFECT OF GRAB BAR ORIENTATION AND USE STRATEGY ON FALL PREVENTION DURING CHALLENGING BATHING TASKS

Iris C. Levine[1], Konika Nirmalanathan[1,2], Rebecca M. Greene[1,2], Roger E. Montgomery[1], Alison C. Novak[1,2,3]

1 Toronto Rehabilitation Institute-KITE, University Health Network, Toronto, ON

2 Rehabilitation Science Institute, University of Toronto, Toronto, ON

3 Department of Occupational Science & Occupational Therapy, University of Toronto, Toronto, ON

iris.levine@uhn.ca

ABSTRACT

More than a third of fall-related emergency department visits in older adults occur due to incidents in the bathroom, while one in four bathroom-related injuries requires hospitalization. Grab bars are recommended to reduce the risk of falls during bathtub ingress, egress, and bathing; however, literature-based evidence regarding the position and use of grab bars is limited. This presentation will summarize results of four ongoing studies regarding the use of grab bars to prevent falls during challenging bathing activities: 1. Influence of grab bar orientation on balance recovery following a slip during bathtub egress in healthy younger and older adults, 2. Effect of grab bar orientation on biomechanical stability and fall risk while lowering to, and rising from, a bath seat, 3. Evaluation of the effectiveness of permanent and temporary grab bars to prevent falls in older adults with bathing disability, and 4. Probability of successful and effective grab bar grasp after unexpected slips during bathtub egress. Key outcome measures will include grab bar loading, grasp location, balance and fall risk metrics, and differences between proactive and reactive grasp strategies. These results have implications for bathroom design standards, prescription of grab bars to high-fall-risk populations, and development of technology and educational materials to reduce fall risk in bathing environments.

Keywords: grab bars, slips, contaminant, experimental, accessibility, aging

Topic: The role of Architectural Design; Ergonomics, rehabilitation and assistance products; Research & development of innovative products

1. INTRODUCTION

Bathroom navigation is an essential skill for maintaining independence as an older adult. However slippery floors represent mobility challenges during bathing. More than 35% of fall-related emergency department visits in older adults are the results of incidents in the bathroom (Rosen, Mack, & Noonan, 2013), and 25% of bathroom-related injuries require hospitalization (Stevens, Haas, & Haileyesus, 2011). Older adults, in particular, are four times as likely to suffer injuries in the bathtub or shower as young adults (Stevens et al., 2011).

To reduce the risk of falls during bathing, grab bars are recommended during bathing transfers, such as bathtub egress and rising from a bath seat; however, literature-based evidence regarding the position and type of grab bar is limited. Although there are standards and codes guiding grab bar installation, there is little empirical evidence to support these guidelines. Policies are generally based on perception of comfort, safety, and ease of use, and clinical experience, rather than effectiveness of the grab bar for fall prevention (Aminzadeh, Edwards, Lockett, & Nair, 2000; Guitard, Sveistrup, Edwards, & Lockett, 2011). Due to lack of legal requirement for a permanent grab bar affixed to the wall, some people who require a grab bar to support bathing transfers are forced to rely on temporary rim-mounted grab bars, bath seats, or non-purpose-built items to prevent falls. Additionally, there are few evidence-based clinical practice guidelines to assist occupational therapists in deciding how to implement grab bars.

To address these gaps, we devised four studies to evaluate grab bar effectiveness during bathing transfers: 1. Influence of grab bar orientation on balance recovery following a slip during bathtub egress in healthy younger and older adults, 2. Effect of grab bar orientation on biomechanical stability and fall risk while lowering to, and rising from, a bath seat, 3. Evaluation of the effectiveness of permanent and temporary grab bar to prevent falls in older adults with bathing disability, and 4. Probability of successful and effective grab bar grasp after unexpected slips during bathtub egress.

2. THE LABORATORY ENVIRONMENT

The studies took place in the General Purpose Lab of the Challenging Environment Assessment Laboratory in the Toronto Rehabilitation Institute (Toronto, Canada) (Figure 1). The lab is a modifiable 5.55 x 5.15m space, which can remain stationary or be affixed to a 6-degree-of-freedom motion base (Rexroth, Lohr a. Main, Germany) capable of producing translational motion to evoke perturbations. A custom-built weldment was designed to permit the installation of vertically-, horizontally-, and diagonally-oriented grab bars (3.8 cm diameter, enamel-coated steel) as well as a simulated bathroom wall without a grab bar. All grab bars were equipped with tri-axial load cells (1000 Hz; MC3A-6-1000, AMTI, Watertown, USA) on each end, for acquisition of applied forces. A customized bathtub was modified so that all edges of the bathtub were removed and replaced with a foam block (41 cm, coinciding with the rim height of the bathtub in its initial state) to replicate the bathtub's rim. The tub was mounted to a force plate (1000 Hz; BP12001200, AMTI, Watertown, USA), adjacent to the horizontal and vertical grab bars. A corrugated, white plastic sheet, backed by plywood was placed behind the grab bars to reduce contrast between the apparatus and the grab bars. Temporary grab bars were mounted to the foam wall via a bridge to allow independent force acquisition.

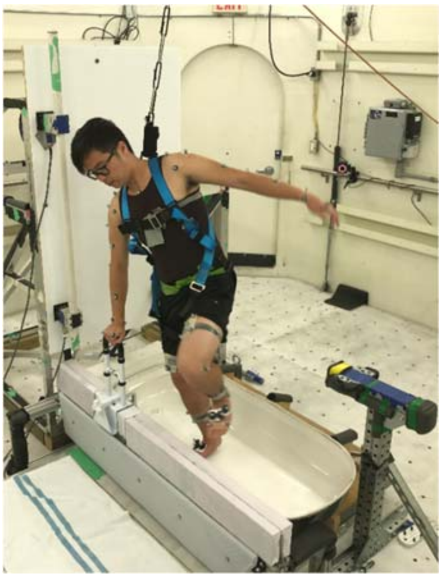
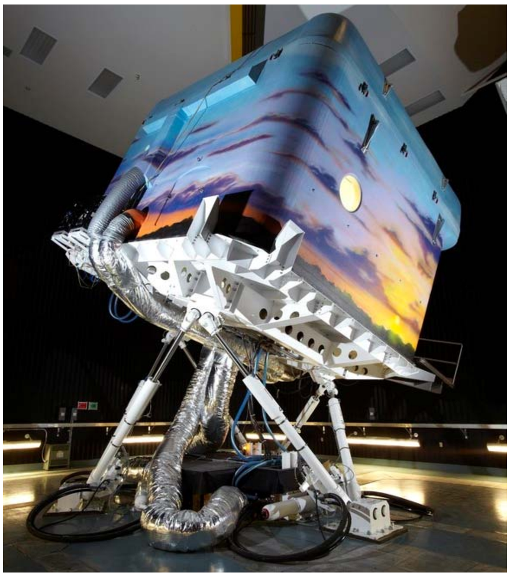
a)  b) 

Figure 1: The laboratory environment (a) is outfitted with a bathtub, which can be rotated so that a grab bar is along the control end of the bathtub or the back wall of the bathtub. Next to the bathtub is a wall, to which grab bars can be attached. A rim-mounted grab bar is demonstrated, with a vertical grab bar in the background. The lab can remain stationary, or it can be mounted on a 6-degree-of-freedom motion base (b).

One litre of diluted sodium lauryl sulfate (SLS) was used to simulate a realistic bathing environment. For Studies 2 and 3, 1 g SLS per litre of water was used in accordance with the British Standard Institution slip resistant test standard (BS EN 13845) to create a moderately slippery surface while maintaining the safety of participants with bathing difficulty. For Studies 1 and 4, 2 g SLS/litre was used, as it more consistently resulted in slips during pilot testing.

For bathtub ingress and egress tasks, participants wore a harness, tethered via a fall arrest line to a robotic overhead gantry (BerkelaarMRT, Delft, Netherlands) equipped with two load cells (250 Hz; LSB352-1000lb-FSH02101 & LSB210-5lb-QSH00487, Futek, Irvine, USA) to measure harness reliance. Harness reliance of over 30% body weight was categorized as a fall (Yang & Yi-Chung, 2011), while harness reliance between 10 (the system noise threshold) and 30% was categorized as a balance loss (i.e. a fall was likely to occur without harness assistance).

A 15-camera motion capture system (200 Hz; Motion Analysis Corp, Santa Rosa, USA) tracked body position via reflective markers. Four video cameras (30 Hz, FLIR Systems, Inc., Nashua, USA) collected overhead, front, back and side views of the participant during the tasks.

For studies in which a perturbation was delivered by the motion base, a laser sensor was affixed in line with the outer edge of the bathtub wall, such that when a participant lifted their leg over the wall and past the sensor, the perturbation (perpendicular to the direction of travel; 2m/s^2; peak velocity: 0.4 m/s; peak displacement: 0.08 m (Guitard et al., 2011)) was triggered.

3. STUDY 1: INFLUENCE OF GRAB BAR ORIENTATION ON BALANCE RECOVERY FOLLOWING A SLIP DURING BATHTUB EGRESS IN HEALTHY YOUNGER AND OLDER ADULTS

Crossing an obstacle, such as the bathtub rim, makes bathtub egress risky for older adults. Age-related physiological changes, such as reduced lower-extremity muscle strength, can affect older adults' ability to maintain balance during the task (Alexander, 1994; Kovacs, 2005). Proactive grab bar use, using a hand-in-place (HIP) strategy provides constant tactile feedback (Martinelli, Coelho, Magalhaes, Kohn, & Teixeira, 2015). A reactive reach-to-grasp (RTG) grab bar strategy requires rapid neural processing to target an effective grasp strategy and generate stabilizing moments. Both approaches (if successful) extend the base of support and reduce lower limb effort. While a variety of grab bar configurations are suggested in standards and codes to assist with bathtub egress, there is little scientific evidence to back these guidelines.

For this study, twenty younger adults (YA, 18-35 years) and 10 healthy older adults (OA, 65+ years) were recruited. All older adults (5 female) self-selected to complete the protocol using a HIP approach. Younger adults were continuously recruited until there were 10 who used a RTG approach (7 female), and 10 who used a HIP approach (5 female). Individuals exited the bathtub under three different grab bar conditions: (1) a low horizontal grab bar, 86.5 cm above the ground (2012 ADA Standards for Accessible Design #607 Bathtubs, cross-referencing section 609.4), (2) a high horizontal grab bar at 102 cm above the ground (based on findings from Batista et al., 2016), and (3) a vertical grab bar directly above the bathtub rim. The graspable length of the horizontal grab bar was 51 cm, terminating at the bathtub rim. The vertical grab bar was installed in accordance with the CSA Standards on grab bars and the Ontario Building Code (lower bound 35 cm above the bathtub rim, 85 cm graspable height). The order of grab bar conditions tested was randomized across participants. Participants entered and exited the bathtub several times, before a perturbation was introduced on a randomly-selected exit trial.

Using the vertical grab bar, all participants grasped the grab bar in a range of 75-106 cm above the bathtub rim. RTG participants grasped the grab bar an average (SD) of 8.7 (6.6) cm lower during the perturbation than their previous bathtub exit trials. Using the horizontal grab bars, participants grasped between the bathtub rim and 35.5 cm inside the bathtub, with no differences in age or strategy group. Grasp location was correlated with participant height only for young adults using a HIP strategy with the vertical grab bar (r^2=0.488, p=0.027).

No falls were observed, while four younger adult participants using a RTG strategy experienced balance loss during the perturbation trial. RTG participants experienced riskier centre of mass (COM) trajectories than participants with a HIP strategy, with greater downward and lateral (away from the wall) COM displacement for YA RTG than YA HIP (both p<0.01). Forward COM displacement was, on average, 2.9 cm greater when using the vertical grab bar than the high horizontal grab bar, and 3.5 cm greater when using the vertical grab bar than the low horizontal grab bar (both p<0.01). However, no differences in downward or lateral COM displacement were observed between grab bar orientations. The forward position of the vertical grab bar was equal to the most forward position of the horizontal grab bars (in line with the threshold of the bathtub). Participants may have grasped closer to their initial COM position with the horizontal grab bars, yet when forced to grasp forward of their COM with the vertical grab bar, they allowed the COM to displace forward during the perturbation, closer to the grab bar. However, across participants and strategies, the peak position of the COM was within 9 cm of the bathtub wall, within the expected base of support at foot contact by the leading leg.

Grab bar forces were directed primarily downwards and either away from or towards the wall, with a maximum resultant load of 394 N across all participants. The resultant force was significantly lower for the YA-RTG group than the YA-HIP group (p=0.001). RTG participants may have had less time to accurately target and generate stabilizing forces, or they may have already generated a large enough stabilizing force via the lower limbs by the time they grasped the grab bar. Lower forces were observed for the vertical grab bar than the low horizontal grab bar (p=0.012). Higher handrail grasp is linked to lower forces and greater stabilizing moments (Komisar , Nirmalanathan, King, Maki, & Novak, 2019), indicating that the vertical grab bar is more advantageous for maintaining balance than the low horizontal grab bar.

4. STUDY 2: EFFECT OF GRAB BAR ORIENTATION ON BIOMECHANICAL STABILITY AND FALL RISK WHILE LOWERING TO, AND RISING FROM, A BATH SEAT

Bath seats are used to prevent bathing-related falls by providing a more stable bathing posture, and allowing the user to focus on the bathing task rather than on standing balance. However during the sit-to-stand (STS) motion, grab bar use is linked to better anterior stability (in the direction of motion), but riskier frontal plane asymmetrical motion (O'Meara & Smith, 2006); a slippery bathtub floor may change the effectiveness or risks of grab bar use while transferring with a bath seat. Many bath seat designs include handholds within the seat pan to facilitate placement of the bath seat. A bather may choose to use handholds within the seat pan of the bath seat instead of a grab bar. In an experimental setting, participants preferred horizontal rather than vertical grab bars during STS (Batista, Bertani, & Young, 2016). Older adults reported a preference and perception of safety for horizontal and angled grab bars along the back wall of the bathtub (Sveistrup, Lockett, Edwards, & Aminzadeh, 2006). However, the effect of grab bar and seat pan handhold use on fall risk during STS bathing transfers has not been evaluated.

Eleven healthy older adults (6 female) and eight older adults with bathing difficulty (6 female) participated in this study. Participants with bathing difficulty met one or more of the following requirements: 1) identified as having trouble with bathing transfers, 2) a documented health issue such as joint replacement or balance disorder, or 3) achieved fewer than 60% of the maximum number of points on the Mini-BESTest. Participants completed the STS task with one of seven grab bar conditions, in a randomized order: 1) horizontal grab bar 86.5 cm off the floor (2012 ADA Standards for Accessible Design #607 Bathtubs, cross-referencing section 609.4); 2) 58.5 cm horizontal (2012 ADA Standards for Accessible Design #607 Bathtubs; 2017 Ontario Building Code, Section 3.8.3.13); 3) 45° incline (to fit a 24" (61 cm) grab bar between two 16" (40.5 cm)-spaced studs); 4) 60° incline (available in prefabricated angled designs); 5) Vertical (consistent with the vertical portion of the l-shape grab bar specified in the 2017 Ontario Building Code); 6) using only the seat-pan handholds, and 7) using no assistance. The task was completed using a backless bath seat, adjusted so that the seat pan was level with knee crease.

All participants completed trials using the high vertical, high horizontal, and 45° angled grab bars. Two participants declined to complete the 60° angled grab bar condition due to fatigue (for both cases, the 60° angled condition was last), while one participant refused to complete the low horizontal condition, and three participants refused to complete the no assistance or seat pan handhold conditions. Participants reported higher perception of task ease, safety and likelihood of grab bar use for the angled grab bars, citing hand and arm comfort, and feeling of greater stability and ease. Lowest scores for the same outcomes were reported for no assistance and seat pan handholds. Scores for the low horizontal and vertical grab bars were varied, with some participants reporting that the low horizontal and vertical grab bars felt as though they were in the wrong position (too low, too close) relative to the bath seat.

Participants grasped between 21-88 cm above the bath seat using the Vertical and 60° angled grab bar, but grasped lower (3-69 cm) using the 45° angled grab bar (p<0.05 for all comparisons).

Participant height was weakly positively correlated with grasp location for the vertical and 60° angled grab bar (for both vertical and 60° angled combined, r^2=0.147, p=0.011), but not the 45° angled grab bar. The steeper grab bars may have allowed participants to target the optimal vertical position for stability while standing, while they may have selected other strategies, such as grasping closer to the seated position, using the 45° angled grab bar. Participants selected different horizontal grasp locations for all grab bars (p<0.05) except high horizontal vs. 60° angled, and 45° angled vs. 60° angled. Participants grasped closest to the bath seat (the initial position of the COM) using the high horizontal grab bar and angled grab bars (0-32 cm), and furthest away using the low horizontal grab bar (13-44 cm, high vs. low). Height was negatively correlated with grasp location for the low horizontal grab bar (r^2=0.305, p=0.009), such that taller participants grasped closer to the bath seat, likely using a more flexed posture.

5. STUDY 3: EVALUATION OF THE EFFECTIVENESS OF PERMANENT AND TEMPORARY GRAB BAR TO PREVENT FALLS IN OLDER ADULTS WITH BATHING DISABILITY

While permanent grab bars represent a long-term solution, several barriers may prevent their use. Obstacles include cost (Arim, 2015), lack of funding from, or prohibition by insurance providers and government-funded programs (Gordon, Kerzner, Sheldon, & Hansen, 2007), the design and structure of a bathroom or the material of the bathtub walls, inability to install permanent accessibility features in rented homes (Bunn, Dickinson, Barnett-Page, Mcinnes, & Horton, 2008), a lack of perception they are required or relevant at a current life stage (Mahmood, Lee, Yamamto, & Steggell, 2007), and social stigma, design preference and age stereotyping (Thrall, 2012). When installation of a permanent grab bar is not feasible, potential solutions include temporary grab bars such as rim-mounted grab bars.

As an alternative to wall-mounted grab bars, temporary rim-mounted grab bars are designed to be attached to the bathtub rim. These grab bars are generally limited in height range, where the shorter grab bars require unstable postures and increased trunk flexion as the user reaches down to use them (King & Novak, 2017), posing challenges for dynamic balance. Taller temporary grab bars may accommodate taller users; however, since the rail extends vertically from a single attachment site at the bathtub rim, taller rails present longer moment arms than shorter rails resulting in greater moments-of-force when force is exerted on them by the user. In this study we aimed to compare applied loads and stability metrics during bathtub egress and STS transfers between temporary and permanent grab bars.

Seven participants with bathing difficulty (as qualified in Study 2; 6 females) and eleven healthy older adults (5 females) participated. Participants were asked to complete a bathtub exit task, and a STS task using a bath seat (described in Study 2), and 1) a permanently installed vertical (during exit) or horizontal (during STS) grab bar, 2) a rim-mounted grab bar adjusted to the highest position (RMH), or 3) a rim-mounted grab bar adjusted to the lowest position (RML).

Two participants declined to complete the bathtub exit task, and two participants declined to complete the STS task using RML. Participants with bathing difficulty applied 9.5% greater forces than healthy participants, across conditions and grab bars (p<0.001). Participants used 75% greater resultant force during the exit task than the STS task. During the exit task, loads were directed primarily downwards and towards the wall when using the vertical grab bar, and evenly across directions with the temporary grab bars. Participants applied 59% greater forces to the

RMH GB than the Vertical GB and 96% higher forces to the RML GB than the Vertical GB (both p<0.001). The greatest loads were applied to the RML GB, with a maximum resultant applied load of 285.7N. Greater loads applied to the temporary grab bars likely reflect less adequate stabilizing moments (Komisar et al., 2019). During the STS task, loads were directed downwards and towards the participant with the horizontal grab bar, and towards the participant with the temporary grab bars. This loading direction has the potential to cause the temporary grab bar to slide along the bathtub wall. In contrast with the exit task, the greatest loads were applied to the horizontal grab bar (63% greater than RMH, 67% greater than RML, both p<0.01). This may be interpreted as increased confidence, better mechanical advantage or more optimal hand position for the horizontal grab bar relative to the temporary grab bars.

6. STUDY 4: PROBABILITY OF SUCCESSFUL AND EFFECTIVE GRAB BAR GRASP AFTER UNEXPECTED SLIPS DURING BATHTUB EGRESS

Given the barriers discussed in Study 3, grab bars are frequently absent in the homes of adults with mobility impairments, representing a modifiable environmental hazard (Gill, Robison, Williams, & Tinetti, 1999). Codes Canada has recently submitted a public review for a proposed change to the National Building Code requiring grab bars to be installed in bathtubs and showers (https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-development-process/public-review/proposed_changes_index.html). However, the value of installing grab bars is questioned on a cost-benefit basis. While it is generally accepted that grab bars can prevent falls and reduce injury risk during a fall, currently there is no empirical data to support this, and therefore evidence to support cost-benefit analysis of grab bar installation is limited. The goal of this study was to evaluate the change in fall risk associated with the presence of a grab bar.

Sixty-three adults (18-45 years) participated in this study. Thirty-two participants (20 female) had a vertical grab bar available to them during a bathtub ingress/egress task (grab bar present-GBP), while thirty-one participants (18 female) did not (no grab bar-NGB). Participants were instructed to enter and exit the bathtub up to five times “to view their typical bathing pattern”, and were advised that a perturbation would be delivered after a practice session. However, a perturbation was delivered during a randomly selected egress trial during the practice session.

GBP participants were 75% less likely to experience harness support (fall and balance loss combined) during perturbations (p=0.034). However, there was no difference in fall frequency between GBP and NGB (p=0.323). Of 32 GBP participants, only 16 self-selected to use a HIP strategy. None of the participants who used a HIP strategy required any harness support during the perturbation. Of 16 participants who used a RTG strategy, only six (37.5%) were able to successfully grasp the grab bar.

GBP participants who were unable to successfully grasp the grab bar commonly experienced one of two errors: grasp accuracy errors, or inappropriate leading leg strategy. Grasp accuracy errors included reaching too far behind or ahead of the grab bar, hitting the grab bar, or hitting the wall surrounding the grab bar. The three participants who used a RTG strategy and experienced harness support all exited the bathtub with the right leg (the leg closer to the grab bar), which oriented the torso away from the grab bar during the perturbation. Expanding on this, participants who used a HIP strategy were 186% more likely to exit the bathtub with their left leg (i.e. turning towards the grab bar) than RTG participants. This points towards having a grab bar available on the side of the preferred leading leg as important for a successful RTG strategy. However, it should be noted that while 93.7% of participants in this study self-reported as right-side dominant, 52.4% used a left leading leg; therefore, preferred leading leg cannot be inferred from self-reported sidedness. Twelve NGB participants used, or attempted to use, the wall beside the bathtub for support, while one attempted to use the wall of the bathtub for support. Several participants attempted to grasp the edge of the wall beside the bathtub (as if it were a grab bar) during early trials, before being asked not to, suggesting that these participants might use a grab bar, or another graspable object (such as a towel bar) if it were available to them.

7. DISCUSSION

The goal of our project was to comprehensively evaluate how various aspects of bathroom grab installation can prevent falls in the bathing environment, and to understand how grab bars are used to assist people during challenging bathing activities. We found that risk of falls was minimal when participants had a grab bar available to them, and used the grab bar with a proactive hand-in-place strategy. Approximately 50% of younger adults, and 100% of older adults included in these studies opted to use grab bars, even when not instructed to. Additionally, we found that participants preferred grab bars with higher grasp heights, and selected grasp locations relative to their height, which may be linked to control of stabilizing moments.

Proactive HIP strategies appear to be a critical for fall prevention using grab bars. We found that a RTG strategy was linked to lower COM control, less successful grasping accuracy, and may require more force generation at the lower limbs to control loss of balance. While all of the older adults included in this study opted to use the grab bar, many older adults feel that a grab bar is unnecessary or unappealing for their stage of life (Mahmood et al., 2007; Thrall, 2012). Further, only 50% of younger adults used grab bars proactively. However, our “younger adult” group overlaps with an age group (41-60 years) recently identified as high risk for experiencing falls in bathrooms (Schellenberg et al., 2019). Additionally, while the rate of bathing-related injuries increases with age, the proportion of bathing-related injuries vs. other injuries in the bathroom is highest for younger adults under 25 years (Stevens et al., 2011). Therefore, installation and proactive use of grab bars should be targeted at younger adults, in order to destigmatize and normalize grab bar use.

In our studies, participants grasped between 75-106 cm above the bathtub rim during bathtub exit. Accordingly, a grab bar at the entrance to a bathtub should reach at least one meter above the bathroom rim, and extend low enough to be graspable by children, to support safe bathtub transfers. Further, participants grasped close to the bath seat horizontally, and 3-88 cm above the bath seat (or approximately 3-96 cm above the bathtub rim, accounting for bath seat height) during sit-to-stand. Higher, and potentially angled grab bars extending the length of the back wall would be supportive of bath seat use, as well as other bathing transfers such as traversing the length of the bathtub. These grab bars should be able to support a person during a fall. While in this study, the loads sustained by the grab bar were relatively low, it should be considered that the participants were wearing a safety harness for scenarios where a fall was likely to occur. The actual support required of a grab bar is likely much greater.

There are a few key limitations to this project. First, we have not yet evaluated suction cup grab bars. These grab bars can be placed in a variety of positions, however, their structural strength is assumed to be extremely low. It would be valuable to understand how people use these versatile, but potentially unstable grab bars. Second, in Study 3, we permanently affixed the temporary grab bars to the load cell bridge structure in order to evaluate how participants applied forces to the grab bars. However, in an actual bathing environment, the temporary grab bar would not be bolted to the bathtub rim. The results of this study should be considered under this light, and further research to understand the limitations of this fixation method is warranted. Finally, we conducted all studies using a single, standard bathtub. However, the coefficient of friction of the underfoot surface is a critical component of understanding and predicting falls during bathing activities. Accordingly, it would be valuable to evaluate bathing tasks with varying bathtub surface materials to understand how prevention of slips, in conjunction with grab bar use, affects fall risk.

In sum, grab bars are a critical component of fall prevention. Optimal location, orientation and position of grab bars differs between bathtub exit and sit-to-stand tasks. Therefore, we recommend a minimum of one grab bar at the bathtub entry point, and one grab bar along the back wall. Finally, proactive grab bar use is critical for fall prevention at all ages, and should be encouraged and destigmatized to reduce the rate of falls in bathrooms.

8. ACKNOWLEGEMENTS

The authors would like to acknowledge CIHR Project Grant funding for this research, AGE-WELL, The Government of Ontario, NSERC, Toronto Rehabilitation Institute and the University of Toronto for their funding of student fellowships, TRI-KITE and the Ontario Ministry for Seniors and Accessibility for honouring the research with the Focus on Accessibility Award, and Abishesh Homagain, Allegra Gracile, Mackenzie Collins and Victor Tran for their assistance with data collection.

9. REFERENCES

Alexander, N. (1994). Postural control in Older adults. *Journal of the American Geriatrics Society, 42*(1), 93-108.

Americans With Disabilities Act (2012). Standards for Accessible Design #607 Bathtubs.

Americans With Disabilities Act (2012). Standards for Accessible Design #609.4 Position of Grab Bars.

Aminzadeh, F., Edwards, N., Lockett, D., & Nair, R. (2000). Utilization of bathroom safety devices, patterns of bathing and toileting, and bathroom falls in a sample of community living older adults. *Technology and Disability, 13*, 95-103.

Arim, R. (2015). *A profile of persons with disabilities among Canadians aged 15 years or older, 2012*: Statistics Canada= Statistique Canada.

Batista, N. A., Bertani, L. F. B. B., & Young, J. G. (2016). *Handhold location and utilization during bathtub ingress/egress and sit-to-stand tasks: a pilot study.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Bunn, F., Dickinson, A., Barnett-Page, E., Mcinnes, E., & Horton, K. (2008). A systematic review of older people's perceptions of facilitators and barriers to participation in falls prevention interventions. *Ageing and Society, 28*, 449-472.

Canadian Standards Association (2018). CSA B651-12 “Accessible Design for the Built Environment”

Gill, T., Robison, J., Williams, C., & Tinetti, M. (1999). Mismatches Between the Home Environment and Physical Capabilities among Community-Living Older Persons. *Journal of the American Geriatrics Society, 47*(1), 88-92.

Gordon, P., Kerzner, L., Sheldon, T., & Hansen, E. (2007). *Assistive Devices in Canada: Ensuring inclusion and independence*. Retrieved from Toronto, ON:

Guitard, P., Sveistrup, H., Edwards, N., & Lockett, D. (2011). Use of Different Bath Grab Bar Configuration Following a Balance Perturbation. *Assistive Technology, 23*, 205-215.

King, E., & Novak, A. (2017). Effect of Bathroom Aids and Age on Balance Control During Bathing Transfers. *The American Journal of Occupational Therapy, 71*(6), 1-9.

Komisar , V., Nirmalanathan, K., King, E., Maki, B., & Novak, A. (2019). Use of handrails for balance and stability: Characterizing loading profiles in younger adults. *Applied Ergonomics, 76*, 20-31.

Kovacs, C. R. (2005). Age-Related Changes in Gait and Obstacle Avoidance Capabilities in Older Adults: A Review. *The Journal of Applied Gerontology, 24*(1), 21-34.

Mahmood, A., Lee, M., Yamamto, T., & Steggell, C. (2007). *Babyboomers' perceptions of gerotechnology.* Paper presented at the Proceedings of the 2nd International Conference on Technology and Aging, Toronto, ON.

Martinelli, A. R., Coelho, D. B., Magalhaes, F. H., Kohn, A. F., & Teixeira, L. A. (2015). Light touch modulates balance recovery following perturbation: from fast response to stance restabilization. *Experimental Brain Research, 233*(5), 1399-1408.

O'Meara, D. M., & Smith, R. M. (2006). The effects of unilateral grab rail assistance on the sit-to-stand performance of older aged adults. *Human movement science, 25*(2), 257-274.

Ontario Building Code (2015). O. Reg. 332/12: BUILDING CODE Showers and Bathtubs 3.8.3.13.

Rosen, T., Mack, K. A., & Noonan, R. K. (2013). Slipping and tripping: fall injuries in adults associated with rugs and carpets. *Journal of injury and violence research, 5*(1), 61.

Schellenberg, M., Inaba, K., Chen, J., Bardes, J. M., Crow, E., Lam, L., . . . Demetriades, D. (2019). Falls in the bathroom: a mechanism of injury for all ages. *Journal of surgical research, 234*, 283-286.

Stevens, J. A., Haas, E. N., & Haileyesus, T. (2011). Nonfatal bathroom injuries among persons aged≥ 15years—United States, 2008. *Journal of safety research, 42*(4), 311-315.

Sveistrup, H., Lockett, D., Edwards, N., & Aminzadeh, F. (2006). Evaluation of bath grab bar placement for older adults. *Technology and Disability, 18*(2), 45-55.

Thrall, P. (2012). *Perceptions of residential grab bars among community dwelling seniors*. Retrieved from

Yang, F., & Yi-Chung, P. (2011). Automatic recognition of falls in gait-slip training: Harness load cell based criteria. *Journal of Biomechanics, 44*(12), 2243-2249.

APPLICABILITY OF IOT TECHNOLOGIES AS A DIGITAL TOOL FOR THE EVALUATION OF THE USE OF SAFETY FOOTWEAR

Alberto Villarino[1], Alberto Benito[1], Javier Caridad[2], Jose Ignacio Villarino [1] Miguel Ángel Casanova[2], Alejandro Alañon[1],

[1]Department of Construction and Agronomy, Construction Engineering Area, High Polytechnic School of Ávila, University of Salamanca, Hornos Caleros, 50, 05003 Ávila, Spain.

[2]AlfaIOT - Automatización del Internet de las Cosas SL, Av. Campoamor, 30, Bajo, 37003 Salamanca, Spain.

avillarino@usal.es

ABSTRACT

Nowadays there are circumstances where, due to negligence of the worker or the promoter, ignorance or forgetfulness, mandatory safety footwear that meets the characteristics for the realization of certain jobs is not used. These circumstances take place in numerous and varied activities, for example both industrially, logistically and in the construction sector.

The consequences of not using appropriate footwear correctly range from slips, trips and falls to bumps, fractures, burns, electric shocks, or partial or total amputation of the foot, which may even result in a temporary or permanent disability of the employee.

In compliance with current regulations, the company is obliged to monitor the correct use of mandatory safety footwear. Currently this surveillance is carried out visually by technician or prevention responsible, being this method in numerous occasions ineffective and of anachronistic character, not having technologies available that, automatically and remotely, allow them to detect if a worker makes proper use of safety footwear.

Therefore, a study is proposed to assess the potential, applicability, and scope offered by IIoT (Industrial Internet of Things) and the standards of 4.0 industry for the development of a system based on simple digital tools, of low cost, that control and monitor, automatically, remotely, and in real time, the use of mandatory safety footwear, and therefore avoid the damages mentioned above. This will allow modernization and improvement of control and surveillance systems in the area of occupational safety, with measures that avoid and / or minimize the consequences of accidents and labour incidents due to the inappropriate use of safety footwear.

Keywords: Safety footwear, Slips, Trips, Personal Protective Equipment (PPE), IIoT, Industry 4.0

Topic: Footwear, fall prevention.

1. INTRODUCTION

Innovations in safety at work are limited to improving the ergonomics of PPE, without innovating functionalities and control. For instance, safety footwear with reinforced toecap remains basically the same since its appearance, but without having received a major technological innovation in its conception [1]. And the consequences of not wearing the right safety footwear include multiple injuries to the foot from crushing, impacts, fractures, burns, and electrical shocks to slips that can cause major injuries to other parts of the body [2], which may even result in temporary or permanent disability of the worker. Such circumstances occur in many and varied work activities where there is, for example, electrical, mechanical, chemical, thermal risk, etc., both at the industrial level and in factories in the metallurgical, iron and steel or automotive sectors, as well as at the logistical level, in distribution and storage centres involving a continuous flow of loading and unloading of different types of materials [3]. According to the latest data from the Occupational Accident Statistics published by the Ministry of Labor, Migration and Social Security, in 2018, 28.7% of all disability claims worldwide involved foot injuries [4].

The main problem is that there are circumstances where, due to the recklessness of the worker or the employer, ignorance or simple forgetfulness, the appropriate safety footwear is not used. And in compliance with the regulations in force [5], the company is obliged to monitor the correct use of PPE.

But at present, this surveillance is carried out visually by the prevention technician, who has no system that automatically and remotely detects whether a worker is wearing safety footwear. This task of supervising the prevention technician is made difficult on numerous occasions, due to the large number of existing workers, the size of the work centres and/or the multitude and variety of different types of obligatory PPE in certain work areas. This fact opens the door to the study of technologies that allow for the modernisation of occupational risk prevention and the control of PPE. Especially in today's world that is moving towards continuous quantification and monitoring of our environment and our activities, following the standards of Industry 4.0 and IIoT (Industrial Internet of Things) [6].

Small sensorized and connected devices (commonly known as IoT or Internet of Things) allow us to access numerous sources of information in a simple and economical way. All this information, properly treated with statistical techniques of massive data analysis (Big Data), allows us to analyze a series of information and data with which to generate new knowledge and give answers to situations that currently do not have them. In addition, to show everything to the end user, there are many tools based on new information and communication technologies (ICT) that allow to reach the end user in a more agile way [7].

All this allows to improve in a significant way costs, processes, agility and capacity of reaction and prediction of events.

The figure 1 shows the new value structure generated using new IoT technologies.

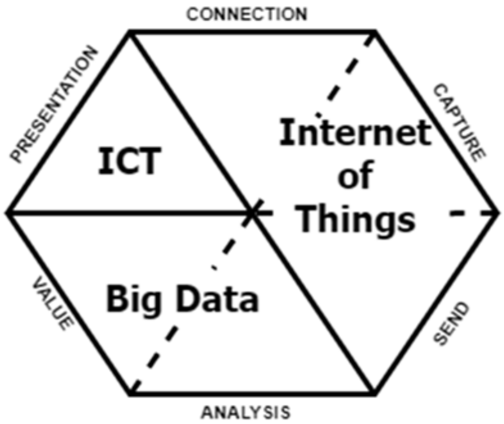


Figure 1: Structure generated using new IoT technologies.

This whole new paradigm has allowed science and technology, through computer science, to have increasing applicability and acceptance in our society. Samples of this can be seen in new applications such as sustainable management of resources, maintenance, urban services, and health. Numerous studies show that the use of these technologies is in full adoption and growth among companies in all sectors [8] [9].

For the analysis of technologies that allow the control of safety footwear, its characteristics must be previously studied. On the one hand, PPE may be used in multiple work environments with different types of floors and pavements, and on whose surfaces products of all types derived from production processes may be found, such as chemical agents, oils, water, steel burrs, abrasives and solvents. On the other hand, it is a safety element that suffers continuous wear during practically the entire working day, in addition to being designed to withstand efforts and blows of a certain intensity. [10] These characteristics of safety footwear make it necessary to control it with technologies whose identification systems are safe, robust, and allow for biunivocal identification.

Figure 2 shows the different communication protocols of the IoT devices. It shows a double-entry table showing the range of action versus consumption required.

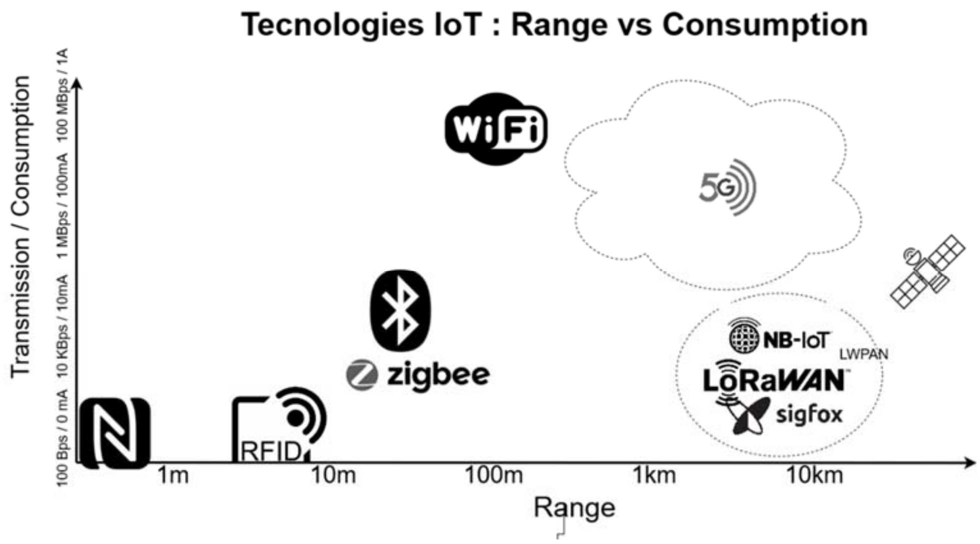


Figure 2: Communication protocols of the IoT devices

As can be seen, there are two technologies that facilitate the use of passive devices, essential for not hindering the daily life of companies and users. Both NFC and RFID allow the identification of users as well as the protection equipment they carry, however, the use of NFC would imply that users must make a registration on a voluntary basis and ensure that the system performs the readings correctly [11].

2. PROPOSED SYSTEM

Figure 3 describes the architecture of the application in charge of monitoring the use of safety footwear by workers. The system uses passive RFID tags under the ISO/IEC 18000-6C standard working at 868MHz that are placed on the footwear of the workers in this way is identified in a biunivocal way. At the accesses to the work areas, directional RFID antennas are placed in charge of reading the identifiers of the boots. These antennas with a range of up to 10m are placed on the roof or integrated into the floor. All workers are identified in this way as well as the safety footwear they wear. The antenna sends the information that is processed by the servers and stored in the database. In the application layer, the characteristics of the areas that need to be controlled, the type of safety footwear, and access times are established. These characteristics are stored in the same way in the database and the server oversees crossing the data between the restrictions of the zone and the properties of the selected safety footwear.

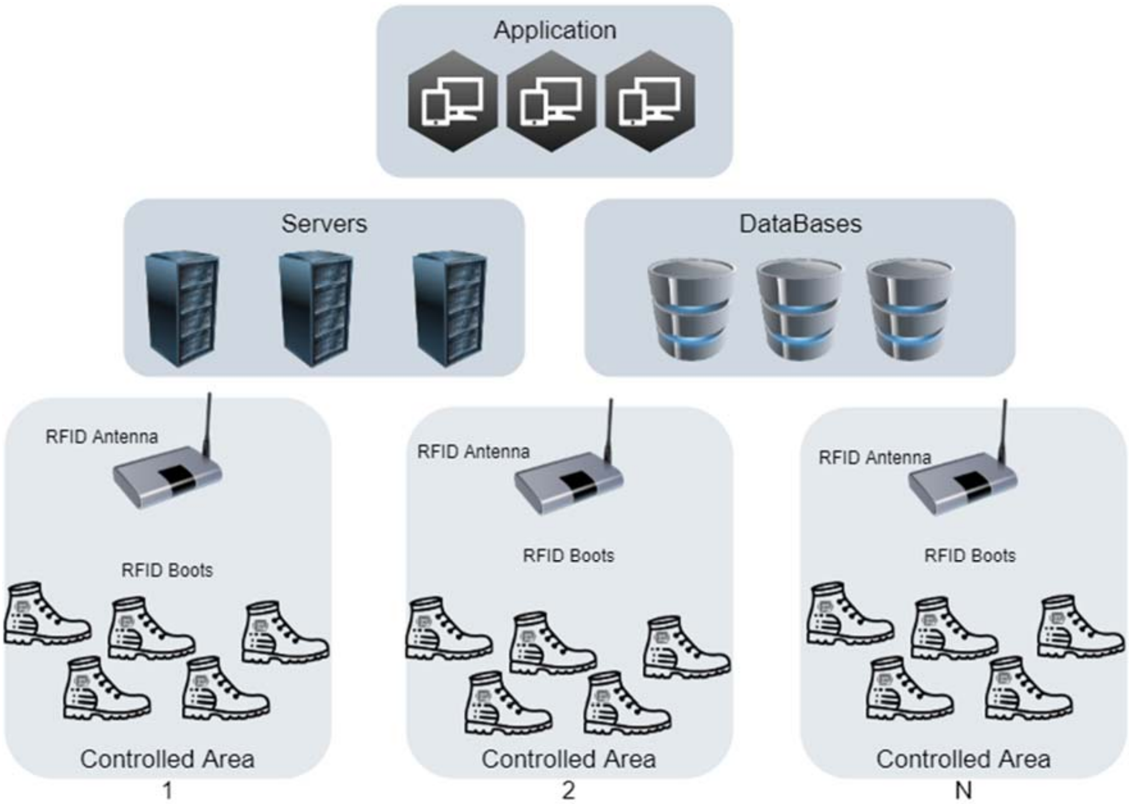


Figure 3: Architecture of application to monitor safety footwear

The proposed system can be incorporated as an information layer to limit access to restricted areas and force the use of the safety footwear established for each zone.

3. SYSTEM VALIDATION AND RESULTS

The results provided by the RFID technology, as an application to the control of safety footwear at work, will inform us about the use that workers make of the safety footwear. On the one hand, it will identify in a biunivocal way safety footwear - worker with remote, automatic and real time alert of such circumstance.

For the identification, an antenna with circular polarization has been used since it allows a wide range of operation distance as well as a better identification of the different tags in simultaneous conditions.

As shown in Table 1, the circularly polarized antennas provide an unbeatable range-failure ratio. Therefore, they are implemented in the system because in the case of use it is very important to limit the error rate or lack of readings.

Table1: Circularly polarized antennas

Antenna polarization	Max. detection	Range (>75% readingssuccess)	Rate (tags/s)	% Fails
Monopole	8m	0-6m	10	10%
Yagi	16m	0-12m	12	10%
Circular	12m	0-10m	12	2%

In addition, using the system, data will be obtained on traceability, time of use of safety footwear by each worker, as well as records of safety footwear efficiency. The data obtained will allow to extract knowledge about the wear that the footwear suffers, both of the external coating and of the sole, data that can be analysed with the type of work to be done, as well as with the surface where the work is developed. This will make it possible to obtain data relating the wear and tear of safety footwear soles to the type of flooring and the accident rate of the workers.

Obtaining with its information based on the use of the footwear in the real scope of work and real data of the quality of the safety footwear and its useful life.

At a logistic level it will allow the control of the stock according to the state of wear as well as the study of the amortizations.

In a complementary way, there will be a dissuasive effect and an awareness of the workers of their own safety and that of their environment, as a consequence of the perception of an automatic and digitalized control, being able to implement systems of gamification in which the users are rewarded for the correct use of the safety footwear (or penalized in the opposite case).

This will minimise and/or prevent non-compliance with existing safety regulations. In addition, compensation for temporary sick leave and permanent disability due to damage to the foot carries a high monetary cost, both for companies and the State.

4. CONCLUSIONS

The potential and scope offered by the Industrial IoT technology (Industrial Internet of Things) and the standards of the industry 4.0 make possible the study of its applicability in the control of the safety footwear.

The architecture designed around RFID technology will allow the design of a digital and low-cost system that wirelessly connects the work areas and the worker's protection and safety footwear, so that it detects if the footwear is being used when accessing the areas of mandatory use.

In addition, statistics on the use of safety footwear can be analysed to infer safety situations and commitments in advance through statistical analysis and implementation of machine learning techniques, enabling early response and improvement of safety conditions in working environments.

Providing companies and industries with a tool that, in a digital and automated way, modernises and improves control and surveillance systems in the field of safety at work. This will make it possible to avoid and/or minimize the consequences of accidents and incidents at work that take place in large and prominent industrial sectors.

This solution can be integrated into any industrial complex, regardless of its infrastructure or logistics, and will have an immediate and direct impact on occupational safety, on the reduction of occupational accidents, their severity and on the awareness of workers.

5. REFERENCES

[1] Dobson, J. A., Riddiford-Harland, D. L., Bell, A. F., & Steele, J. R. (2017). Work boot design affects the way workers walk: A systematic review of the literature. Applied ergonomics, 61, 53-68.

[2] Kirk, P., & Parker, R. (1994). The effect of spiked boots on logger safety, productivity and workload. Applied ergonomics, 25(2), 106-110.

[3] Hintikka, N. (2011). Accidents at work during temporary agency work in Finland–Comparisons between certain major industries and other industries. Safety science, 49(3), 473-483.

[4] Ministerio de trabajo migraciones y seguridad social (2018). Estadisticas de accidentes en el trabajo. Madrid: Subsecretaria Secretaria General Técnica. Subdirección general de estadistica y analisis sociolaboral.

[5] del Estado, B. O. (1995). Ley 31/1995, de 8 de noviembre, de Prevención de Riesgos Laborales. Boletín Oficial del Estado, 10, 32590-32611

[6] Wollschlaeger Martin, Sauter Thilo, Jasperneite JürgenRecent (2017). Trends in Automation Technology The Future of Industrial Communication Automation Networks in the Era of the Internet of Things and Industry 4.0. IEEE Industrial Electronics magazine, 11, 17 – 27.

[7] Jayavardhana Gubbi, Rajkumar Buyya, Slaven Marusic, Marimuthu Palaniswami.(2013) Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems.29. 1645-1660.

[8] Lozano Á., Caridad J., De Paz J., Villarrubia González G., Bajo J. (2018) Smart Waste Collection System with Low Consumption LoRaWAN Nodes and Route Optimization. Sensors, 18(5), 1465.

[9] T. N. Pham, M. Tsai, D. B. Nguyen, C. Dow and D. Deng. (2015). "A Cloud-Based Smart-Parking System Based on Internet-of-Things Technologies," in *IEEE Access*, vol. 3, pp. 1581-1591.

[10] Leclercq, S. (1999). The prevention of slipping accidents: a review and discussion of work related to the methodology of measuring slip resistance. Safety science, 31(2), 95-125.

[11] Defu Liu, Guowu Yang, Yong Huang, and Jinzhao Wu. (2019). “Inductive Method for Evaluating RFID Security Protocols,” Wireless Communications and Mobile Computing, vol. 2019, 8 pages.

ANALYSIS OF TEST METHODS TO DETERMINE FOOTWEAR SLIP RESISTANCE ON MELTING AND COLD ICE SURFACES

Chantal Gauvin[1], Yue (Sophia) Li[2], Atena Roshan Fekr[2,3], Tilak Dutta[2,3]

[1] IRSST (Institut de recherche Robert-Sauvé en santé et en sécurité du travail)

[2] KITE-Toronto Rehabilitation Institute, University Health Network (TRI-UHN)

[3] Institute of Biomaterials and Biomedical Engineering, University of Toronto

chantal.gauvin@irsst.qc.ca

ABSTRACT

Workers from the Nordic countries who perform activities outdoors rely on their safety boots to prevent them from slipping. A project was carried out to evaluate the ability of a mechanical test method, using the SATRA STM603 whole shoe tester, to measure the coefficient of friction (COF) on ice surfaces comparing to a human-centred test method developed by KITE-TRI-UHN, the Maximum Achievable Angle (MAA) method. The study was conducted in three phases: (1) evaluation of the repeatability and reproducibility of the mechanical method at two laboratories, (2) comparison of the mechanical and MAA results, and (3) investigation of which method is most likely to reflect real-world slip risk using a motion tracking system for gait analysis and slips detection. For melting ice, the COFs of 10 boots obtained from the mechanical method were statistically equivalent between the two labs and showed good agreement with the MAA results. For cold ice, although the footwear ranking was equivalent, a systematic bias in COF values was observed between mechanical tests of the two labs. However, the mechanical method did not show good agreement with the MAA method on cold ice, both in COF values and boot ranking. Moreover, the outcomes from gait analysis showed better agreement with the MAA results than with the mechanical method results. This study highlighted the challenges of developing a mechanical method that is reproducible and has the ability to estimate the slip resistance of the footwear that is comparable to the human-centred testing methods, especially on cold ice.

Keywords: Slips, coefficient of friction, ice surface, footwear, test method

Topic: Footwear

DOES SLIP RESISTANT WINTER FOOTWEAR REDUCE SLIPS AMONG OUTDOOR WORKERS ON SNOW AND ICE?

Li, Y.[1], Morrone, K.[1,2], Bagheri, Z.S.[1], Patel, N.[1,3], Levine, I.[1]

[1] The Kite Research Institute, Toronto Rehabilitation Institute, University Health Network, Toronto, Canada

[2]Department of Mechanical and Industrial Engineering, University of Toronto, Toronto, Canada

[3]Department of Kinesiology, University of Waterloo, Waterloo, Canada

Yue.li@uhn.ca

ABSTRACT

Slip-and-fall incidents are the leading cause of occupational injuries in worker groups exposed to outdoor winter conditions. The Research team from the Toronto Rehabilitation Institute-University Health Network (TRI-UHN) worked alongside an organization's Health and Safety Team to evaluate two types of slip-resistant winter footwear in winter. The intervention group were provided with a pair of one-snowflake rated slip resistant winter footwear (www.ratemytreads.com). The control group wore their usual footwear to work, but were provided with a pair of one-snowflake rated slip resistant winter footwear at the end of their participation in the trial. The primary outcome in this study is the incidence rate of self-reported slips, not necessarily resulting in a fall or injury, in the workplace over a two-month period (January-March). The results demonstrated that the rate of slips significantly dropped for the participants wearing one-snowflake rated slip resistant winter footwear compared to the ones wearing their own footwear. In order to reduce the risk of slip-related injuries caused by slipping on ice and snow, we recommend outdoor workers to wear slip resistant winter footwear during the winter season. We also recommend that footwear industries should seek practical strategies to produce a type of safety footwear for use in cold climates that incorporates both slip-resistance and comfort factors holistically. It is also important to develop a wear indicator on footwear (like those on tires) and a large-scale wear effect study is needed to determine how often footwear should be replaced.

Keywords: winter, footwear, workers, slip-resistance, wear-effect, comfort

Topic: slipping on ice and snow

1. INTRODUCTION

Slips and falls are the leading cause of injuries for workers exposed to outdoor winter conditions. Slip-resistance of footwear plays an important role in reducing the risk of slip and fall-related injuries [1]. However, outdoor workers exposed to winter conditions have not had access to valid slip-resistance testing information for winter footwear [2]. A human-centred test method has been developed to evaluate footwear slip resistance on ice surfaces using WinterLab at the Toronto Rehabilitation Institute – University Health Network (TRI-UHN). This test method, called the Maximum Achievable Angle (MAA) test, measures the steepest incline, covered in ice, which participants can walk up and down without experiencing a slip. Using these test results, a rating system for outdoor winter footwear has been developed for customers (www.ratemytreads.com).

The performance of the slip resistant winter footwear in the real world needs to be evaluated through a field test. The field evaluation results, therefore, could be used to further validate the MMA method as a measurement of footwear slip-resistance. The Research team from the Kite Research Institute at Toronto Rehabilitation Institute-University Health Network (TRI-UHN) worked alongside an organization's Health and Safety Team to evaluate two types of slip-resistant winter footwear in winter. The intervention group was provided with a pair of one-snowflake rated slip resistant winter footwear (www.ratemytreads.com). The control group wore their usual footwear to work, but were provided with a pair of one-snowflake rated slip resistant winter footwear at the end of their participation in the trial. The primary outcome in this study is the incidence rate of self-reported slips, not necessarily resulting in a fall or injury, in the workplace over a two-month period (January-March).

2. METHODOLOGY

A total of 304 outdoor workers were contacted by the Health and Safety Team and 253 of them agreed to participate and were recruited for the field evaluation. Each worker was to wear the One-Snowflake-Footwear1, One-Snowflake-Footwear2 or winter footwear of their choice (control group) and answer six questionnaires regarding their perceptions of the footwear throughout the evaluation period. The workers were asked to wear their selected footwear and go about their daily work activities and not expected to alter their behaviour or path of travel. Consent forms were sent to all participants and upon completion of the consent form, they were sent the introductory questionnaire, which asked participants to report how their previous winter footwear performed in the two months prior to the start of the study.. After the introduction questionnaire, four surveys were distributed in two-week intervals to gather the participants' experience with their winter footwear. Participants were asked to report how their study footwear (One-Snowflake-Footwear1, One-Snowflake-Footwear2, or their own footwear) performed in a two-week period. If a slip did occur during this period, they were to describe the event. After 8 weeks, a final questionnaire was sent to participants and ask them to report how the footwear performed overall during the two-month evaluation period. The final questionnaire followed the format of the introductory questionnaire.

3. RESULTS

The introductory questionnaire asked questions based on winter footwear experience two months prior to receiving the assigned footwear. The average numbers of slips per participant were not significantly different between all three groups in the introductory survey. This is expected as the respondents were not assigned either One-Snowflake-Footwear1 or One-Snowflake-Footwear2 footwear at the time of the introductory survey and they were asked to answer about their experience for the past two months with their own footwear. Therefore, we expected that the three footwear groups would experience a similar rate of slips and the survey results confirmed that there was no significant difference between all three groups in the introductory survey.

However, the average numbers of slips per participant were significantly higher in the Control group than in One-Snowflake-Footwear1 group or One-Snowflake-Footwear2 group for the Biweekly 1, Biweekly 4 and final surveys. There was no significant difference between One-Snowflake-Footwear2 and One-Snowflake-Footwear1 groups for all the 4 Biweekly surveys as well as for the final survey. These results showed that One-Snowflake-Footwear1 and One-Snowflake-Footwear2 footwear were equally effective in preventing slips and both provide better traction compared to participants' own pairs of footwear (Control).

According to the participants' perception of the role of their assigned shoes in causing the fall, both types of intervention footwear were rated as less important in comparison to the control group. Fourteen percent of participants in the control group believed that their shoes were very to extremely important in causing the fall as opposed to only 5% in One-Snowflake-Footwear2 and 0% in One-Snowflake-Footwear1 group. Similarly, the majority of participants in the intervention groups (One-Snowflake-Footwear1=83%, One-Snowflake-Footwear2=66%) thought their assigned footwear was very to extremely resistant to slipping as opposed to the control group (41%). As a result, they are very to extremely effective at preventing slips (One-Snowflake-Footwear2=69%, One-Snowflake-Footwear1=74%). In addition, most of the respondents believed that the intervention footwear was less slippery than their own footwear, with no statistical difference between the two assigned footwear (One-Snowflake-Footwear1= 76%, One-Snowflake-Footwear2= 57%, p=0.125).

The final survey was conducted at the end of the study and mainly focused on the questions regarding participants' perceptions of several ergonomic features related to their assigned footwear. These results were used to analyze similarities and dissimilarities between One-Snowflake-Footwear1 and One-Snowflake-Footwear2 footwear and identify the footwear that satisfies most needs of the workers. Results revealed that warmth was listed as the most important feature for One-Snowflake-Footwear1 (70%) and One-Snowflake-Footwear2 (78%) groups followed by ankle support in One-Snowflake-Footwear2 (59%) and waterproofing in One-Snowflake-Footwear1 groups (70%).

4. DISCUSSION

Slip-resistance of footwear plays an important role in the prevention of slips and falls by providing traction to prevent balance loss [3, 4]. The results of the current study demonstrated that the rate of slips significantly dropped for the outdoor workers wearing either One-Snowflake-Footwear1 or One-Snowflake-Footwear2 footwear compared to the ones wearing their own footwear. This was expected as both of these footwear passed our MAA testing method. The footwear that achieves or surpasses a rating greater than 7° receives a positive recommendation on our review website. This 7° cut-off was based on the maximum allowable slope for a curb ramp based on existing accessibility guidelines for the built environment. The One-Snowflake-Footwear1 and One-Snowflake-Footwear2 that were evaluated in this study are among the recommended footwear on our website (www.ratemytreads.com).

A larger MAA indicates that the footwear is safer on all surfaces. We expected that an outdoor worker wearing slip-resistant footwear with a high MAA score will be less likely to slip on an unexpected patch of ice on a level surface or on sloped surfaces in the built environment. This was confirmed with the results of the current study. The One-Snowflake-Footwear1 and One-Snowflake-Footwear2 footwear both have an MAA score of 8, thus they were recommended on our review website. Based on our current results, the average number of slips per participant significantly dropped for participants wearing either One-Snowflake-Footwear1 or One-Snowflake-Footwear2 footwear as opposed to the ones wearing their own footwear. This was because the outsoles of the footwear were made of different materials which allowed for better traction. The One-Snowflake-Footwear2 has Vibram Arctic Grip technology and the One-Snowflake-Footwear1 has Anti-slip Green Diamond technology. Both of these technologies allow for enhanced traction features for a safer way to walk on ice.

5. CONCLUSION

This intervention study compared rates of slip incidents between two types of slip-resistant footwear (One-Snowflake-Footwear1 and One-Snowflake-Footwear2) in the field over a two-month period. Both One-Snowflake-Footwear1 and One-Snowflake-Footwear2 footwear provided enhanced traction on ice and significantly decreased the risk of slip incidents as compared to what participants wore typically to work (Control). However, there is a need to develop a wider selection of footwear with anti-slip characteristics as few are available to this worker group. In addition to slip-resistance, wearability of safety footwear for use in the winter season also needs improvement such to achieve the integration of several distinct protection and comfort demands simultaneously. In order to reduce the risk of slip-related injuries caused by slipping on ice and snow, we recommend outdoor workers to wear slip resistant winter footwear during the winter season. We also recommend that footwear industries should seek practical strategies to produce a type of safety footwear for use in cold climates that incorporates both slip-resistance and comfort factors holistically. A possible solution could be the development of effective slip-resistant outsoles that can be attached to different footwear upper designs incorporating all of the comfort factors.

6. REFERENCES

[1] D. I. Swedler, S. K. Verma, Y. H. Huang, D. A. Lombardi, W. R. Chang, M. Brennan, and T. K. Courtney, “A structural equation modelling approach examining the pathways between safety climate, behaviour performance and workplace slipping." Occup Environ Med, 2015, vol. 72, pp. 476–481.

[2] T.A. Bentley, and R.A. Haslam, “Slip, trip and fall accidents occurring during the delivery of mail”. Ergonomics, 1998, vol. 41(12), pp. 1859-1872.

[3] Staal, C. Reducing employee slips, trips, and falls during employee-assisted patient activities. Rehabil Nurs, 2004, 29(6): p.211-4.

[4] Verma, S. A prospective study of floor surface, shoes, floor cleaning and slipping in US limited-service restaurant workers. Occup Environ Med, 2011, 68(4): 279-85.

INFLUENCE OF INDIVIDUAL GAIT AND SHOE DESIGN FACTORS ON TREAD WEAR

Sarah L. Hemler[1], Kurt E. Beschorner[1]

[1] University of Pittsburgh, Department of Bioengineering

SLH148@pitt.edu

ABSTRACT

Slipping events, which originate at the shoe-floor interface, contribute to 40-50% of fall-related injuries. Increased shoe tread wear leads to higher risk of slipping. To develop new slip prevention strategies, improved knowledge of factors contributing to shoe wear is needed. The aim of this research is to explore individual gait and shoe design factors that influence tread wear. In this analysis, shoes were worn down naturally (NW) and artificially (AW). Shoe tread wear rates were determined by dividing the volumetric wear rates by the distance walked in the shoes (NW) or the distance the shoes were slid abrasively (AW). Our findings show that shoe tread wear rates are influenced by the peak required coefficient of friction during gait, but not by the peak normal force during gait. Shoe outsoles with more tread coverage were associated with lower wear rates. Surprisingly, the material hardness of the shoe outsole was not associated with the wear rate. These factors influencing shoe tread wear rates can act to guide gait analysis for shoe recommendations and can impact shoe design.

Keywords: Footwear, tread, wear, fluid dynamics, friction, gait parameters

Topic: Shoe wear

1. INTRODUCTION

Slips and falls accidents are a leading cause of injuries in the workplace. In the U.S., worker's compensation costs associated with slips, trips, and falls injuries are over $18 billion annually according to a 2017 report (Liberty Mutual Research Institute for Safety, 2017). Slips, trips, and falls contributed to 26% of all workplace injuries in 2017 (U.S. Department of Labor - Bureau of Labor Statistics, 2019). Furthermore, slipping leads to 40-50% of all fall-related injuries (Courtney, Sorock, Manning, Collins, & Holbein-Jenny, 2001).

Footwear has been shown to be a modifiable factor for preventing slips and falls. Previous research has indicated that increased shoe wear leads to a larger risk of slipping (Beschorner, Albert, Chambers, & Redfern, 2014) and that newer shoes (worn for less than six months) were associated with fewer slips than older shoes (worn for more than six months) (Verma et al., 2014). Shoe companies have also designed tools to determine when shoes should be replaced based on tread depth (ShoesForCrews, 2019). However, tread wear rates vary across individuals (Hemler, Pliner, Redfern, Haight, & Beschorner, 2019) and shoes often wear unevenly across the heel of the shoe (Hemler, Charbonneau, Iraqi, et al., 2019). Thus, opportunities exist to improve current tools.

Tribology experimental methods for assessing shoe slip risk include measurement of under-shoe fluid pressures and the available coefficient of friction (ACOF), collectively termed as traction performance (Hemler, Pliner, et al., 2019). As fluid is dispersed under the shoe through tread channels, under-shoe fluid pressures decrease, reducing the risk of slipping. Similarly, ACOF is a measure of the shoe's traction with the flooring. As shoes wear down, these tread channels become compromised leading to an increase in under-shoe fluid pressures and a decrease in ACOF (Hemler, Charbonneau, Iraqi, et al., 2019). Slip-resistant (SR) shoes have been associated with increased ACOF (Jones, Iraqi, & Beschorner, 2017) and a decreased rate of slipping compared to non-SR shoes (Verma et al., 2011).

Previous research has determined that certain features of tread and gait may affect tread wear rates. Shoe outsole tread is often composed of elastomeric materials, which tend to fail in tension (Mars & Fatemi, 2002). As RCOF (shear force divided by normal force) increases, the shear force increases relative to the compressive normal force. Thus, the principle tensile stress of the rubber simultaneously increases. This increase in tensile stress can lead to failure of the rubber and cause wear particles to form (Mars & Fatemi, 2002). Therefore, a mechanics pathway exists where increased RCOF leads to increased wear of the shoe tread. Archard's wear law states that the volume of adhesive wear is proportional to the applied normal force and sliding distance, and inversely proportion to the hardness, indicating that these variables may influence wear (Archard, 1953). Furthermore, Moghaddam found deviations between predicted and observed wear patterns that suggested a power-law relationship between contact pressure and wear rate (Moghaddam, Hemler, Redfern, Jacobs, & Beschorner, 2019). If such a relationship existed, shoes with overall lower contact pressures from higher contact area would wear slower than shoes with lower contact pressures. Thus, greater treaded surface area may lead to a longer shoe life. However, there is a lack of research analyzing the effects of these shoe design (tread proportion and hardness) and gait factors (RCOF and normal force) on shoe tread wear which affects slip risk.

The aim of this paper is to describe the individual gait and shoe design factors affecting shoe tread wear via accelerated and natural wear.

2. MATERIALS & METHODS

Shoes were worn down via accelerated (AW) and natural wear (NW) protocols. The methods are outlined in previous manuscripts, simplified versions are offered (Hemler, Charbonneau, & Beschorner, 2019; Hemler, Charbonneau, Iraqi, et al., 2019; Hemler, Pliner, et al., 2019).

2.1 AW Protocol

Two AW protocols (AW1 & AW2) were conducted with the first experiment focusing on commercially-available slip-resistant shoes and the second experiment focused on shoes with systematically modified tread patterns. Both experiments achieved shoe wear via sliding abrasive paper. Five SR shoes were used for AW1. Nine shoes consisting of a factorial analysis of three tread patterns and three hardness values were used for AW2 (Figure 1). For both protocols, shoes were worn down at three sagittal plane angles (17°, 7°, and 2°) for a total of 60 s per wear cycle (Hemler, Charbonneau, Iraqi, et al., 2019). At baseline and after each wear cycle, shoe traction performance was assessed using a robotic slip tester and the heel tread geometry was recorded using a silicone rubber mold. For AW1, the abrasive protocol and mechanical shoe testing were conducted with a 0° coronal plane angle from vertical. For the AW2 protocol, a coronal plane angle of 6° was used to simulate wear due to pronation commonly seen in gait. In AW1, shoes were retired after the measure of load supported by the fluid (fluid force) exceeded 50 N for five wear cycles (Hemler, Charbonneau, Iraqi, et al., 2019).

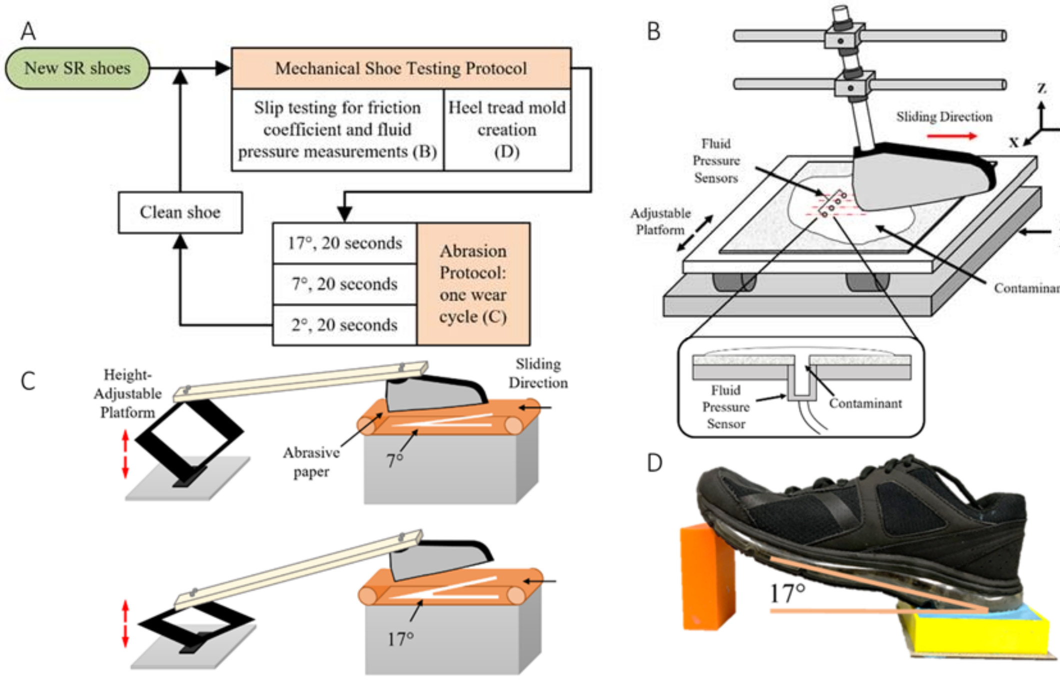


Figure 1. Accelerated Wear Protocols for SR footwear (AW1 & AW2). Figure copied from (Hemler, Charbonneau, & Beschorner, 2019).

2.2 NW Protocol

The NW protocol consisted of two components: a gait assessment and subsequent shoe wear in the workplace (Figure 2). During the gait assessment, 14 participants wore two pair of SR shoes (Shoe A and Shoe B1/B2) while walking over two force plates. Ground reaction forces were recorded for 10 trials for each shoe type. Peak RCOF (shear force/ normal force) and peak normal force were calculated from the force plate data. Prior to wear and after each month of wear in the shoes, mechanical shoe testing (ACOF and under-shoe fluid pressures) and heel mold tread creation were conducted in the same way as in AW1 & AW2.

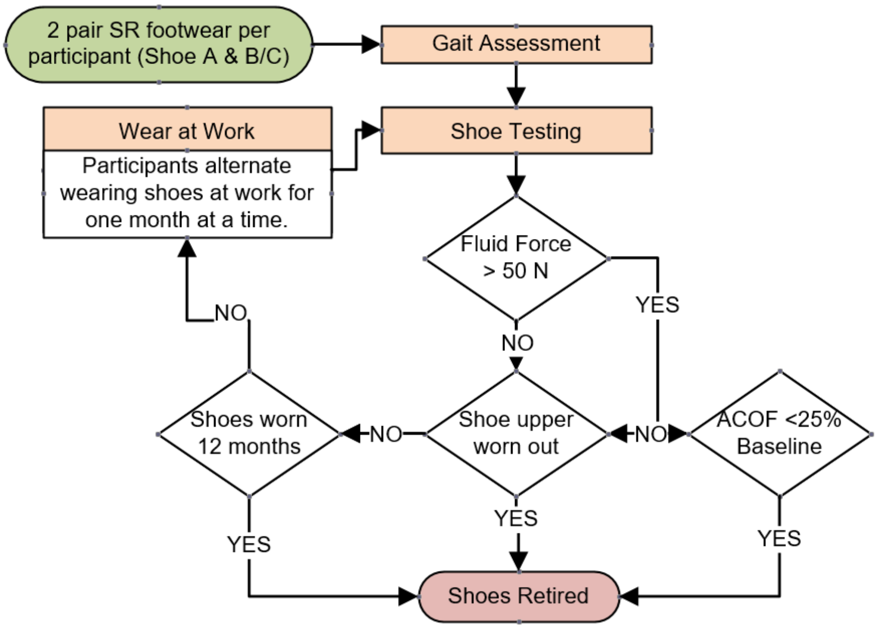


Figure 2. Natural Wear Protocol for SR footwear worn in the workplace. Shoe Testing protocols are similar to the AW protocol.

2.3 Tread Metrics

For AW1, AW2, and NW, the tread volume loss was measured using the heel tread molds. The tread blocks in the molds for each wear cycle (AW1 and AW2) or month (NW) were filled with water. The change in the mass of the water from baseline to each wear cycle was converted to the volumetric tread loss. The shoe tread wear rate was determined by dividing the volumetric tread loss by the distance the shoes were worn (AW1 & AW2) or distance walked in the shoes (NW).

The amount of tread that covered the outsole was termed the tread proportion. This measure was determined for shoes in AW1 by measuring the surface area of the tread on the heel in proportion to the total surface area of the heel parallel to the ground.

2.4 Statistical Analysis

Data for the AW studies were used to determine the impact of tread design factors on wear rate. A bivariate correlation analysis was used to determine the relationship between tread proportion and total distance the shoes were worn (model 1). A linear regression model was used to assess the relationship between wear rate and hardness for all protocols (model 2).

Data for the NW were analysed to determine the gait factors that influenced wear rate. For model 3, the independent variables were the shoe design (A, B, C), peak RCOF, and their interaction. For model 4, the independent variables were the shoe type, peak normal force, and their interaction. The dependent variable was the wear rate (log transformed to normalize residuals) for both models.

3. RESULTS

3.1 Shoe Design Factors

In model 1, shoes with a larger tread proportion required more time to reach the 50 N threshold for the load carried by the fluid, and thus a longer time to wear down (p=.027, R^2=0.85) (Figure 3). In model 2, the shoe outsole material hardness did not influence the shoe tread wear rates for any of the three protocols (AW1&2: p=.54; NW: p=.10).

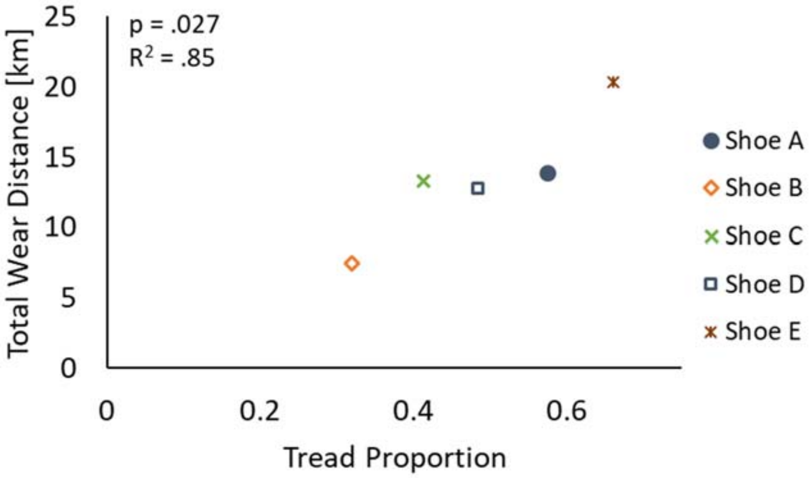


Figure 3. The total distance each shoe in AW1 was worn until reaching the wear threshold. Shoes A, B, and *C* had the same tread type as those used in the NW protocol.

In model 3, increased peak RCOF was associated with higher shoe tread wear rates ($F_{1,16}$=5.56, p=.031) (Figure 4). The wear rate was also dependent on the shoe type ($F_{1,16}$=3.94, p=.041). The interaction between peak RCOF and shoe type did not affect the wear rate ($F_{1,16}$=0.85, p=.45). In model 4, the peak normal force during gait ($F_{1,17}$=0.78, p=.78) and interaction between peak normal force and shoe type ($F_{1,16}$=0.12, p=.89) were not associated with a change in tread wear rates. However, in model 2, the shoe type influenced the wear rate ($F_{1,16}$=6.03, p=.011).

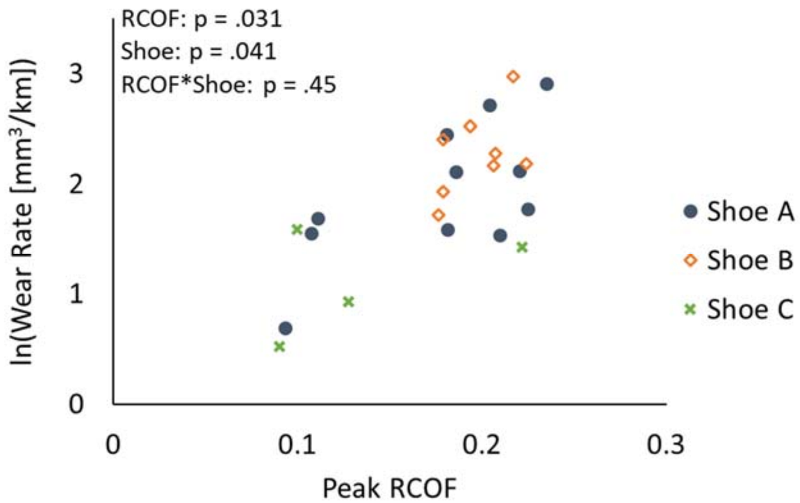


Figure 4. Wear rate plotted relative to the peak RCOF for each shoe type in the NW protocol. To meet the linearity assumption for the model, wear rate was log transformed. Significance is reported for each independent variable in the top left corner.

4. DISCUSSION

In this analysis, peak RCOF and tread proportion influenced the wear rate of SR shoes. Peak normal force did not influence the rate at which shoes wore down. Hardness did not affect the tread wear rate. Furthermore, the variety of SR shoe tread patterns and hardness values as well as the two methods of wear used in these analysis supports the validity of these results.

The results are consistent with mechanics theory. Elastomeric outsoles tend to wear more as the principle tensile stress increases due to increased shear forces (Mars & Fatemi, 2002). Therefore, these findings of increased wear associated with higher RCOF is supported by this theory. Furthermore, increased shoe outsole contact area has been linked to decreased localized pressures (Moghaddam et al., 2019). As such, previous research supports these findings that larger tread proportions lead to increased shoe-floor contact, decreasing localized pressure and subsequent wear.

These findings show that RCOF and tread proportion may be important indicators of shoe tread wear rates. This analysis also reveals that normal force and shoe outsole hardness do not influence tread wear rates. Further study of gait and shoe design factors influencing wear will improve overall understanding of shoe wear replacement guidelines. When recommending shoe replacements, RCOF could be a good gait measure to use such that individuals with a higher RCOF replace shoes more often or are provided with more durable shoe soles. Also, since shoes with higher tread proportions wear down slower than shoes with lower tread proportions, shoe tread durability can be improved by increasing the tread proportion without compromising the fluid drainage capabilities. Overall, the RCOF and tread proportion are good metrics to use to guide gait analysis practice and recommendations for shoe replacement and design.

5. REFERENCES

Archard, J. (1953). Contact and rubbing of flat surfaces. *Journal of applied physics, 24*(8), 981-988.

Beschorner, K. E., Albert, D. L., Chambers, A. J., & Redfern, M. S. (2014). Fluid pressures at the shoe–floor–contaminant interface during slips: Effects of tread & implications on slip severity. *Journal of Biomechanics, 47*(2), 458-463.

Courtney, T. K., Sorock, G. S., Manning, D. P., Collins, J. W., & Holbein-Jenny, M. A. (2001). Occupational slip, trip, and fall-related injuries–can the contribution of slipperiness be isolated? *Ergonomics, 44*(13), 1118-1137.

Hemler, S. L., Charbonneau, D. N., & Beschorner, K. E. (2019). Predicting Hydrodynamic Conditions under Worn Shoes using the Tapered-Wedge Solution of Reynolds Equation. *Tribology International, In Review*.

Hemler, S. L., Charbonneau, D. N., Iraqi, A., Redfern, M. S., Haight, J. M., Moyer, B. E., & Beschorner, K. E. (2019). Changes in under-shoe traction and fluid drainage for progressively worn shoe tread. *Applied ergonomics, 80*, 35-42.

Hemler, S. L., Pliner, E. M., Redfern, M. S., Haight, J. M., & Beschorner, K. E. (2019). Traction performance across the life of slip-resistant footwear: preliminary results from a longitudinal study. *Journal of Safety Research. In Review.*

Jones, T. G., Iraqi, A., & Beschorner, K. E. (2017). Coefficient of friction of work shoes labeled as slip resistant. *Applied Ergonomics, In review*.

Liberty Mutual Research Institute for Safety. (2017). *2017 Liberty Mutual Workplace Safety Index*. Retrieved from https://www.libertymutualgroup.com/about-liberty-mutual-site/news-site/Pages/2017-Liberty-Mutual-Workplace-Safety-Index.aspx

Mars, W., & Fatemi, A. (2002). A literature survey on fatigue analysis approaches for rubber. *International Journal of fatigue, 24*(9), 949-961.

Moghaddam, S. R. M., Hemler, S. L., Redfern, M. S., Jacobs, T. D., & Beschorner, K. E. (2019). Computational Model of Shoe Wear Progression: Comparison with Experimental Results. *Wear*.

ShoesForCrews. (2019). Shoe Care and Cleaning Tips. Accessed 18 January 2019. Retrieved from https://www.shoesforcrews.com/sfc3/index.cfm?changeWebsite=US_en&route=inserts.QA/cleaning_caring

U.S. Department of Labor - Bureau of Labor Statistics. (2019). *Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work, 2017*. Retrieved from Washington, D.C.:

Verma, S. K., Chang, W. R., Courtney, T. K., Lombardi, D. A., Huang, Y.-H., Brennan, M. J., . . . Perry, M. J. (2011). A prospective study of floor surface, shoes, floor cleaning and slipping in US limited-service restaurant workers. *Occupational and environmental medicine, 68*(4), 279-285.

Verma, S. K., Zhao, Z., Courtney, T. K., Chang, W.-R., Lombardi, D. A., Huang, Y.-H., . . . Perry, M. J. (2014). Duration of slip-resistant shoe usage and the rate of slipping in limited-service restaurants: results from a prospective and crossover study. *Ergonomics, 57*(12), 1919-1926.

TECHNICAL SESSIONS (IV)

Analysing accidents and determining fall causes. Prevention measures. Risk management. Human & Behavioural Factors. Ageing

RISKS ON ROOF WORKS: PRESERVE LIFE IS THE KEY

Sanz Albert, Fernando[1]; Limón García, Elena[2]

[1] Instituto Nacional de Seguridad y Salud en el Trabajo, O.A.,M.P.

fernando.sanz@insst.mitramiss.es

ABSTRACT

In construction sector, most of fatal labour accidents are due to falls from height. About 50% of these falls occur while carrying out maintenance works on roofs. Usually these tasks are done by small and medium enterprises and self-employed persons. According to the data gathered, the main causes of these accidents are: lack of awareness of the serious consequences of not working safely and lack of knowledge of their legal duties and of the preventive measures that should be taken when working on a roof.

In order to reduce the incidence rate of this type of accidents, Spanish National Institute for Safety and Health at Work intends to develop a campaign in 2020 on safe roofs works, whose slogan is "*Risks on roof works: preserve life is the key*". The target audience of this campaign are: the ones who design buildings, the owners of the buildings and the ones who develop tasks on roofs. The campaign aims to raise awareness of all these target groups about these risks and to improve their technical knowledge to reduce these accidents. For that purpose different informative products have been elaborated (video, brochures, technical documents, etc.). These accidents can occur in any type of building (industrial building, office building, residential housing, etc.), therefore this issue is a matter of social interest.

Keywords: roof, falls, safety, designer, owner, contractor.

Topic: Risks on roof works

1. INTRODUCTION

In construction sector, most of fatal labour accidents are due to falls from height. In 2015, Construction Working Group of the National Commission for Occupational Health and Safety (CNSST) published the study “Minor construction works: Labour accident analysis (2010-2014)”. This study revealed that more than 60% of labour accidents while carrying out minor construction works (works with small budget, short duration, that do not affect structural elements or landscape, etc.) were due to falls from height. Half of these accidents happened while performing some maintenance or conservation tasks on roofs (tile repair, waterproofing, installation of solar panels, cleaning of gutters and chimneys, etc.). This means that, in the period studied, at least 80 workers died or suffered serious damage because of fallings from roofs.

Main causes of these accidents are the lack of risk assessment, working method or protections against falls.

The Construction Working Group of the CNSST carried out a more detailed analysis of this problem, in order to identify the critical points and priority actions that should be undertaken to reduce these kind of accidents. This analysis was based on data related to serious and fatal occupational accidents, investigated by competent bodies, on the knowledge of experts in occupational safety and health, and taking into account social stakeholders and architect-engineer official associations’ opinions.

Once the analysis was finished, a report “Repair and maintenance works on roofs” was published by CNSST. This report includes the results of this analysis and proposals to avoid labour accidents due to falls from roofs. Precisely, the objective of this communication is to present the main actions proposed that can be classified into two groups:

1. Actions to ensure that roof protection systems are included at the design stage, so future roof works can be carried out in a safe way.

2. Actions to raise awareness of the serious consequences of not working safely on a roof and to provide technical knowledge to adopt the appropriate measures while working on a roof. These actions are aimed at the owner of buildings and the ones who carry out the tasks on a roof.

Both types of actions are described in more detail below.

2. ACTIONS DIRECTED TO THE DESIGN OF SAFE ROOFS FROM THE PROJECT

In Spain, a high percentage of buildings (residential buildings, warehouses, detached houses, etc.), do not have the necessary elements for carrying out conservation and maintenance tasks safely (such as, elements to go up to and down from the roof, perimeter protections systems, skylight protections, etc.). For this reasons, works on roofs are risky. The small or medium enterprise or the self-employed person hired to perform some maintenance tasks on a roof will have to install these protection systems which is often dangerous, technically complex, expensive and requires more time to execute the works. These difficulties could be largely avoided if at the designing step the architect/ engineer includes in the project the necessary elements. Therefore, future works on the roof could be carried out safer, in a shorter period of time and with a smaller budget.

Unfortunately, the truth is that nowadays many buildings are designed without including these elements. Although there can be many causes that originate this circumstance, we can say that there is a low awareness and / or knowledge of the designers about their obligation to integrate occupational risk prevention when designing buildings. At European level, this obligation is included in the regulations on occupational health and safety in construction works (Directive 92/57 / EEC, of June 24, establishes the minimum health and safety provisions that must be applied in construction works temporary or mobile construction, transposed to the Spanish legal system by Royal Decree 1627/1997, of October 24, which establishes minimum health and safety provisions in construction works).

Considering the above, the most relevant actions proposed to improve this circumstance are the following:

2.1 Raise awareness among designers about their obligation to integrate occupational safety into building projects

To reach this goal, it was considered appropriate to include in the technical reference regulations for the design of buildings (in Spain, the Technical Building Code, approved by Royal Decree 314/2006, of March 17), a comment referring to the obligation of designers to integrate occupational risk prevention into projects. In this sense, in June 2018, a comment was incorporated in the Basic Document on Safety of Use and Accessibility (DB SUA), of the aforementioned Technical Building Code, referring to occupational health and safety regulations in construction works. This comment emphasizes the obligation of designers to include in the projects the necessary elements so that future interventions on roofs can be carried out safely. In addition, informative actions are necessary to sensitize and improve the knowledge of the designers about this obligation.

2.2 Improve training in occupational risk prevention in university degrees with competence to project

Preliminary studies show that the number of credits related to occupational health and safety is clearly insufficient in most university degrees with competence to project. Therefore, it is considered necessary to promote an increase in the workload in terms of prevention of occupational risks that is taken in the university degrees. This circumstance has been informed to the Education and Training in Prevention of Occupational Risks Working Group of the aforementioned CNSST, in order to propose to the competent entities actions that can improve this training.

2.3. Adopt coercive measures on the obligation to integrate occupational risk prevention into building projects

In addition to the previous mentioned measures, coercive actions are also considered necessary to promote compliance with the obligation to integrate occupational safety into the projects of the buildings. In this regard, in Spain, the National Labour Inspection has issued a statement to its inspectors about the advisability of verifying, during their inspection actions, that the necessary elements have been incorporated into the building projects so that future interventions on the roofs can be made safely.

3. ACTIONS DIRECTED TO IMPROVE THE AWARENESS AND KNOWLEDGE ON SAFETY DURING ROOF WORKS

Notwithstanding the foregoing, the owners of the buildings and the companies that carry out the works have obligations that are related to each other. However, the data analysed on accidents due to roof falls denote an insufficient application of the necessary safety technical and organizational measures in order to carry out the tasks safely.

Consequently, it was consider necessary to develop and disseminate technical and informative materials in order to raise awareness and improve the knowledge of the owners of the buildings that hire works on their roofs and of the companies and workers that execute these tasks, as well.

In this regard, the National Institute for Health and Safety at Work of Spain (INSST), together with the bodies responsible for the prevention of occupational hazards from different regions and the Construction Labor Foundation (FLC), has developed some materials on work on roofs, which will be intensely disseminated during 2020, in the form of an informative campaign under the slogan "*Risks on roof works: preserve life is the key*".

The materials of this campaign are the following:

- Spot on the consequences of occupational accidents due to falls from roofs: the spot displays some radiographs that show the physical damage caused by falls from roofs (referring to "the wounds that are seen"). Also, the spot shows some images to illustrate the emotional damage that accident cause in the workers who suffer them and, especially, in relatives and people close to the injured (referring to "the wounds that are not seen"). The spot ends with a set of images about works on roofs, summarizing the steps that must be followed to avoid falls.
- Three posters on the consequences of occupational accidents due to falls from roofs: the posters show different dangerous situations during work on roofs, as well as physical and emotional damages that may arise in the event of an accident. Additionally, the posters list the ten basic rules that must be followed when working on roofs.
- Informative booklet on roof works: the booklet describes the process that must be followed to hire and carry out the work on roofs safely. The process consists of six stages, in each of which the roles of the owner of the building and the contractor are explained.
- Two leaflets on the actions that must be carried out by the building owner and the contractor, respectively.

All these materials are available at the following link on the INSST website: https://www.insst.es/-/trabajos-en-cubiertas-lo-importante-es-bajar-con-vida

It should be noted that these materials emphasize the need to follow a six-stage process in which both, the building owner and the contractor, must carry out a series of actions to ensure that the work is executed in safe way. As a summary, these stages are the following:

3.1 Collection of previous information on the roof

When the owner of a building decides to request a budget to carry out any intervention on its roof, it is essential to collect all the relevant information about it (access, dimensions, existence of protections, presence of skylights, etc.). This information should be available to potential contractors in order to properly budget the works, integrating all necessary preventive measures. At this stage, it is always recommended that potential contractors visit the building to complete the information provided by the building owner.

3.2 Hiring the works

Among the possible contractors, the building owner must select someone who can demonstrate to work safely, with sufficient resources and degree of specialization. It is always advisable to select a budget that includes the incorporation of permanent security elements in the roof, so that future interventions are facilitated.

3.3 Work planning

This stage is mainly the responsibility of the contractor. He should plan the works taking into account the information of the roof previously provided by the building owner. At this stage, a work procedure will be developed. This procedure should describe in detail the steps to carry out the tasks, including the preventive measures that should be taken. Also the actions to follow in case of accident or emergency should be described.

3.4 Work preparation

Before starting the work, it will be verified that all the necessary material resources are available to carry out the tasks (access equipment, signalling, protections, etc.) and that these are in a good state of maintenance. Likewise, the work procedure will be reviewed with the workers, making sure that they understand and assume it and they have the necessary training to execute it safely.

3.5 Work execution

During the execution of the tasks, it is necessary that a worker with adequate training supervises the intervention. He will verify that the work is done according to the procedure and he will resolve any incident that may arise in relation to the safety of the workers. If necessary, modifications in the work procedure will be made, but works shouldn´t be improvised in any case.

3.6 End of work

Once the work is finished, the contractor will provide the building owner with any relevant information about the intervention carried out (for example, how to keep the permanent protection elements that may have been installed on the roof or information related to fragile or damaged areas detected during the intervention). The building owner will keep this information which will be available to potential contractors who, in the future, may perform another intervention on the roof.

4. CONCLUSIONS AND CHALLENGES TO THE FUTURE

As a result of the developed study, it is necessary to carry out an intense sensitization work. It should be focus on designers, building owners and contractors.

In this sense, accidents from roofs must be considered as an issue that affect the population in general. Anyone may require hiring a work on their roof and their decisions have a huge impact on health and safety of the workers who execute it.

Therefore, through this communication, the different entities involved (public administrations, professional colleges of architects and engineers, town halls, communities of owners, business associations and trade unions, etc.) are urged to join this campaign. They should develop the actions, within the scope of their competences and possibilities, to reduce accidents due to falls from roofs.

5. REFERENCES

National Occupational Health and Safety Commission (2019, November). Repair and maintenance work on roofs. www.insst.es

National Institute of Safety and Health at Work (2019, September). Work on roofs: preserve life is the key. www.insst.es

National Institute of Safety and Health at Work (2017, July). Occupational safety in minor construction works (without project). www.insst.es

National Occupational Health and Safety Commission (2015, December). Analysis of accidents and their causes in minor works. www.insst.es

National Institute of Safety and Health at Work (2014, November). Basic guidelines for the integration of occupational risk prevention in construction works. www.insst.es

RISK OF FALLS OF OLDER PEOPLE DURING HOSPITALIZATION

Izabela Witczak[1], Anna Kołcz[2], Joanna Rosińczuk[3], Piotr Karniej[4], Piotr Pobrotyn[5], Łukasz Rypicz[1]

[1] Division of Economics and Quality in Health Care, Faculty of Health Sciences, Wroclaw Medical University, Wroclaw, Poland

[2]Laboratory of Ergonomics and Biomedical Monitoring, Faculty of Health Sciences, Wroclaw Medical University, Wroclaw, Poland

[3] Division of Nervous System Diseases, Faculty of Health Sciences, Wroclaw Medical University, Wroclaw, Poland

[4]Division of Organisation and Management, Faculty of Health Sciences, Wroclaw Medical University, Wroclaw, Poland

[5]University Teaching Hospital of the Jan Mikulicz-Radecki in Wroclaw

lukasz.rypicz@umed.wroc.pl

ABSTRACT

In connection with the aging of the population, in recent years, there has been an increase in the number of older people among hospitalized patients. Falls of older people during hospitalization and their consequences are a serious problem, both medical and social as well as economic. The study was conducted at the University Clinical Hospital in Wroclaw. A retrospective method of reporting adverse events by medical personnel in the category of patient falls was used in 2017-2018. The analysis includes internal and external risk factors for patient falls. In the reporting period, 57 and 64 patients, respectively, suffered a fall with various health consequences for patients and economic costs for the hospital. The above analyses have contributed to preventive measures taken by the hospital. At the turn of 2018/2019, the hospital developed and implemented a procedure for assessing risk factors in every patient over 65 years of age. The assessment is made by an interdisciplinary team consisting of a nurse, physiotherapists and ultimately by doctors. If high risk factors are identified, preventive measures are taken (patient's label with a reflective band, additional equipment, and intensive observation by nursing staff). The analysis of falls registered in the hospital in the first half of 2019 allows us to conclude that preventive measures taken have helped to reduce the number of falls of patients.

Keywords: patient, hospitalization, falls, risk, prevention

Topic: Falls prevention

1. INTRODUCTION

The publication of the “To Err is Human” report by the Institute of Medicine in 1999 revolutionised the perception of safety culture in the health care system. Looking from the perspective of time, this report was a breakthrough because it emphasized the responsibility of the health care provider in the area of imperfections in the processes implemented in medical institutions and the need to improve them. The emphasis was placed on the importance of involving all medical staff in reporting adverse events without stigmatising the perpetrator. (DiCuccio, 2015).

Patient falls are one of the most serious adverse events that hospitals face. Falls can cause death and affect the morbidity of patients. Moreover, this translates into increased legal risk and costs for the health care provider. It is estimated that there are more than 1 million patient falls worldwide every year. This means that falls become one of the most frequently reported adverse events in hospitals. The number of falls ranges from 2% to even 20% of hospital admissions and 10-30% of accidents cause injuries. Injuries accompanying falls cause pain, disability, limited mobility and even death. The most vulnerable to hospital falls are elderly patients, which means that they are more likely to suffer injuries and related complications. Falls of patients result in an increase in hospitalization costs and related compensation. (Spetz et al., 2015, Schwendimann et al., 2006 and Healey et al., 2008).

In the literature on the subject, the following risk factors are enumerated as fall risk factors in older people: imbalance and gait disturbances, visual disturbances, advanced age, the female sex, polypharmacy, pain, deterioration of cognitive or environmental functions. (Mazur et al., 2016).

2. THE OBJECTIVE OF THE STUDY

The objective of this study is to analyse the risk factors of falls in elderly people during hospitalization.

3. METHODOLOGY

The study was conducted at the University Clinical Hospital in Wroclaw. A retrospective method of analysis of forms for reporting adverse events by medical personnel in the category of patient falls was used in 2017-2018 and in the first half of 2019.

The University Clinical Hospital has a *System for monitoring adverse events in patient care*. According to the rules of this system, every adverse event is registered in accordance with the Catalogue of Adverse Events and assessed by points depending on severity using the Safety Assessment Code Matrix (SAC). The assessment provides a basis for a possible root cause analysis. Patient falls are predominant among reported adverse events. In this connection, at the turn of 2018/2019, the Hospital implemented the procedure “Preventing falls of patients treated at the University Clinical Hospital. Fall risk assessment”. The falls registered in the first half of 2019 were analysed in detail.

4. RESULTS

In 2017 and 2018, the number of registered patient falls was 57 and 64 respectively. In the period from 01.01.2019 to 30.06.2019, 21 (100%) adverse events involving falls were registered at the University Clinical Hospital (Table 1). The average age of patients was 69.7 years. The oldest patient who suffered a fall was 95 years old and the youngest was 19 years old. 7 (33.3%) patients were over 80 years of age. 14 (66.7%) patients who suffered a fall were women.

Initial assessment carried out during the admission to the hospital

In accordance with the procedure “Preventing falls of patients treated at the University Clinical Hospital. Fall risk assessment.” all patients admitted to the hospital should be pre-assessed by medical staff (nurses/ midwives) for the risk of falling. The assessment is made by answering simple questions.

Based on the data contained in the reports describing falls, 2 patients (9.5%) who fell were not assessed and 5 (23.8%) fall notifications lack the data concerning the assessment, which can be also treated as the lack of preliminary risk assessment. The remaining patients who suffered a fall were included in the following groups:

a) 1 patient – minimal risk of falling,
b) 6 patients – increased risk of falling,
c) 7 patients – high risk of falling.

All patients who belong to a high-risk group in the opinion of a nurse/ midwife should be referred (with a written referral) by a doctor for shortened Tinetti Test used for the assessment of gait and balance by a physiotherapist. Up to 28 points can be obtained in the test: 16 for the balance and 12 for the gait. Obtaining less than 19 points indicates a high risk of falling - the risk of falling increases fivefold, a score between 19 and 24 means that there is a tendency to fall, a score above 24 points means that the risk of falling is low. From the fall notifications received, it appears that:

a) 1 high-risk patient before the age of 65 was permanently in bed and there were no grounds for such an assessment,
b) 2 people under 65 years of age were assessed but the test result was not entered,
c) 5 people over 65 years of age were not assessed by a physiotherapist or no answer was provided (no entry)
d) 2 people over 65 years of age were permanently in bed,
e) in 11 people the risk of falling was assessed as high.

An in-depth analysis indicates that falls occurred in 0.08% of adult patients hospitalized in the first half of 2019 (21 falls out of 25,388 hospitalizations).

Falls and injuries constitute the second largest group of registered adverse events after bedsores developed in the hospital – 18.6%.

A more detailed analysis showed that the most frequent falls of patients occurred in the patient's ward – 13 (61.9%) and 6 times in the toilet/bathroom (28.6%) (Table 2).

There were 5 (23.8%) falls of adult patients, despite the installation of safety barriers to the patients' beds. These falls can be described as slipping off, falling out of the bed.

The causes of events related to the patients falls should be mainly attributed to:

a) technical malfunctions,
b) patients' health condition (physical and mental) - depressive thoughts, agitation, misjudgement of reality, difficult communication, wandering.
c) disrupted communication between the patient/ visitors and the staff, between then staff and the staff
d) incorrect assessment of the patient's current health condition.

It should be emphasized that some falls necessitated medical intervention, and in all cases were the cause of additional measures and outlays in terms of time and money (additional expenditures on diagnostics and treatment by the hospital). They were classified into either **2nd** or **1st** severity group of the SAC matrix depending on the effects they had on the patient's health.

The most common falls occurred in adults during the following hours (Table 4):

a) 24:00 - 2:59, 5 people (23.8%), it is the time when patients stay in bed and need to go to the toilet, often do not want to call for help so that someone could help them to move around, patients advanced in years may be lost in a new place, not knowing the way or not being aware of any architectural obstacles;
b) 18:00 - 20:59, 8 people (16%), after 3:00 pm there is usually a reduced number of staff in the ward which is due to the work schedule and human resources.

The consequences of falls varied from the absence of any complaints, through nervous breakdowns or break in skin integrity (Table 3). It is often necessary to carry out additional diagnostic imaging tests, treat skin abrasions, and even apply stitches or perform a surgery.

5. DISCUSSION

This study has shown that taking preventive measures to protect patient safety provides measurable benefits for both the patient and the hospital. Patient care should be embedded in the patient safety culture which is today a challenge for many health care systems around the world.

The safety culture should be seen in a multidimensional context. It consists of, among others, the following elements: leadership styles, individual and group ethical values, attitudes and behavioural patterns, but also evidence-based clinical practice. Patient-to-staff communication and a patient-focused approach (Manzanera et al., 2018) are crucial to building a safety culture.

The authors' own research showed that the average age of people who suffered a fall was over 69 years. These are people who have already experienced a decrease in psychophysical fitness.

In addition, there is an aspect of multimorbidity, which is also important in the case of patient falls.

Literature on the subject indicates that older people are a group of people with a higher incidence of adverse events. This is a result of many factors, such as the use of many drugs and concurrent occurrence of multimorbidity. The loss of the functional reserve of the organism is also not without significance (Passarelli et al. 2005).

This study also revealed communication deficits between a nurse/ midwife/physiotherapist and a doctor, which resulted in 7 patients not having had a fall risk assessment or it was not documented. Improper communication, particularly in care for the elderly, can increase the incidence of adverse events.

Effective communication is an important aspect of patient care, but also a key element in ensuring high quality care, which is reflected in patient safety and satisfaction. It is stressed that effective interpersonal communication of interdisciplinary medical teams is indispensable for the effective provision of health care (Norouzinia et al., 2016).

A fall in a hospitalized patient often has long-term and cost-intensive consequences for both the patient and the hospital. The authors' own research showed what procedures are performed in patients with trauma (imaging diagnostics, surgical procedures or long-term rehabilitation). It is also important to bear in mind the costs of any claims that may arise. Awareness of the staff and preventive measures are therefore important.

In the UK, fall-related expenditure is estimated at over GBP 2.3 billion in 2013. In the U.S., almost 66% of fall-related expenditure is spent on treatment of injuries requiring hospitalization, 21% on injuries treated in emergency departments and 13% on injuries treated in outpatient settings (Stevens et al. 2006, Vieira et al. 2016).

In everyday building of safety culture in medical facilities we should not forget about elderly people, who are an extremely important group of health care beneficiaries. Taking preventive actions should be an everyday reality, which, as numerous studies show, yields measurable benefits. Adverse events, including falls, can have unpleasant consequences. With extensive knowledge of this matter, we are able to reduce a significant proportion of these events. This requires the involvement and awareness of health professionals.

6. CONCLUSION

In the era of an ageing population, an increase in the percentage of elderly people among hospitalized patients is also noticeable. This group is particularly vulnerable to falls during hospitalization. This is due to many factors, including multimorbidity, imbalance in balance and gait, or dementia changes. As shown by the above study, the implementation of preventive measures to limit falls brings measurable results. However, this requires the involvement of an interdisciplinary team of medical staff (doctors, nurses, midwives, physiotherapists) and some financial outlays. The involvement of the management team, which understands and supports activities aimed at increasing patient safety, is not without significance. A measurable advantage of the undertaken actions is the reduction of costs incurred due to adverse events, in this specific example of patient falls and possible claims affecting the prestige of the hospital.

Table 1: The number of falls registered in the hospital in different years

Year	Number of falls
2017	57
2018	64
The first half of 2019*	21

* After conducting the procedure "Preventing falls of patients treated at the University Clinical Hospital. Fall risk assessment".

Table 2: A place of fall

	ward	bathroom	stairs	hall
2017	34	12	5	6
2018	36	15	4	7
The first half of 2019	13	6	1	1

Table 3: Types of procedures performed on patients who have suffered a fall

Procedure / additional activities	2017	2018	The first half of 2019
X-ray	29	36	9
CT head	14	11	5
Applying the dressing to the damaged part of the body	16	20	4
Orthopaedic consultation	7	8	2
Neurological consultation	5	4	2
Surgical consultation	8	6	1
Surgical procedure	2	3	1

Table 4: The frequency of falls during the day in the first half of 2019

Time	6:00 - 8:59	9:00 - 11:59	12:00 - 14:59	15:00 - 17:59	18:00 - 20:59	21:00 - 23:59	24:00 - 2:59	3:00 - 5:59
Number of falls	2 (9.5%)	3 (14.3%)	2 (9.5%)	2 (9.5%)	5 (23.8%)	2 (9.5%)	4 (19%)	1 (4.8%)

7. REFERENCES

1 DiCuccio M.H. (2015) The Relationship Between Patient Safety Culture and Patient Outcomes: A Systematic Review. J Patient Saf 11(3), p.135-142.

2 Spetz J., Brown D. S., Aydin C. (2015) The Economics of Preventing Hospital Falls, Demonstrating ROI Through a Simple Model. The Journal of Nursing Administration 45(1), p.50-57

3 Schwendimann R., Buhler H., de Geest S., Milisen K. (2006) Falls and consequent injuries in hospitalized patients: effects of an interdisciplinary falls prevention program. BMC Health Serv 6(69), p-1-17.

4 Healey F., Scobie S., Oliver D., Pryce A., Thomson R., Glampson B. (2008) Falls in English and Welsh hospitals: a national observational study based on retrospective analysis of 12 months of patient safety incident reports. Qual Saf Health Care. 17(6), p. 424-430.

5 Mazur K., Wilczyński K., Szewieczek J. (2016) Geriatric falls in the context of a hospital fall prevention program: delirium, low body mass index, and other risk factors. Clinical Interventions in Aging 11, p. 1253–1261

6 Manzanera R., Diego M., Guilaber M., Plana M., Gálvez G., Ortner J., Mira J. (2018) Quality Assurance and Patient Safety Measures:A Comparative Longitudinal Analysis, International Jurnal of Enviromental Reserarch and Public Health. Int. J. Environ. Res. Public Health; 15, 1568,

7 Passarelli M.C.G, Jacob-Filh W., Figueras A. (2005) Adverse Drug Reactions in an Elderly Hospitalised Population Inappropriate Prescription is a Leading Cause. Drugs Aging, 22 (9), p. 767-777

8 Norouzinia R., Aghabarari M., Shiri M., Karimi M., Samami E. (2016) Communication Barriers Perceived by Nurses and Patients. Global Journal of Health Science 8(6); p. 65-74.

9 Stevens J.A., Corso P.S., Finkelstein E.A., Miller T.R. (2006). The costs of fatal and non-fatal falls among older adults. Inj Prev; 12:290-5

10 Vieira E. R., Palmer R. C., Chaves P. H. M. (2016) Prevention of falls in older people living in the community. BMJ 2016; 353 :i1419

THE RISK OF A WOKER'S FALL AND INJURY AT WORK IN THE CONTEXT OF EMPLOYER'S RESPONSABILITY AND OPERATING COSTS IN HEALTH CARE INSTITUTION

Piotr Karniej[1], Izabela Witczak[2], Anna Kołcz[3], Joanna Rosińczuk[4], Łukasz Rypicz[2]

[1]Division of Organisation and Management, Faculty of Health Sciences, Wroclaw Medical University, Wroclaw, Poland

[2] Division of Economics and Quality in Health Care, Faculty of Health Sciences, Wroclaw Medical University, Wroclaw, Poland

[3]Laboratory of Ergonomics and Biomedical Monitoring, Faculty of Health Sciences, Wroclaw Medical University, Wroclaw, Poland

[4] Division of Nervous System Diseases, Faculty of Health Sciences, Wroclaw Medical University, Wroclaw, Poland

piotr.karniej@umed.wroc.pl

ABSTRACT

Employees are the most important resource for a medical organization. From the point of view of the safety of a hospital (as a institution), the patient's safety is very often considered as not involving additional risks, i.e. fall, injury, improper drug, etc. In hospitals and clinics, the context of the employee is omitted, so whether or not the medical service is safe for him and does not expose him to health - both in the short and long term. The aim of the presented study is to analyze the risks occurring at selected positions in health care, in the context of possible injuries and statistical data on injuries associated with falling.

The study used the desktop research methodology, direct observations, participant observations, as well as a study with the focus group, whose task was to identify individual risks in the context of the goal of the study.

The conclusions from the study are that the employees (at hospitals, outpatient clinics, nursing homes) don't pay much attention to the avoiding the risk of falling, they don't associate it with the probability of absenteeism, shortening the time of ability to work. Employers in the surveyed group don't offer trainings in the field of avoiding the risk of falling, don't refund ergonomic footwear, allow the use of shoes with an exposed heel, and don't invest in ergonomic chairs and rest areas. There is also no need to provide devices to relax muscles in rest areas.

Keywords: risk management, fall, employee, employer's responsibility

Topic: Falls prevention

SAFE AND ACCESSIBLE SPACES

Raquel García Campillo, PhD Architect

SRGS. SLIP RESISTANCE GROUP SPAIN

rgarcia@anivel.es

ABSTRACT

The increasing need for citizens to recover their relationship with their environment as they seek to improve quality of life has made us reconsider cities and the elements that constitute them.

This research paper is focused on urban pavements as an essential element of connection between the citizen and their environment in the urban area. The urban area provides pavements as an external and visible part of its skin, its epidermis, upon which all activity is supported and carried out, shaping and influencing the quality of space.

Safety and comfort must be assured in the use of urban pavements on public roads by citizens

The main objective of this research paper is to establish criteria for the design and use of urban pavements, according to both functional parameters (study of human walking – normal and pathological, ergonometric, anthropometric, and biomechanical) as well as formal or design parameters (related to size, shape, color, texture, joinings, usability, and durabilitye). Further external considerations are considered such as pollution, location, use and climate.

Current regulations, both national and internationally, do not establish a standard degree of safety for exterior pavements. The situation is complicated further by the existence of several test methods and European directives, that do not reach a consensus on the most appropriate test methods on usage and materials.

The focus should be citizen-centric. Materials should be chosen according to how appropriate they are for the location and the designated usage. Understanding and knowing the site and the proposed use are of fundamental necessity when defining the characteristics that are unchanging over a reasonable period.

Keywords: Fall, slip, safe, accessibility, pavement

1. INTRODUCTION

There should be a relationship established between the needs of the pedestrian and the requirements that urban environments must fulfill, adapting the city to the pedestrian, which must be introduced as a variable and main protagonist, taking into account their diversity (age, mobility, use of mobility aids). We seek more sustainable urban designs for urban and human development, giving greater importance to walking than to motorized transport.

The characteristics of pavements are decisive when preventing falls. Their surface finish will be key - hence the importance of meeting specific regulations. Depending on the characteristics and finishes, a pavement will be able to avoid and reduce the sliding speed and therefore the reaction of the individual, increasing or decreasing their imbalance and, therefore, avoiding the fall.

The problem arises when we analyze the statistical data on falls and see that they are one of the main causes of involuntary injuries. Despite having legislation, the CTE Building Technical Code since 2006, which establishes an adequate slippery rate for some indoor uses, we see that the data does not vary and that the percentage of people suffering falls continues to increase. Older and physically disabled people, people with reduced mobility, or those who use support mobility aids such as crutches or canes are the most affected and prone to slips or tripping. However, test methods do not take into account all users or all ambulation conditions. Not all intrinsic and external factors, individual and environment, are taken into account.

Nationally, the Injury Prevention Program: Detection of Domestic and Leisure Accidents, 2011, **D.A.D.O.**, published data showing that accidents caused by carrying out daily life activities (sports, educational and play) have a common factor as a cause of such accidents: the pavement (type of surface and state) and the need for care of users in hospitals:

- About 280 domestic accidents occur per hour of which 140 are due to falls, of which 27 are due to slipping or stumbling on the pavement.
- 32% of workplace accidents occur from slipping.
- The second cause of tetraplegia is a direct result of slipping accidents.
- Four out of ten children suffer slip-and-stop accidents.
- More than 1,180,000 hospital admissions occur annually from slipping.
- More than 60,000 people suffer from hip fractures as a result of a slipping.
- Falls are the fifth leading cause of death by accident in Spain and the second leading cause of disability.
- They cause associated illnesses such as "post-fall syndrome".

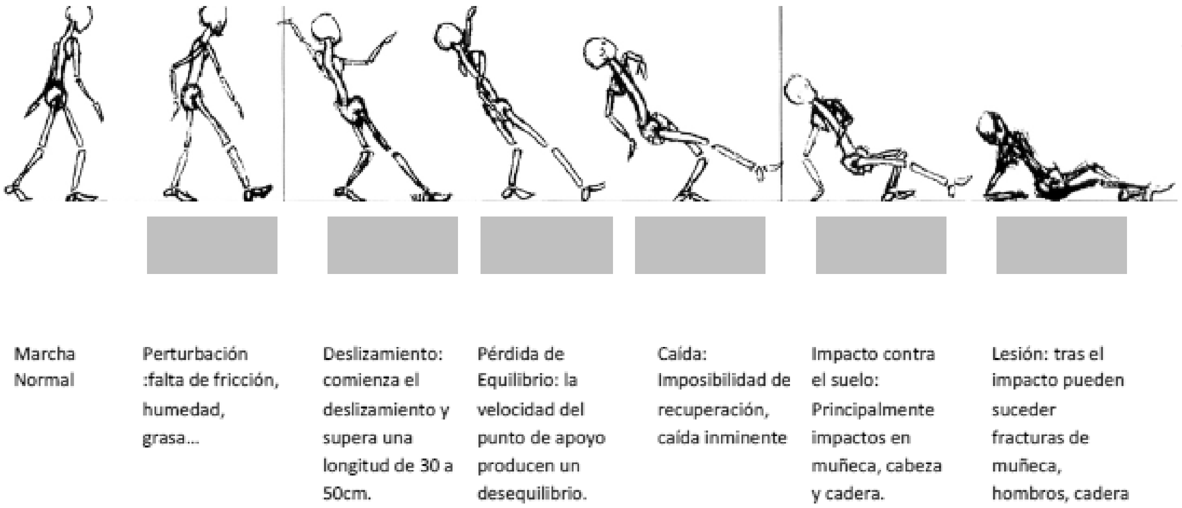
Falls due to slips, stumbles or slippages, and their consequences, have a high economic and social impact (death, permanent or temporary disability, hospitalization, inability to attend work or school), among others.

D.A.D.O. concludes that **the main elements causing injuries are stationary furniture (29.8%) and the pavement (20.3%).** It adds that within daily activities, the origin of accidents is the floor or pavement, explaining 30.7% of cases. Transformed, outdoor and ground surfaces cause more than 50% of injuries during sporting activities.

Table 1: Evolution of the accident mechanism. Source: D.A.D.O. 2011. Own compilation

EVOLUTION OF ACCIDENT MECHANISMS (%)								
Mechanism of accident	1999	2000	2001	2002	2003	2004	2007	2011
Falls	51,3	50,9	50,1	44,2	42,9	45,7	44,1	51,1
Hits/bumps	18,1	14,1	15,0	15,5	15,1	14,2	13,0	16,6
Cuts/crushes	14,6	16,3	16,1	16,9	18,3	19,2	22,6	14,2
Foreign bodies	1,4	1,5	1,4	1,9	1,6	1,5	1,5	0,9
Asphyxia	0,3	0,4	0,6	0,5	0,4	0,7	0,9	0,3
Effect of Chemical products	1,4	1,7	1,1	1,7	1,2	1,0	3,5	1,3
Effect of Thermal products	7,2	8,8	9,9	9,4	10,9	10,6	9,6	9,1
Effect of electricity and building work	0,3	0,5	0,6	0,5	0,8	0,5	0,5	0,2
Physical effort, exhaustion	4,9	5,3	5,1	3,4	2,9	6,2	4,2	4,6
Other mechanisms	0,6	0,3	0,3	6,0	5,8	0,3	0,1	1,7
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Currently, pavements whose slippage rate is not lower than a certain value are considered safe. The rate may be different depending on the test method used (German Ramp, Friction Pendulum, BOT-3000, TORTUS). It is believed that the applied and mandatory requirements are not sufficient or valid to create safe and comfortable environments, emphasizing that pavements are the urban element that most interact with individuals and therefore must have greater safety requirements to avoid falls from tripping or slipping.



Normal walking	*Disturbance:* lack of friction, moisture, greasiness	*Slippage:* slipping starts and reaches 30-50cm in length	*Loss of balance:* the speed of the support foot causes imbalance	*Fall:* impossibility to recover balance and imminent fall	*Impact on the ground:* main impacts on wrists, head and hips	*Injury:* following impact there may be fractures to the wrist, shoulders, hips, etc,

Figure 1: Chain of events that occur in most falls causing by slipping on a level surface, Chiu and Robinovitch (1998). Source: Zamora Alvarez, Tomás. 2012

2. PROBLEMS ARISING FROM PAVEMENTS INSTALLED

Analyzing the datasheets of pavements, as an indication of the regulations in force in our country and many European countries, we can see that manufacturers and prescribers are limited to complying with legislation. We guarantee construction products, since it is mandatory, so that each product has its certificate, Macado CE. But should we ourselves the following question: what happens when all products become part of a system?(1)

On many occasions we find that the product, referring to pavements, is installed for a use that is not appropriate, in an unsuitable place, in a climate that is not favorable.

A wrong choice of pavement support (flexible or rigid), poor execution of the support base, surface finish, or thickness may result in deterioration of the pavement and thereby a loss of satisfactory characteristics obtained in manufacturing.

Figure 2: Pavment in pedestrian street of Tres Cantos. Own source

Figure 3: Access Town Hall Square, San Sebastián de los Reyes. Natural Stone. Own source

Figures 4 and 5 show a poor choice in the placement of pavement in an outdoor area. The conditions of use have forced the removal of the lawn between the design features of the pavement, creating a more homogeneous and walkable route.

(1) The system understood as the context in which the product we have selected is inserted.

Figure 4: College of Architects of Madrid. Own source

Figure 5: College of Architects of Madrid. Own source

The CE marking of construction products declares the value of the slip resistance test or incorporates the acronym NPD (parameter not determined) into the labelling, according to the test method applicable in the Member State intended destination (that also must also be declared). One of the common problems is that the certificates are for a product model (cobble or tile) without certifying all the variations of that model. Product certificates, as can be seen in the annexes, may correspond to previous years. Products are not usually tested before nor after installation.(2)

Wear and tear of a surface can be caused by the traffic (pedestrian or road) to which it is subjected. That it is why it is important to consider wear resistance and pavement durability. A piece with a rough surface finish (scratched, flamed, veined) indicates a priori a slippage value higher than specified by the norm at the time of installation. But these characteristics can change if the product is made of materials that are easily disintegrated, turning the pavement into a slippery floor due to the wear of the exposed surface, meaning that it is hard to maintain its category for the lifetime of its use, indicated by the CTE.

Maintenance by conservation services must also be taken into account. High-pressure water hosing can also accelerate wear out of the pavement .

In very cold and rainy climates, surface finishes such as polished and textured finishes on outdoor floors should be avoided, as they can create slippage problems. It is better to use the flamed, bushed or some other rough finish. It is advisable to apply an anti-slip finish to the stone.

(2) Listing 25 of the Annex is the certificate granted to a manufacturer in 2008 effective until 2017

Some of the causes that make a pedestrian route an unsafe space would be:

- Water presence: due to a settlement of the lower layers, dampness gathers and water is accumulated water on the surface. Also, an inadequate execution of the street sloping for the evacuation of water.
- Shifting or breaking of parts: Poor execution of the lower layers of settlement
- Discontinuity in the pathway: The loss of jointing on certain pavements, especially those made with natural cobblestones.
- Cracks: the presence of water and the entrance of water in the lower layers of the ground, especially in winter, causes abrupt changes in temperature, producing dilations and contractions.
- Wear out by use: Poor choice of a type of material for specific uses.
- Surface finish: poor choice of surface finish of the pieces.

3. CONCLUSIONS

Insecurity is a complex phenomenon that not only depends on the individual, their physical characteristics and walking patterns, or the type of footwear used and the surface finish of the pavement. We must also consider that the pavement has a contaminant agent (dirt, water, oil or sand) and the state, in which the pavement is located (deteriorated, worn, lack of joints,). The phenomenon of erosion or wear out plays a very important role in determining the safety of a pavement.

Statistics (D.A.D.O. report) show that falls caused by slippage or stumbling on level surfaces remain one of the leading causes of involuntary injuries.

The inefficiency of the slippage regulation that exists, as well as the methods used, are not enough nor do they take into account all possible variables to create safe and comfortable environments. The data obtained shows us that outdoor environments are still unsafe, despite the coming into effect of the Technical Building Code in 2006 (the regulations that establish slippage values) or the Ministerial Order VIV/561/2010 on Accessibility in Urbanized Spaces, in 2010.

Falls due to slippage, stumbling or sliding, and their consequences, have a high economic and social impact (death, permanent or temporary disability, hospitalization, inability to attend the work center or school).

In the same study, it is established that the main cause of fall injuries is the pavement.

By analyzing the cycle of human walking and the factors that can influence falls among certain groups of people, we can find that on many occasions we adjust our walking to a certain pavement, making it a safer space. The problem arises when we abruptly switch from one type of pavement to another with different slippage values. This transition increases the risk of falls and slips.

There is no reference as to what pavements should be in outdoor public spaces, meaning that a slip resistance benchmark value is not set for outdoor pavements. Pavements are simply described as needing to be non-slip. It is necessary to use the CTE to assign a class and a slip resistance value: class 3 and Rd>45, and use UNE technical standards for products.

We develop new products that come to market and evaluate their characteristics before they are introduced at factory. It is not defined what the conditions of intended use are and it is impossible to define the wear out that will be suffered according to different levels of transit, contaminants, temperature changes, ice shock/melting, breakage of the part due to sudden changes in temperature and whether all these alterations will influence the resistance to slippage. It is therefore concluded that such tests carried out in the laboratory are fictitious and that real commissioning conditions (use, place, climatology) are not taken into account, confirming that the resistance to slippage does not only depend on the pavement.

We must know how the passage of time affects products and what properties are lost. What are the characteristics that make the pavement suitable in origin, according to manufacturing and laboratory testing, and how do they become inadequate, dangerous, sliding or unsafe?

It is also concluded that it is impossible to convert the data obtained using one test method to another. There is no correlation of values or classification, when using totally different measuring equipment, contaminants, contact materials and classification criteria. The same would happen when trying to establish relationships with the other methods.

One of the main problems we encounter when performing the slippage resistance test (on the same pavement in different approved laboratories) are the different results - especially when contaminants such as water or oil start to be introduced. Depending on the test method, they may be disparate results in the classification of the pavements. The data obtained by different laboratories reflects different values for the same product. The problem lies in the elements used for testing (shoe rubber type and system calibration for pendulum testing; footwear type and ramp contaminants). There is a need to standardize the characteristics of these elements so that equal results are obtained for the same product with the same test method. This conclusion highlights a problem of consensus in testing methods. It would be possible to start by unifying the elements used, standardizing from the contaminant, to the footwear or shoes, calibration of the test elements (pendulum, TORTUS, BOT-3000E, ramp), prototype person (ramp).

The ramp test method only considers an individual prototype, which is the one performing the test. The results that are reflected would be very different if the trial will be performed by a person with reduced mobility, an elder, a child, with mobility aids (stick, crutch), etc.

None of the test methods is capable of making the real and necessary measurements to ensure the installation of a safe pavement. What we achieve with laboratory testing is to prevent a percentage of falls by discarding pavements that are slippery.

There is a lack of European consensus when it comes to designating an appropriate and reliable testing method to provide us with optimal and necessary value to create safe and comfortable spaces. This impossibility of unifying test methods is closely related to the particular interests of countries and, despite the free marketing of products within the EU, to the protectionism of local industry, leading to greater demand on overseas products.

When all these factors come together, we cannot think that the method of measuring the slippage resistance value should be limited to a unrealistic system, performed in the laboratory. Similarly, a universal system has not been achieved that unifies and validates the results that are performed on the same pavement with different methods.

Today, an update of the regulations is still necessary in order to verify the values or sizing of the regulated minimum parameters and standards, and thereby provide a clear structure in which both individual and collective needs are met, ensuring the interaction of as many individuals with diverse capacities as possible.

As a final conclusion, the needs of the citizen must be taken into account by selecting appropriate materials for the site and looking for the appropriate characteristics of the material according to the intended conditions of use. It is essential to know the place and intended use so that we may define the fundamental characteristics that may remain unchanged over a reasonable period of time:

- **User**: perception of the environment. Assessment of the pavements (active participation in design)
    - Weight
    - Age
    - Physical abilities
    - Sensory capabilities
- **Use** (pedestrian, bike, private vehicle, public transport)
- **Lighting:** Visibility of the route. Natural and artificial lighting.
- **Place:** Geographical area and location in sunny or shaded area. Areas with a slope.
- **Climatology:** rainy areas, with presence of moisture, saline environments, risk of frost, etc.
- **Related test methods:** before installation and after installation. Establishing periodic reviews to observe that it maintains its properties and determining the new values.
    - Durability (thermal shocks/ice/melt)
    - Wear (abrasion)
    - Friction/slip/sliding/
- **Life cycle:** materials used and material reuse
- **Conservation/maintenance/costs**
- **Safety and comfort:** Derived from testing methods, conservation, maintenance and periodic reviews
- **Contaminants:** dirt, water, oil, sand
- **Environmental adequacy**

KEY LECTURES

PATIENT CHARACTERISTICS AND IMMEDIATE AND 6-MONTH OUTCOMES BY CAUSES AMONG OLDER ADULTS PRESENTING TO SPANISH EMERGENCY DEPARTMENTS AFTER A FALL

Berenice N. Brizzi[1], Montserral Lázaro del Nogal[2,3], Sira Aguiló[4], Òscar Miró[4,5], Elena Fuentes[6], Javier Jacob[6], Adriana Gil[7], Pere Llorens[7,8], Raquel Cenjor[9], Pablo Herrero[9], Cristina Fernández[10], Francisco Javier Martín Sánchez[1,3]

[1] Emergency Department, Hospital Clínico San Carlos, Madrid, Spain
[2] Geriatric Department, Hospital Clínico San Carlos, Madrid, Spain
[3] Complutense University, Madrid, Spain, Madrid, Spain
[4] Emergency Department, Hospital Clínic, Barcelona, Spain
[5] University of Barcelona, Spain
[5]Emergency Depatment, Hospital de Bellvitge, L'Hospitalet de Llobregat, Barcelona, Spain
[7] Emergency Department, Short Stay Unit and Hospitalization at Home, Hospital Universitario General de Alicante, Spain.
[8] Miguel Hernández University, Elche, Spain.
[9] Emergency Department, Hospital Central de Asturias, Oviedo, Spain.
[10] Preventive Medicine Department, Hospital Clínico San Carlos, Madrid, Spain

fjjms@hotmail.com

ABSTRACT

OBJECTIVE: To study patient profile and fall-related immediate and 6-month outcomes according to fall causes among older people presenting to the ED after a fall.

METHODS: a retrospective analysis of the FALL-ER registry that included patients aged ≥65 years old who presented to 5 Spanish ED after a fall. Fallers were classified into three categories (extrinsic, intrinsic and non-identified causes) and patient and fall characteristics, immediate and 6-month outcomes were analyzed.

RESULTS: We included 1569 patients, 936 (59.7%) extrinsic, 245 (15%) intrinsic and 388 (24.7%) not-identified causes. Fallers profile was very old community living women with a high frequency of severe comorbidity, polypharmacy and geriatric syndromes and the half of them had some degree of disability. The majority of falls were daytime, outdoor and witnessed. Eight out of ten fallers experienced an immediate adverse event (66.9% severe injury, 20.0% functional decline, 47.1% fear of falling and 2.1% died) and one out two suffered a 6-month poor outcome (30.5% functional decline; 12.7% fall-related injuries, 4.4% fall-related injuries, 8.4% fall-related ED revisit and 9.8% died). Some differences were seen among patient characteristics and immediate injuries when extrinsic and intrinsic falls were considered. Regarding consequences, there was difference between three groups in terms of 6-month composite outcome (p<0.001), but no respect for the immediate composite outcome (p=0.117).

CONCLUSIONS: older fallers profile and 6-month outcomes are different according to fall causes.

Keywords: Fall; older; emergency department; prevention; geriatric medicine.

1. INTRODUCTION

Falls are an essential health problem for older subjects [1], affecting one of every three adults aged ≥65 years old living in the community per year, a risk that increases with age [2]. Falls represent one of the leading causes of injury, functional deterioration, recurrent falls, admission to nursing care facilities and mortality in this age group [3]. Falls and fall-related injuries are increasing with population ageing and constitute a routine Emergency Department (ED) care cause [4, 5].

It is known that one out of four older fallers is attended in EDs [6]. Falls have been associated with a future adverse result [7]. Despite this fact, ED assessment is mainly focused on the acute consequences of falling, underestimating the importance of identifying fall causes [8]. Falls are a complex interaction of biological, behavioural and environmental risk factors [9], and they can be the consequence of the interaction of the patient with environmental hazards but also the expression of an underlying internal medical condition among older adults.

Considering that little information is available about the older patient profile and consequences of falling at Spanish EDs, FALL-ER registry (FALLs attended at the Emergency Room) was designed. It includes patients aged ≥65 years old presenting to Spanish ED after a fall. Currently, the causes of fall are not systematically in medical assessment because this depends on the medical specialist who visits the patient in EDs. For the present study, we aimed to describe the profile and the immediate and 6-month outcomes according to fall causes among older adults presenting to Spanish EDs after a fall.

2. PATIENTS AND METHODS

2.1 Study design

This was a retrospective analysis of the FALL-ER Registry (FALLs attended at the Emergency Room). Five Spanish tertiary teaching EDs participated in this prospective cohort: Hospital Universitario Clínico San Carlos (HCSC) of Madrid, Hospital Universitario General de Alicante (HUGA), Hospital Universitari de Bellvitge of Barcelona (HUBB), Hospital Clinic of Barcelona (HCB) and Hospital Universitario Central de Asturias (HUCA) of Oviedo. Clinical research committee approved this register. Patients or legal representatives gave written informed consent to participate.

2.2 Patients

The FALL-ER Registry included all consecutive patients aged ≥65 years that were attended at the participating EDs after witnessed or self-referred fall. The definition of fall was that proposed by the World Health Organization [9]: any event that precipitates the patient to the ground, against his/her will. Motor vehicle accidents were excluded. The period of inclusion comprised from 1 September 2014 to 31 August 2015, and patient enrolment was performed during 52 randomly predefined days along 1-year period (one day per week, from 8:00 am to 7:59 am of the next day).

When attending physician detected an eligible patient, one investigator of each centre checked that patient meets selection criteria. All participants were offered to be followed up after ED attention to assess adverse outcomes. As inclusion criteria for the follow-up, patients had to agree with the monitoring and provide adequate contact details. They had to be able to answer by themselves a questionnaire or to have a permanent caregiver if they were not able to answer by themselves, who ultimately answered the survey.

2.3 Variables

Independent variables included demographic data, comorbidity, chronic treatments, functional, social and cognitive status, geriatric syndromes, characteristics of the fall, healthcare resources use, physical, functional and psychological consequences after the fall. The aetiology of the fall was classified into extrinsic (an external condition precipitated the fall), intrinsic (a medical condition precipitated the fall) or not-identified.

Variables were collected prospectively by investigators based on the clinical history and face-to-face interviews at the index fall and through a phone call at six-month follow-up.

2.4 Outcomes

We considered the presence of severe injury, acute functional impairment, fear of falling and in-hospital mortality as immediate adverse outcomes. A severe injury was defined as the presence of wounds that needed suture, fractures that needed immobilization or surgical intervention, traumatic brain injury, thoracic contusion, abdominal contusion or any other injury that required hospitalization. Functional status was assessed using the Spanish version of the Barthel Index (BI) [10]. Acute functional impairment was defined as the BI loss of ≥10 points at discharge (from ED or hospitalization if admitted) concerning BI at baseline (calculated at the ED interview with the patient or caregiver functional reported status the month before the fall). Fear of falling was defined as an affirmative response to the question “are you afraid of falling again?” [11], asked by the investigator to the patient. In-hospital mortality was defined as death from any cause during hospitalization due to a fall.

At six-month follow up, we considered functional decline, fall-related injury, fall-related fractures, fall-related ED revisit and all-cause mortality as adverse outcomes. Functional decline was defined as the BI loss of ≥10 points at 6-month follow-up assessment concerning BI at baseline.

2.5 Statistical analysis

Qualitative data were expressed as absolute values and percentages. Quantitative data were expressed as mean and standard deviation (SD) or as median and interquartile range (IQR) if the variables did not fit a normal distribution. We divided the sample into three groups (extrinsic, intrinsic and non-identified causes), and we compared the clinical characteristics between them. For qualitative data, the differences between groups were investigated using the chi-square test with Bonferroni correction for multiple comparisons. For quantitative data, the differences between groups were investigated using ANOVA assess if the distribution met normality principle (which was analysed by the Kolmogorov-Smirnov test) or by the nonparametric Kruskal-Wallis test if they did.

3. RESULTS

The FALL-ER Registry included 1610 patients, 1569 (97.5%) of whom were included in the present study. Mean age was 79.9 (SD 8.1) years, and 68.9% were women. The majority (59.7%) of falls were due to extrinsic causes, whereas intrinsic causes only represent 15%, remaining non-identified the cause of falling in one out of four (24.7%) patients.

The majority of fallers were community-living older adults (only 6.3% in nursing homes). Approximately one of half was independent (58.2%) for activities of daily living (ADLs). Comorbidity was high (median 4 (SD 2-6) of Charlson index). Hypertension (67.8%), arthrosis (47.5%), diabetes (27.8%) and cerebrovascular disease (19.1%) were prevalent conditions. The use of chronic medication and the presence of previous geriatric syndromes was frequent (**Table 1a** and **Table 1b**).

Regarding fall characteristics, extrinsic-cause falls occurred more frequently during the day, in the presence of witnesses and outdoors than intrinsic-falls, although in more than a half (64.9%) cases falls occurred at home (**Table 2**). Almost one-third (31.4%) of fallers needed medical attention at the scene, and nearly half of them (45.6%) were transferred by ambulance to the hospital. Both prehospital and hospital healthcare resource use statistically increased when intrinsic-causes were suspected (**Table 2**).

Tables 1a and **1b** show patient characteristics according to fall causes. Extrinsic-cause fallers profile had a significantly higher frequency of women (72.5%), arthrosis (50.8%) and better functional status (65.6% independent for ADLs). Otherwise, among intrinsic-cause fallers, functional dependence, comorbidities such as cerebrovascular disease, and the use of antipsychotics, antihypertensive vasodilators, diuretics, alcohol or drugs were more frequent. One out of three (32.8%) patients in this group had fallen in the previous year being significantly more common than the extrinsic groups (19.6%).

Respect to the immediate consequences, over eighty percentage (85.5%) of fallers experienced an adverse event: 1046 (66.9%) patients sustained a severe injury, 215 (20%) experienced functional decline, 703 (47.1%) had a fear of falling again and 24 (1.6%) died during hospitalization (**Figure 1a**). There was no difference between the three groups regarding the immediate composite outcome (p=0.117). Despite the fact that no difference was seen according to fall causes, fractures were significantly more frequent in extrinsic-cause falls (p=0.001). In contrast, traumatic brain injury and hospitalization were significantly more common in intrinsic-cause falls (p<0.001 for both variables) (**Figure 1b**).

Six months after the index fall, nearly half (47.2%) of fallers experienced an adverse outcome: 385 (30.5%) had functional decline, 167 (12.7%) fall-related injuries, 58 (4.4%) fall-related fractures, 114 (8.4%) fall-related ED revisit and 148 (9.8%) died. There was difference between the three groups regarding the 6-month composite outcome (p<0.001). **Figure 2** shows no differences among the different fall causes and fall-related injury (p=0.704) or ED revisits (p=0.847). At the same time, functional decline (p=0.021), fractures (p=0.031), death (p<0.001) and 6-month composite adverse outcome (p<0.001) increased when intrinsic and non-identified causes are considered.

4. DISCUSSION

This study describes physical, functional, psychological and healthcare resource impact of falls among older presenting to Spanish EDs after a fall. Most patients experienced immediate adverse events, and nearly half of them had a poor outcome within six months of ED presentation after a fall. According to fall aetiology, there are no differences for immediate consequences, whereas those who fall due to intrinsic or non-identified causes are more likely to experience an adverse event within six months of the index fall.

The FALL-ER cohort shows that older subjects assessed for falls in Spanish EDs are very old, predominantly women, with a high degree of comorbidity, geriatric syndromes and polipharmacy [12]. One out of four patients had a previous fall. The frequency of fractures, hospitalization and mortality rates are similar to those reported in previous studies [12-17].

In our study, most falls were classified as extrinsic, whereas intrinsic causes only represent 15%. When considering patient characteristics, extrinsic cause fallers were more commonly independent. This may justify that nearly half of the falls occurred outdoors [12,18,19]. These results emphasize the importance of prevention in the public environment. On the contrary, intrinsic-cause fallers had higher proportions of individuals with a history of falls, dependence for ADLs and use of chronic medications that have been associated with an increased risk of falling [20]. Previous studies have shown that the risk of recurrent falls is related to inappropriate medication use [21] and that alcohol use could have synergic effects with medications among the elderly [22]. All these circumstances should be considered at ED discharge, considering medication withdrawal of inappropriate medications [23, 24].

The probability of falling at home, during the night and being unable to get up was higher in the intrinsic cause group. This remarks on the importance of prevention on home and behavioural risk factors as well as social support. Important modifiable environmental risk factors include lighting, stair and bath rails, clutter, gait aids, and wet surfaces [25] and intervention in high-risk groups may reduce fall risk [26]. Healthcare resource use was higher in this group, considering prehospital and ED assistance and hospitalization rates, which indicates a higher risk group at the first attention.

This study shows that most patients experienced an adverse event after a fall, with no differences between extrinsic and intrinsic causes for severe injury, fear of falling, acute functional impairment or mortality. Despite this fact, fractures are more frequent in the extrinsic cause group while traumatic brain injury is more frequent in the intrinsic cause group. This may be related to the interference of patient reflexes when the fall is precipitated by medical conditions, differentiating it from extrinsic cause falls when they tend to extend their arms as they fall resulting in higher head trauma the former and forearm fractures the latter [25]. Therefore, these data support the importance of fall dynamics with both gravitational and kinetic forces in the former versus only gravitational in the latter. This may help to explain that fractures were more frequently in the extrinsic-cause falls. Fear of falling was more common among patients with non-identified causes, but no differences were seen when comparing extrinsic and intrinsic. Activity restriction is associated with fear of falling in older populations, and it has been associated with future falls [27] and functional decline [28].

Regarding 6-month outcomes, differences were seen according to fall causes. Functional decline, fall-related fracture and all-cause mortality are higher when the index fall was classified as intrinsic and non-identified. We would like to highlight that whereas 6-month all-cause mortality was significantly lower for extrinsic causes, no differences were seen between extrinsic and intrinsic causes for the other outcomes. One out of four patients experienced a functional decline, and new falls within 6-month follow up occurred in both groups with no differences for fall-related injuries (12%) and ED revisits (8%). Therefore, the consequences of falling due to extrinsic causes, which are usually discharged from EDs, are not as benign as physicians may predict. In this sense, we suggest that more in-depth diagnosis should be made when causes of falling are not identified, and close monitoring should be implemented despite fall causes.

The present study has several limitations. Firstly, only older adults who presented to EDs due to a fall were included. Therefore, the patients sustaining injuries and those with an unknown mechanism of falling could have been favoured. Secondly, systematic sampling was carried out in centres selected by convenience. Thus, there is a risk for selection bias. Thirdly, the study has been performed under clinical practice conditions at EDs, and its fast-paced nature combined with the complex interaction of risk factors for falls in older people could have limited fall cause assessment and final diagnosis. Despite these limitations, the present study provides a global perspective of older patient's outcomes when presenting to Spanish EDs due to a fall.

In conclusion, this study shows that older fallers profile and their immediate and 6-month outcomes are different according to fall causes. Future studies are necessary to determine whether the older patients attended for a fall require or not a distinct assessment and recommendations after being discharged from EDs.

Conflict of interest: All authors declare that they have no conflict of interest.

Funding: This work was financially supported by a competitive grant of the MAPFRE Foundation [C.I. 14/371-E_BS] for data management and English writer.

TABLES AND FIGURES

Table1a: Characteristics of older fallers according to fall causes

	Total (N=1569)	Extrinsic causes (N=936)	Intrinsic causes (N=245)	Non-identified causes (N=388)	p value
Demographic data – n (%)					
Age, M (SD)	79.9 (8.1)	79.1 (8.2)	80.0 (7.8)	81.6 (7.6)	**<0.001**
Sex, female	1079 (68.9)	678 (72.5)[a]	141 (57.8)	260 (67.0)	**<0.001**
Comorbidity – n (%)					
Alcohol and/or drugs use	82 (5.3)	34 (3.7)[a]	26 (10.7)	22 (5.9)	**<0.001**
Hypertension	1078 (68.9)	632 (67.8)	183 (74.7)	263 (68.0)	0.105
Diabetes mellitus	434 (27.8)	260 (27.9)	73 (30.2)	101 (26.2)	0.551
Myocardial infarction	218 (14.0)	135 (14.5)	32 (13.1)	51 (13.2)	0.750
Chronic heart failure	229 (14.7)	129 (13.9)	35 (14.2)	65 (17.0)	0.346
Significative valvular heart disease	100 (6.4)	49 (5.3)	16 (6.6)	35 (9.0)	**0.040**
Atrial fibrillation / flutter	278 (17.8)	152 (16.3)	45 (18.4)	81 (20.9)	0.132

	Total (N=1569)	Extrinsic causes (N=936)	Intrinsic causes (N=245)	Non-identified causes (N=388)	p value
Ventricular tachicardia episode	21 (1.3)	10 (1.1)	4 (1.6)	7 (1.8)	0.520
Pacemaker	54 (3.5)	31 (3.3)	10 (4.1)	13 (3.4)	0.835
Implantable cardioverter defibrillator	11 (0.7)	6 (0.6)	1 (0.4)	4 (1.0)	0.621
Chronic obstructive pulmonary disease	138 (8.8)	74 (7.9)	29 (11.9)	35 (9.0)	0.152
Liver disease	69 (4.4)	39 (4.2)	10 (4.1)	20 (5.2)	0.707
Peripheral vascular disease	256 (16.4)	158 (17.0)	37 (15.2)	61 (15.8)	0.753
Cerebrovascular disease	299 (19.1)	142 (15.2)[a]	56 (23.0)	101 (26.2)	**<0.001**
Epilepsy	46 (2.9)	22 (2.4)	9 (3.7)	15 (3.9)	0.244
Parkinsonism	95 (6.1)	47 (5.0)	17 (7.0)	31 (8.0)	0.094
Normal pressure hydrocephalus	12 (0.8)	4 (0.4)	2 (0.2)	6 (1.6)	0.102
Central nervous system cancer	10 (0.6)	6 (0.6)	2 (0.8)	2 (0.5)	0.898
Neuromuscular disorders	33 (2.1)	19 (2.0)	7 (2.9)	7 (1.8)	0.646
Arthrosis	737 (47.5)	472 (50.8)[a]	87 (36.1)	178 (46.5)	**<0.001**
Osteoporosis	408 (26.4)	243 (26.2)	48 (20.1)	117 (30.7)	**0.014**
Previous fractures	304 (20.0)	173 (19.1)	39 (16.4)	92 (24.6)	**0.026**
Chronic kidney disease	230 (14.9)	129 (14.0)	38 (15.7)	63 (16.4)	0.484
Anaemia	246 (15.8)	132 (14.2)	35 (14.5)	79 (20.5)	**0.014**
Lower-extremity ulcers	60 (3.9)	42 (4.5)	4 (1.7)	14 (3.7)	0.120
Active cáncer	161 (10.3)	91 (9.8)	30 (12.4)	40 (10.4)	0.493
Connective tissue disease	45 (2.9)	22 (2.4)	8 (3.3)	15 (3.9)	0.295

[a]p<0.05 between extrinsic and intrinsic groups.

Table1b: Characteristics of older fallers according to fall causes

	Total (N=1569)	Extrinsic causes (N=936)	Intrinsic causes (N=245)	Non-identified causes (N=388)	p value
Comorbidity					
Charlson Index, Median (IQR)	4 (2-6)	4 (2-6)	4 (2-6)	5 (3-7)	**<0.001**
Chronic medications – n (%)					
Benzodiazepines	530 (34.0)	311 (33.4)	77 (31.6)	142 (36.8)	0.347
Antidepressants	420 (26.9)	248 (26.6)	60 (24.6)	112 (28.9)	0.469
Antipsychotics	237 (15.2)	114 (12.3)	43 (17.6)	80 (20.9)	**<0.001**
Antihypertensive vasodilators	859 (55.1)	529 (56.9)	140 (57.6)	190 (49.1)	**0.023**

	Total (N=1569)	Extrinsic causes (N=936)	Intrinsic causes (N=245)	Non-identified causes (N=388)	p value
Diuretics	583 (37.4)	317 (34.1)[a]	104 (42.6)	162 (41.9)	**0.006**
Antiarrhythmics	261 (16.8)	155 (16.7)	46 (18.9)	60 (15.6)	0.563
Non-opioid analgesics	607 (39.0)	347 (37.4)	91 (37.3)	169 (43.8)	0.081
Opioid analgesics	194 (12.4)	123 (13.3)	27 (11.1)	44 (11.4)	0.498
Antidiabetic agents	371 (23.9)	221 (23.9)	64 (26.3)	86 (22.2)	0.498
Anticoagulants	252 (16.2)	140 (15.1)	37 (15.2)	75 (19.4)	0.144
Antiplatelet agents	478 (30.7)	280 (30.2)	81 (33.2)	117 (30.4)	0.653
Baseline functional status – n (%)					
Independent ADL	888 (58.2)	598 (65.6)[a]	137 (56.4)	153 (41.0)	**<0.001**
Partially dependent ADL	511 (33.5)	264 (29.0)[a]	79 (32.5)	168 (45.0)	
Dependent ADL	128 (8.4)	49 (5.4)[a]	27 (11.1)	52 (13.9)	
Geriatric Syndromes – n (%)					
Falls in the last 12 months	365 (24.0)	178 (19.6)[a]	79 (32.8)	108 (29.1)	**<0.001**
Visual impairment	916 (60.9)	548 (61.0)	155 (66.8)	213 (57.0)	0.053
Hearing impairment	452 (30.1)	243 (27.1)	76 (32.6)	133 (35.8)	**0.005**
Cognitive impairment	400 (26.4)	183 (20.3)	63 (26.6)	154 (41.2)	**<0.001**
Depression	467 (30.9)	263 (29.1)	71 (30.2)	133 (35.8)	0.064
Urinary incontinence	496 (32.9)	248 (27.6)[a]	88 (37.4)	160 (43.0)	**<0.001**
Insomnia	438 (29.2)	235 (26.2)	78 (33.3)	125 (33.6)	**0.010**
Social support – n (%)					
Live alone	297 (19.9)	172 (19.5)	62 (26.3)	63 (16.8)	**0.015**
Nursing home	94 (6.3)	50 (5.6)	12 (5.0)	32 (8.6)	0.100

1. ADL: Activities of daly living.
[a]p<0.05 between extrinsic and intrinsic groups.

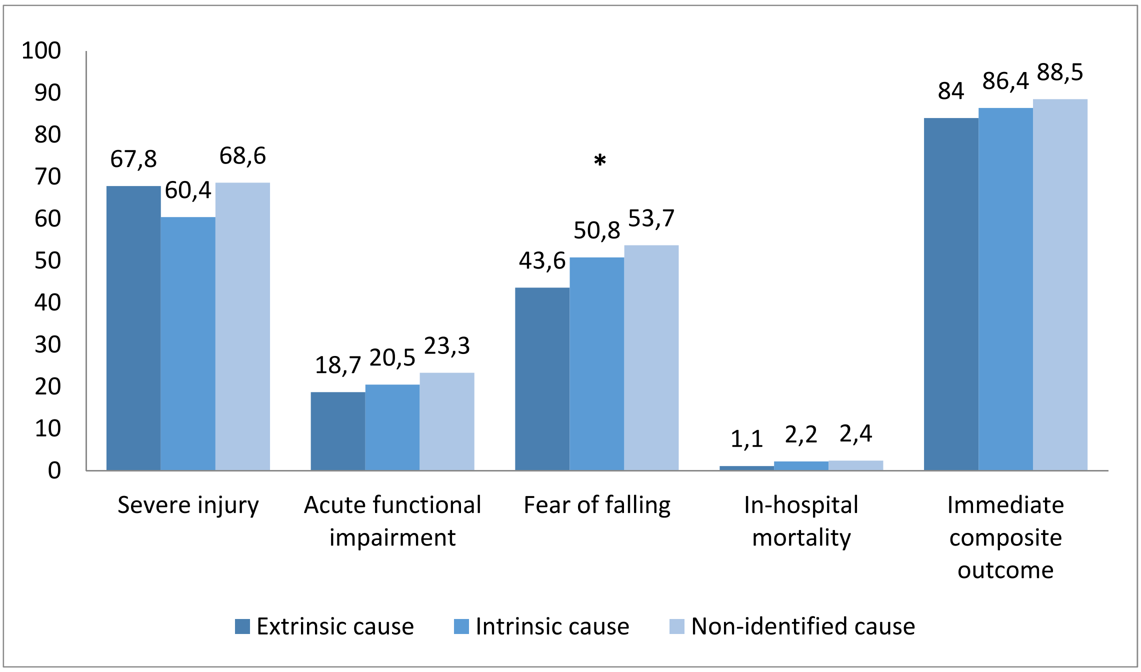
Table2: Characteristics, causes, use of resources and consequences of falls according to fall causes

	Total (N=1569)	Extrinsic causes (N=936)	Intrinsic causes (N=245)	Non-identified causes (N=388)	p value
Fall related characteristics – n(%)					
Daytime fall	1172 (78.3)	740 (82.6)[a]	160 (68.1)	272 (74.3)	**<0.001**
Witnessed fall	828 (56.9)	514 (60.3)	124 (53.0)	190 (51.6)	**0.008**
Indoor	956 (64.9)	498 (57.2)[a]	176 (74.6)	282 (76.6)	**<0.001**
Loss of consciousness	98 (6.4)	17 (1.9)[a]	63 (26.1)	18 (4.8)	**<0.001**
Not to be able to stand up	362 (23.9)	184 (20.3)[a]	75 (31.5)	103 (27.8)	**<0.001**
Medical attention at scene –n(%)					
Medical assistance at scene	475 (31.4)	247 (27.4)[a]	99 (41.4)	129 (34.7)	**<0.001**
CPR	3 (0.2)	1 (0.1)	2 (0.8)	0 (0)	**0.050**
Ambulance requirement	681 (45.6)	363 (40.5)[a]	143 (60.1)	175 (48.6)	**<0.001**
ED diagnostic testing –n(%)					

	Total (N=1569)	Extrinsic causes (N=936)	Intrinsic causes (N=245)	Non-identified causes (N=388)	p value
CBC and/or biochemistry	674 (43.3)	327 (35.3)[a]	183 (75.0)	164 (42.4)	**<0.001**
Radiograph	1327 (85.1)	797 (85.9)	204 (83.3)	326 (84.2)	0.516
Electrocardiogram	447 (28.7)	184 (19.8)[a]	147 (60.2)	116 (30.1)	**<0.001**
Ultrasound scan	14 (0.9)	8 (0.9)	1 (0.4)	5 (1.3)	0.516
Computed tomography scan	392 (25.2)	208 (22.4)[a]	93 (38.1)	91 (23.7)	**<0.001**
ED treatment –n(%)					
Drug prescription	810 (52.1)	438 (47.2)[a]	161 (66.3)	211 (54.7)	**<0.001**
Suture	215 (14.0)	112 (12.2)	36 (14.8)	67 (17.6)	**0.035**
Immobilization techniques	71 (36.9)	373 (40.5)[a]	56 (23.0)	142 (37.2)	**<0.001**
Surgical intervention	172 (11.2)	101 (11.0)	25 (10.2)	46 (12.1)	0.753
Type of injury caused by falls –n(%)					
Contusions or lacerations	816 (56.7)	493 (55.8)	117 (59.4)	206 (57.4)	0.619
Fractures	603 (41.7)	393 (44.4)[a]	60 (30.2)	150 (41.7)	**0.001**
Traumatic brain injury	261 (18.1)	143 (16.2)[a]	56 (28.4)	62 (17.3)	**<0.001**
Disposition –n(%)					
Hospitalization	364 (23.2)	169 (18.1)[a]	87 (35.7)	108 (27.9)	**<0.001**

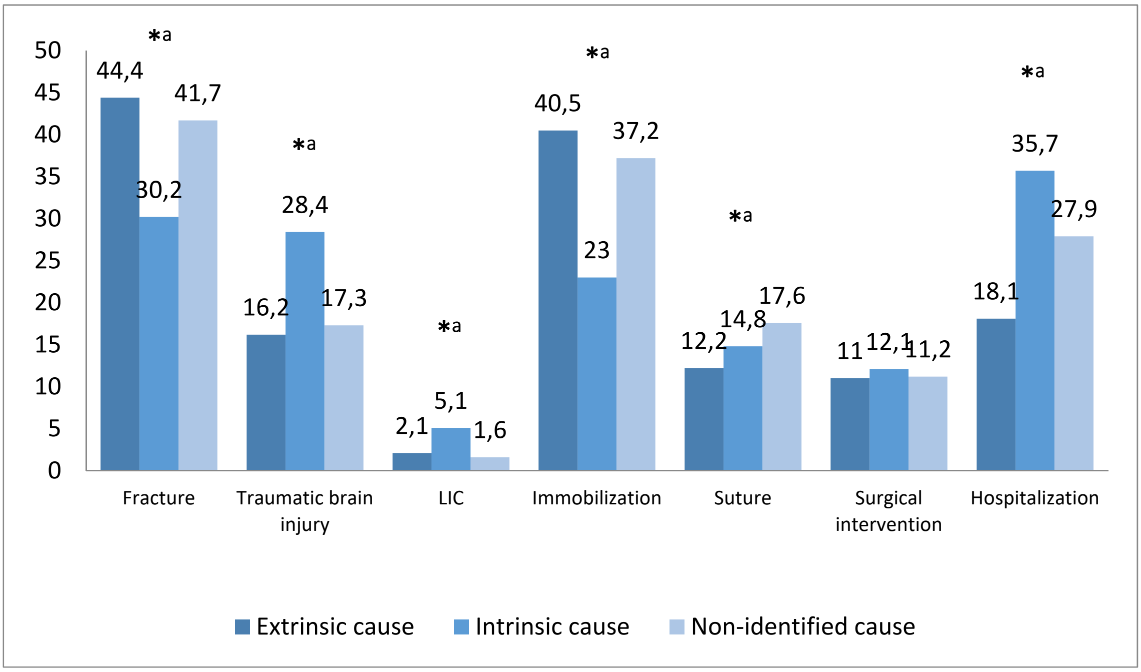
[a]p<0.05 between extrinsic and intrinsic groups.

Figure 1a: Immediate outcomes of older fallers according to fall causes (%)



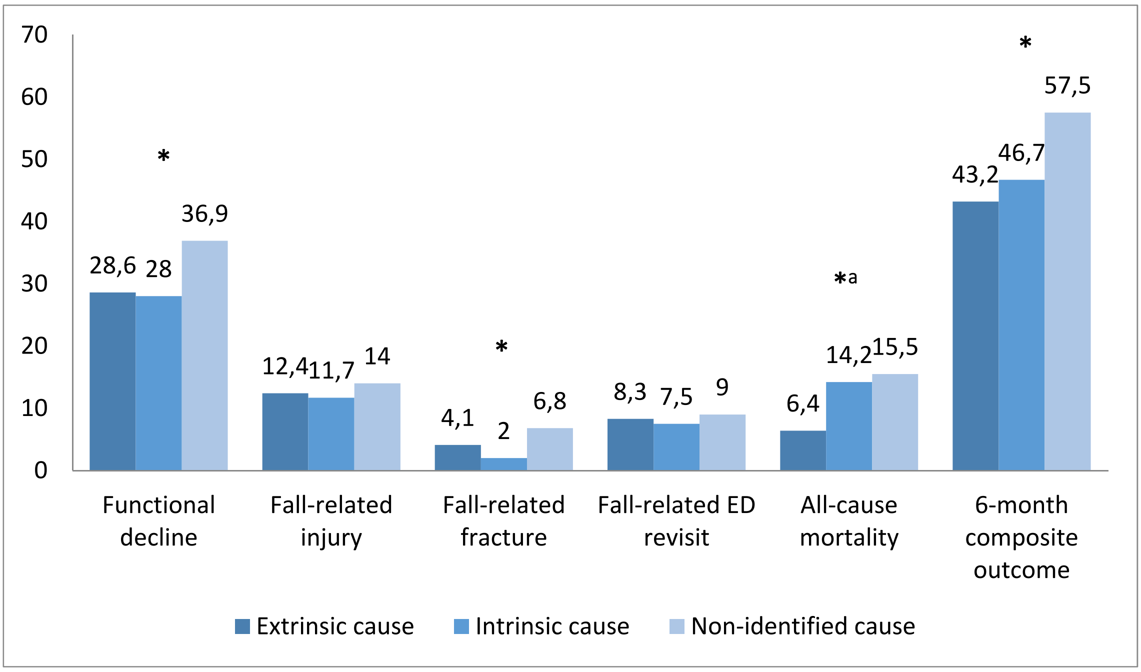
* p<0.05

Figure 1b: Severe injury as a consequence of falling according to fall causes (%)



1. Thoracic organ injury (N=8) and abdominal organ injury (N=1) are not represented in the graphic due to their low frequency. Percentages according to fall causes (extrinsic, intrinsic and non-identified cause) were: 0.3%, 0.8% and 0.8% for thoracic organ injury (p=0.427) and 0.1%, 0% and 0% for abdominal organ injury (p=0.717); *p<0.05; [a] p<0.05 between extrinsic and intrinsic causes.

Figure 2: 6 Month outcomes of older fallers according to fall causes (%)



* p<0.05; [a] p<0.05 between extrinsic and intrinsic causes.

REFERENCES

1. Lázaro Del Nogal M. (2009). Caídas en el anciano [Falls among older persons]. *Medicina clinica*, *133*(4), 147–153. doi:10.1016/j.medcli.2008.12.029

2. Tinetti, M. E., Speechley, M., & Ginter, S. F. (1988). Risk factors for falls among elderly persons living in the community. *The New England journal of medicine*, *319*(26), 1701–1707. doi:10.1056/NEJM198812293192604

3. Kannus, P., Parkkari, J., Koskinen, S., Niemi, S., Palvanen, M., Järvinen, M., & Vuori, I. (1999). Fall-induced injuries and deaths among older adults. *JAMA*, *281*(20), 1895–1899. doi:10.1001/jama.281.20.1895

4. Albert, M., McCaig, L. F., & Ashman, J. J. (2013). Emergency department visits by persons aged 65 and over: United States, 2009-2010. *NCHS data brief*, (130), 1–8

5. Shankar, K. N., Liu, S. W., & Ganz, D. A. (2017). Trends and Characteristics of Emergency Department Visits for Fall-Related Injuries in Older Adults, 2003-2010. *The western journal of emergency medicine*, *18*(5), 785–793. doi:10.5811/westjem.2017.5.33615

6. Cigolle, C. T., Ha, J., Min, L. C., Lee, P. G., Gure, T. R., Alexander, N. B., & Blaum, C. S. (2015). The epidemiologic data on falls, 1998-2010: more older Americans report falling. *JAMA internal medicine*, *175*(3), 443–445. doi:10.1001/jamainternmed.2014.7533

7. Sirois, M. J., Émond, M., Ouellet, M. C., Perry, J., Daoust, R., Morin, J., Allain-Boulé, N. (2013). Cumulative incidence of functional decline after minor injuries in previously independent older Canadian individuals in the emergency department. *Journal of the American Geriatrics Society*, *61*(10), 1661–1668. doi:10.1111/jgs.12482

8. Tirrell, G., Sri-on, J., Lipsitz, L. A., Camargo, C. A., Jr, Kabrhel, C., & Liu, S. W. (2015). Evaluation of older adult patients with falls in the emergency department: discordance with national guidelines. *Academic emergency medicine : official journal of the Society for Academic Emergency Medicine*, *22*(4), 461–467. doi:10.1111/acem.12634

9. World Health Organization. WHO Global report on falls Prevention in older Age [internet]. Geneva: World Health Organization; 2008. Available at: http://apps.who.int/iris/bitstream/10665/43811/1/9789241563536_eng.pdf

10. Baztán, J.J., Pérez del Molino, J., Alarcón, T., San Cristóbal, E., Izquierdo, G., Manzarbeita, I. (1993). Índice de Barthel: instrumento válido para la valoración funcional de pacientes con enfermedad cerebrovascular. *Revista Española de Geriatría y Gerontolología, 28,* 32-40

11. Alarcón, T., González-Montalvo, J. I., & Otero Puime, A. (2009). Evaluación de los pacientes con miedo a caídas. ¿El método empleado modifica los resultados? Una revisión sistemática [Assessing patients with fear of falling. Does the method use change the results? A systematic review]. *Atencion primaria*, *41*(5), 262–268. doi:10.1016/j.aprim.2008.09.019

12. Trevisan, C., Di Gregorio, P., Debiasi, E., Pedrotti, M., La Guardia, M., Manzato, E., … March, A. (2017). Factors influencing short-term outcomes for older patients accessing emergency departments after a fall: The role of fall dynamics. *Gait & posture*, *58*, 463–468. doi:10.1016/j.gaitpost.2017.09.011

13. Bell, A. J., Talbot-Stern, J. K., & Hennessy, A. (2000). Characteristics and outcomes of older patients presenting to the emergency department after a fall: a retrospective analysis. *The Medical journal of Australia*, *173*(4), 179–182

14. Pfortmueller, C. A., Kunz, M., Lindner, G., Zisakis, A., Puig, S., & Exadaktylos, A. K. (2014). Fall-related emergency department admission: fall environment and settings and related injury patterns in 6357 patients with special emphasis on the elderly. *TheScientificWorldJournal*, *2014*, 256519. doi:10.1155/2014/256519

15. Morteza Bagi, H. R., Ahmadi, S., & Hosseini, M. (2017). Demographics of Fall-Related trauma among the Elderly Presenting to Emergency Department; a Cross-Sectional Study. *Emergency (Tehran, Iran)*, *5*(1), e78. doi:10.22037/emergency.v5i1.18497

16. Cimilli Ozturk, T., Ak, R., Unal Akoglu, E., Onur, O., Saritemur, M. (2017). Factors associated with multiple falls among elderly patients admitted to emergency department. *International Journal of Gerontology (11),* 85-89

17. Kim S. H. (2016). Risk factors for severe injury following indoor and outdoor falls in geriatric patients. *Archives of gerontology and geriatrics*, *62*, 75–82. doi:10.1016/j.archger.2015.10.003

18. Duckham, R. L., Procter-Gray, E., Hannan, M. T., Leveille, S. G., Lipsitz, L. A., & Li, W. (2013). Sex differences in circumstances and consequences of outdoor and indoor falls in older adults in the MOBILIZE Boston cohort study. *BMC geriatrics*, *13*, 133. doi:10.1186/1471-2318-13-133

19.- Kelsey, J. L., Procter-Gray, E., Hannan, M. T., & Li, W. (2012). Heterogeneity of falls among older adults: implications for public health prevention. *American journal of public health*, *102*(11), 2149–2156. doi:10.2105/AJPH.2012.300677

20. American College of Emergency Physicians, American Geriatrics Society, Emergency Nurses Association, Society for Academic Emergency Medicine, & Geriatric Emergency Department Guidelines Task Force (2014). Geriatric emergency department guidelines. *Annals of emergency medicine*, *63*(5), e7–e25. doi:10.1016/j.annemergmed.2014.02.008

21. Zia, A., Kamaruzzaman, S. B., & Tan, M. P. (2017). The consumption of two or more fall risk-increasing drugs rather than polypharmacy is associated with falls. *Geriatrics & gerontology international*, *17*(3), 463–470. doi:10.1111/ggi.12741

22. Lin, H.F., Lai, S.W., Liao, K.F., Muo, C.H., Hsientang Hsieh, D.P. (2013). Synergistic interaction between alcoholism and polipharmacy on the risk of falls in the elderly. *International Journal of Gerontology (7)*, 122-123

23. Montali, F., Campaniello, G., Benatti, M.,Rastellli, G., Pedrazzoni, M., Cervellin, G. (2015). Impact of different drug classes on clinical severity of falls in an elderly population: Epidemiological survey in a trauma center. *Journal of Clinical Gerontology and Geriatrics (6)*, 63-67

24. Amorim, A., Guerreiro, M., Morgado, M. (2018). Polypharmacy, risk of falls in older people and deprescribing: A literature review. *International Journal of Clinical Pharmacy (40)*, 245-246

25. Ambrose, A. F., Cruz, L., & Paul, G. (2015). Falls and Fractures: A systematic approach to screening and prevention. *Maturitas*, *82*(1), 85–93. doi:10.1016/j.maturitas.2015.06.035

26. Karlsson, M. K., Vonschewelov, T., Karlsson, C., Cöster, M., & Rosengen, B. E. (2013). Prevention of falls in the elderly: a review. *Scandinavian journal of public health*, *41*(5), 442–454. doi:10.1177/1403494813483215

27. Cronin, M., O'Regan, C.M., Kearney, M., Kenny, R. (2014). Functional and economic associations of fear of falling. *European Geriatric Medicine 5(S1):* 172-173

28. Esbrí-Víctor, M., Huedo-Rodenas, I., López-Utiel, M., Navarro-López, J. L., Martínez-Reig, M., Serra-Rexach, J. A., … Abizanda, P. (2017). Frailty and Fear of Falling: The FISTAC Study. *The Journal of frailty & aging*, *6*(3), 136–140. doi:10.14283/jfa.2017.19

QUALITY OF USER CENTERED DESIGN AND REENGINEERING IN URBANISM BASED IN BIOMECHANICS OF HUMAN MOVEMENT

Kostas Gianikellis[1]

[1]BioẼrgon Research Group, University of Extremadura, Cáceres, Spain.

kgiannik@unex.es

ABSTRACT

Biomechanics offers a lot of possibilities to urban infrastructure professionals because it provides criteria in urban planning in general, and for everything related to accessibility. Biomechanics and Ergonomics allow analysing and simulating the different manifestations of human mobility in urban environments with different characteristics and properties. In Spain, possibilities of the biomechanics of the human movement have not been exploited so far in an applied way to the urban environment. The adaptation of the urban characteristics of the environment acquires special importance, with the possibilities of people with functional diversity, especially users of manual-powered wheelchairs. Biomechanics methodology is based on the use of advanced techniques of analysis of human movement, to help optimize the processes and quality of motor control, which results in greater motor efficiency of users , thus improving the quality of the urban elements, satisfying the explicit and implicit needs of the users, measuring their characteristics and properties so that the products and services are globally competitive.

Keywords: biomechanics, ergonomics, user centered design, usability, accessibility

Topic: Diseño arquitectónico en la prevención de caídas/ The role of Architectural Design

1. INTRODUCTION

1.1. Aims

The aim of this work is to announce to urban infrastructure professionals the possibilities of biomechanical analysis for the elaboration of design criteria in urban planning, in general, and for everything related to falls due to slipping or stumbling in public use spaces; as well as to know and control the friction and damping forces that develop in the interaction between the subject and the support surface, that is, pavements and surfaces in the work, educational, sports and leisure context.

Because the loss of balance in different contexts and situations is a socio-economic problem of considerable relevance, it is important to scientifically analyse cause-effect relationships and propose solutions to prevent falls, slips and trips. These issues are especially important in the context of special population (aged people or people with any disability). This also takes a great importance both in the context of alternative roaming methods (wheelchair, crutches, walkers…), as in the design of environments with ramps and stairs.

In the context of ergonomics (figure 1), biomechanics of human movement takes an important role, because it allows analysing and simulating the different manifestations of human mobility in urban environments with different characteristics and properties. This fact has consolidated it as a field of knowledge in continuous expansion with determining applications in this context, as Margin of Stability (MoS), that is a method by which Center of Mass (CoM) and stability limits are related: A loss of balance occurs when the extrapolated center of mass (XCoM) of the body exceeds the established stability limits with respect to the lift base.

Figure 1: Applications and procedures in Ergonomics.

1. 2. Situation in Spain

In Spain, possibilities of the biomechanics of the human movement have not been exploited so far in an applied way to the urban environment, to the extent that it would correspond to the level of the country as the 9th economic power worldwide. In addition, it has a high participation in the construction of homes, buildings and infrastructure in general.

One of the reasons for this insufficient use of the knowledge of the biomechanics of the human movement and its relevance for urban planning, is also due to training deficiencies, because in the curricula of the corresponding degrees, Biomechanics and Ergonomics is not included, although, instead, the term "accessibility" has been used for many years, which, by definition, is Ergonomics, since "its objective is to generate scientific design criteria, to adapt the products, tasks, tools, spaces and the environment in general, to ensure the safety and health of workers, users or consumers, increase their well-being and improve the efficiency of production processes ("E&E"), taking into account the characteristics of people and especially their morphological characteristics, capacities and limitations " (Gianikellis et al., 2011).

1.3. Usability

In addition, the scientific and technological development in the context marked by the objectives of the *Slips, Trips & Falls Conference*, has much to do with the implementation of alive scenarios that allow monitoring the use of urban building infrastructure, in real conditions, and with usability criteria, defining **usability** as "the extent to which a system, product or service can be used by specific users for specific objectives, in a context of specific use, with effectiveness, satisfaction and efficiency."

There is no doubt that computer simulation of the different manifestations of mobility in any scenario of conditions can contribute to the generation of ergonomic criteria of urban design in both usual spaces and in restricted historical spaces, and provide knowledge and generate design criteria urban planning in the "Smart City" and "Access City" contexts, so that this new "Know-How" contributes to business innovation and technology export.

1.4. User centered design (UCD)

In this context, the adaptation of the urban characteristics of the environment acquires special importance, with the possibilities of people with functional diversity, especially users of manual-powered wheelchairs, a fact that requires research projects aimed at this population to be developed, under the approach of **User Centered Design (UCD)** (figure 2), understood as a "process framework (not restricted to interfaces or technologies) in which usability objectives, user characteristics, environment, tasks and the workflow of a product, service or process receive extensive attention at each stage of the design process ».

Figure 2: User centered design tasks.

2. AVAILABLE METHODOLOGICAL PROCEDURES

Specifically, our work methodology is based on the use of advanced techniques of biomechanical analysis of human movement (presented below), to help optimize the processes and quality of motor control, which results in greater motor efficiency of users , thus improving the quality of the urban elements, satisfying the explicit and implicit needs of the users, measuring their characteristics and properties so that the products and services are globally competitive, in terms of quality, costs, speed, market share and performance of the investment (Quality / Usability / Re-Engineering), taking into account, as *National Research Council* has defined, "the design begins with the understanding of the user's role in the performance of the system as a whole and that the systems exist to serve the user" (Pew, 1983), which has led to what is now known as the user-centered design philosophy, which rec The Human Variability is known as a design factor. Next, some technology available in the lab is showed:

- Inertial human movement capture system, XSENS (figure 3).

Figure 3: Xsens system based on IMUs technology.

- Force platforms (figure 4)

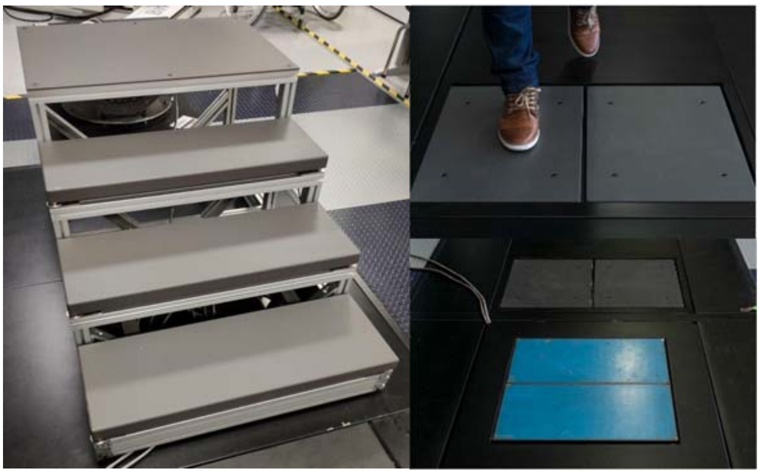


Figure 4: Force platform systems.

- Instrumented wheelchair (figure 5)

Figure 5: Instrumented wheelchair.

- Isokinetic Dynamometer System (figure 6)

Figure 6: Isokinetic dynamometer.

- Electromyography (EMG) (figure 7)

Figure 7: Electromyography system.

- 3D scanner based on laser technology (figure 8)

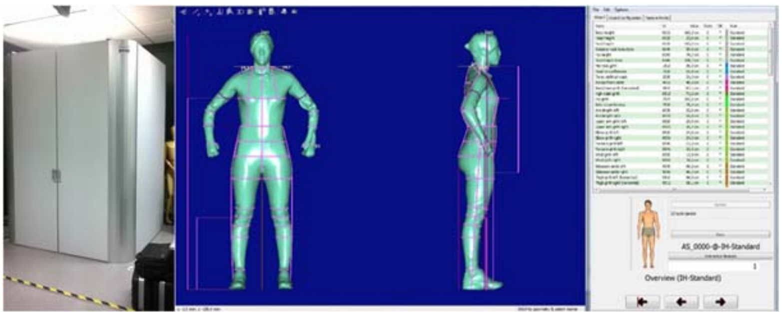


Figure 8: Anthropometric 3D scanner.

- Pressure recording system (figure 9)

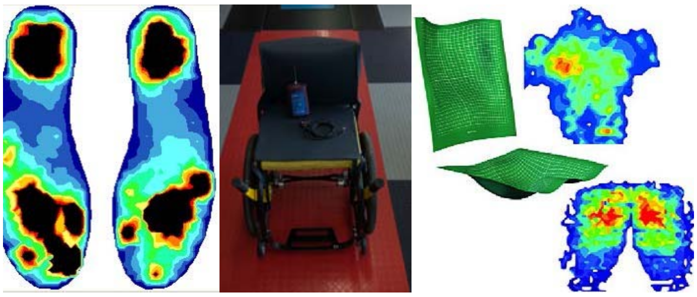


Figure 9: Pressure recording system

- Vibration recording system (figure 10)

Figure 10: Vibration recording system in an instrumented wheelchair.

- Treadmill (figure 11)

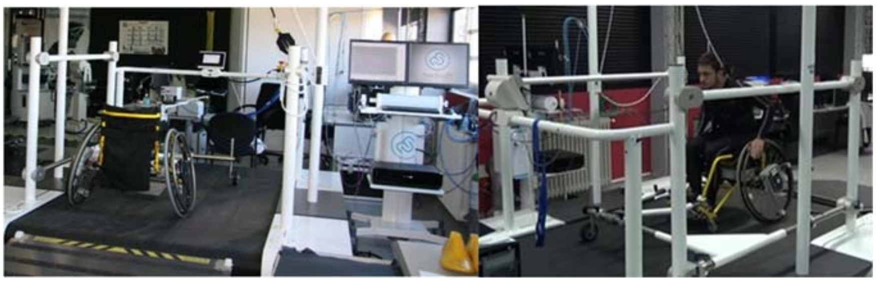


Figure 11: Treadmill integrated with ergospirometry system for wheelchair user evaluation.

- Biomechanical and Simulation analysis software (figure 12)

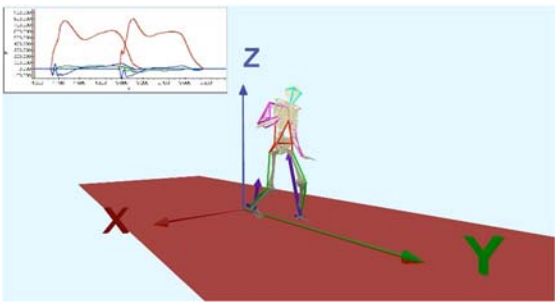


Figure 12: Biomechanical and Simulation analysis software.

- Biomechanical signal treatment (figure 13) and model calculations (figure 14)

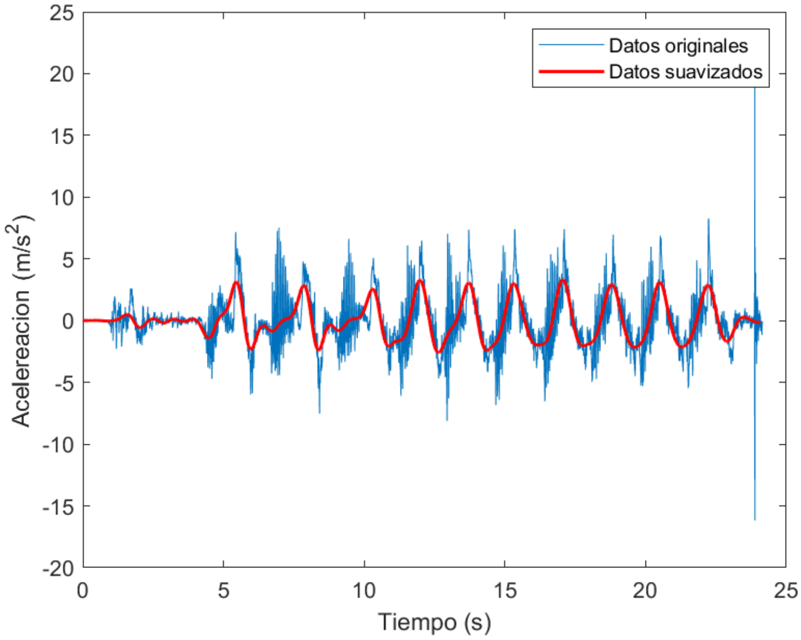


Figure 13: Graphical comparison of filtered and smoothed vs unfiltered acceleration data.

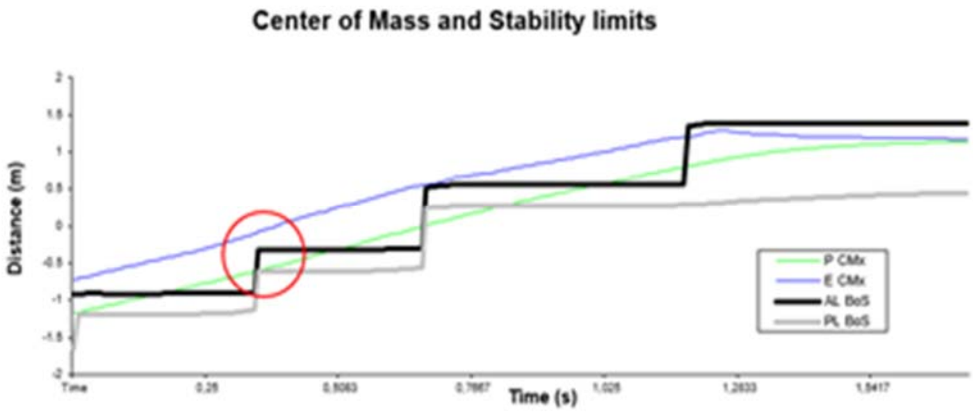


Figure 14: Center of mass, Extrapolated Center of Mass and Margin of Stability (Anterior and Posterior)

3. APPLICATION

Biomechanics has a very important roll in falls prevention depending on the pavement or surface over gait is performed and depending on the specific people’s characteristics. Based on the inverted pendulum model and the concept of the ECM (Hof et al., 2005), in the first graph of figure 15, the subject's body is stable and no additional actions are needed to regain equilibrium, the ECM is within the BS and the MS value is positive, so the subject has only needed one step to regain stability. In the second graph of figure 15, the ECM is outside the BS (negative MS values), so the body is in an unstable situation and requires additional actions to regain stability. This information allows to establish criteria about characteristics of falls in different specific contexts.

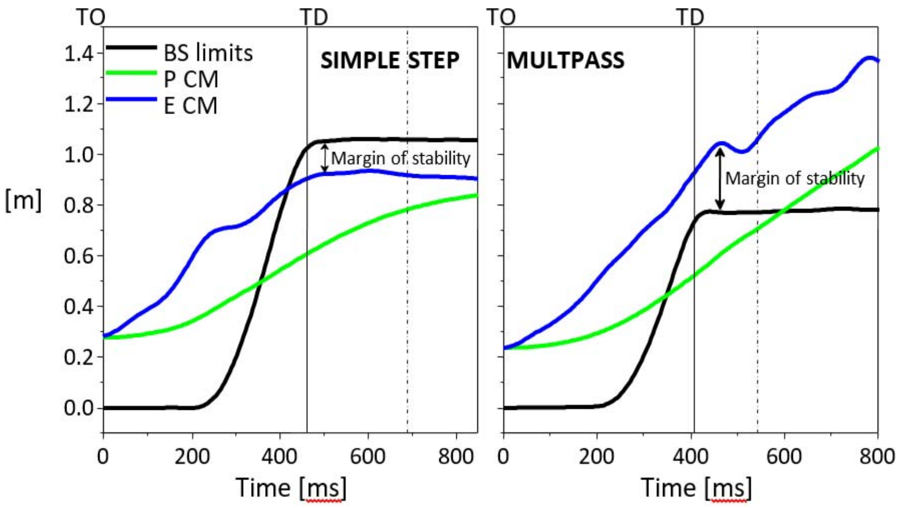


Figure 15: Comparison of the projection of the center of mass, of the extrapolated center of mass, and of the limits of the base of support behavour during the accomplishment of the tasks simple step and multipasses forward.

Analogously to previously mentioned, biomechanics provide criteria for the design of accessible stairs in a way that responds to the needs of the users according to their specific characteristics. Some studies developed by BioẼrgon have showed that users' variability, and their different strategies when climbing and descending stairs, contributes as an important factor in the design factor in stairs (figure 16).

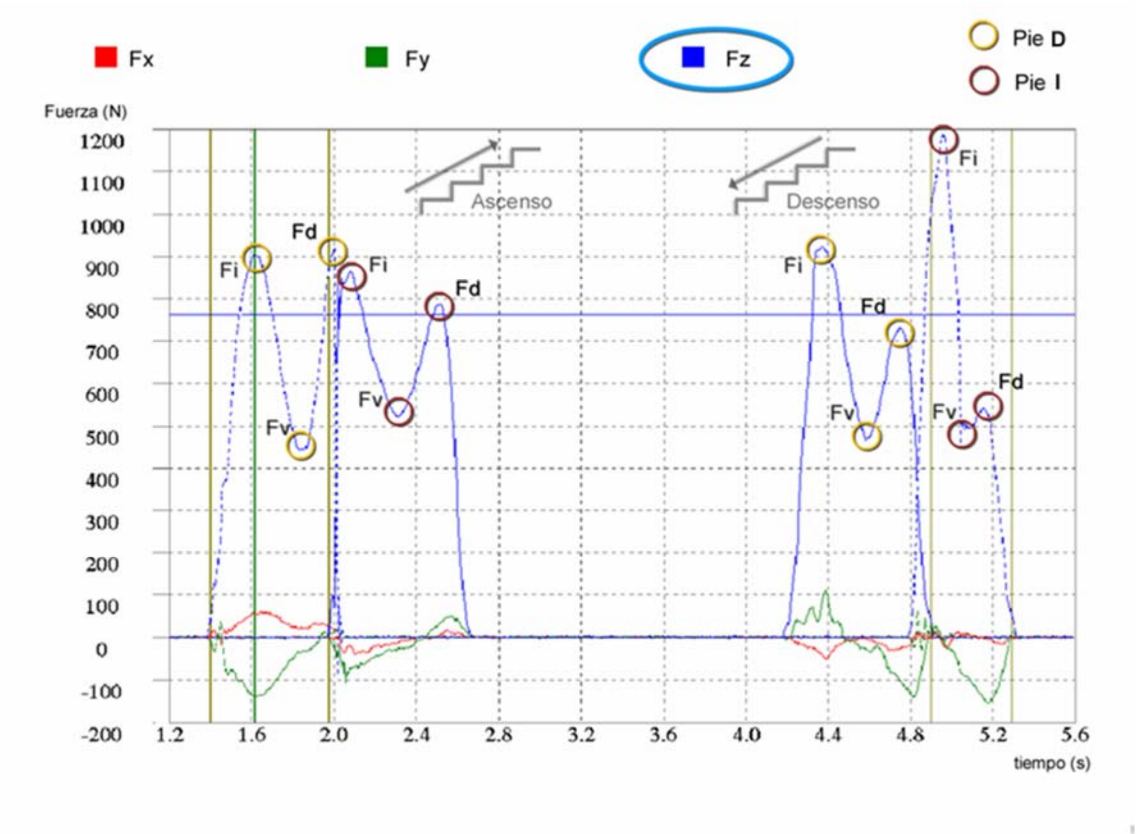


Figure 16: Vertical ground reaction force during the use of stairs.

4. CONCLUSIONS

Considering all of the above, the BioĚrgon research group (University of Extremadura) has developed, for more than 2 decades, technology to meet the two basic needs of ergonomic design in any context, that is, the analysis of tasks and environment and user analysis that is, its morphological and functional characteristics, and its relationship with the fundamental, and differentiated, manifestations of human mobility.

5. REFERENCES

Gianikellis, K., Skiadopoulos, A., & Pantrigo, J. J. (2011). *Evaluación del esfuerzo músculo-esquelético en la zona cuello y hombros para cirugía laparoscópica*. XXXIV Congreso de la Sociedad Ibérica de Biomecánica y Biomateriales, Córdoba, España.

Hof, A., Gazendam, M., & Sinke, W. (2005). The condition for dynamic stability. *Journal of biomechanics*, *38*(1), 1-8.

Pew. (1983). *Research needs for human factors*. National Academies.

ACKNOWLEDGMENTS:

This manuscript has been partially supported by the Government of the Community of Extremadura, Grant Ref. GR15161, project Grant. Ref. IB16198 and GR18191; and the project “Centro de Tecnificación del Deporte Paralímpico – DEPATECH 2014-2015”.

TECHNICAL SESSIONS (V)
Ergonomics. Biomechanics.
Human & Behavioural Factors. Ageing

IT IS TIME FOR US TO BE THE FIRST

Fernando Garcia-Monzon [1], Alfonso Oltra Pastor [2 3]

[1] Architect / University of Valencia, Spain. Collaborator / Order of Spanish Architects. Vice-President / Araprode

[2] Instituto de Biomecánica de Valencia, Universitat Politècnica de València, Valencia, Spain

[3] CIBER de Bioingeniería, Biomateriales y Nanomedicina (CIBER-BBN), Spain

fgmonzon@gmail.com; alfonso.oltra@ibv.org

ABSTRACT

The same way in a traffic accident the road circumstances cannot be accountable for only, but also the driver's; in any Slip, Trip or Fall accident (STF) buildings and users are involved. So, both of them are to be taken into account.

Even if buildings respect norms fully, accidents involving persons happen as a result of STF. While we are conscious about the conditions of buildings, we are not so much about those of users.

Ageing increases the chances of accidents but other personal circumstances, also.

If we balance our knowledge of buildings vs users, it clearly goes against people. If we want to reverse STF accidents it is time we recognize the importance of approaching this issue from the user's conditions.

The Biomechanics Institute of Valencia (www.ibv.org) studies the behaviour of the human body. It set to investigate on this particular field and the outcome was "FallSkip" a biomechanical application (www.fallskip.com) which focuses on the evaluation of physical condition.

This application is an approach to the issue that proves to be the correct path to follow. So, now it's time to proceed investigating into the sensory and cognitive conditions, the same way.

The final goal is to have a tool to assist us when constructing, maintaining or managing buildings, but above all that would give us guidance on the way one should use environments to be on the safe-side in accordance with one's conditions.

Let's give IBV a try. It's time for us to put be first.

Keywords: evaluation, personal-conditions, application, safety, user, biomechanics

Topic: Ergonomics and forensic experts

Index:

0. ROAD ACCIDENTS VS ACCIDENTS IN A BUILDING

When a road accident occurs and people are affected, the condition of the pavement, the signage and even the road design itself, as well as the conditions of the vehicle and those of the driver are investigated.

If we transfer this situation to a person walking on a pavement (inside or outside a building) and by unknown circumstances, suffers an accident in the form of a slip, stumble or fall, it is common to investigate the pavement conditions, its state of cleanliness, conservation, ...but the person and its circumstances are not considered.

There is no doubt both scenarios are comparable, but the reaction to them is not the same in both cases.

If we really want to minimize accidents due to slips, trips or falls where people and pavements are involved, not only pavements will have to be studied, but also users and their circumstances must be considered: biomechanical and sensory parameters, health status, clothing ...

Without forgetting pavements, this communication pretends to point out the importance of getting to know, at the same level, both parts involved in every slip, stumble or fall.

Only considering the two components of the person/pavement binomial we will be able to reverse the current situation.

1. IMPORTANCE OF CONSIDERING ALL PARTIES INVOLVED

The case of a slip accident serves to illustrate this communication.

Every slip is nothing else but the result of a sliding between two surfaces in contact. The relative behavior of these two surfaces responds to the characteristics of each one and is sum up in their relative friction coefficient.

This relative friction coefficient reflects the slide resistance between two surfaces in contact. It is an abstract parameter that depends on many factors: the characteristics of the materials, the finish of their surfaces, the temperature, the relative speed between the two, the pressure between the surfaces, etc.

Therefore, the study of a slide does not make sense if the characteristics of both surfaces in contact are not considered. Consequently, in slip accidents both, pavement and footwear conditions, must be considered since these are the two surfaces involved.

Similarly happens in the case of stumbling. The causes may be due to the condition of the pavement but also to the circumstances or capabilities of the individual, regardless of other factors that may get involved.

Finally, in falls is alike. Although they may be for numerous reasons, we will focus on those that are the subject of this communication: those in result of a slip or stumble, which leads us back to the study of pavement conditions, as well as of people.

2. SENSITIZATION OF SOCIETY TOWARDS BUILDING'S ASPECTS

Buildings design, the construction process, the materials used, their use and conservation, among other aspects, are regulated by multiple standards. All these reflect that society has a high level of awareness towards the conditions in which buildings should be. This awareness refers to both the work as a whole and its parts, and both inside and outside. Pavements are part of this whole and have the same level of demand and control.

The development of society entails the requirement of greater and better performance of buildings, which implies updating the regulatory framework in order to maintain its level of service at high level of expectations. This fact only confirms the zeal of society towards buildings and, as part of them, towards pavements.

It is not necessary to say much more in this respect, since when accidents due to slips, trips or falls occur, there are sufficient references to study to what extent the pavements comply with the requirements.

3. LACK OF SENSITIZATION OF SOCIETY TOWARDS PEOPLE

But if we analyze any slip, stumble or fall from the other side, that is, from the side of the individual, the first thing that should be noted is that society does not have that same level of awareness towards the user. Apart from this reality, it should not be forgotten that when analyzing an accident within the pavement-user binomial, both the pavement and the person are 50% involved in their origin, something that is more frequently forgotten than is due.

In the same way that buildings are designed in compliance with standards, they are also intended to be used under certain conditions and circumstances. Out of them, the level of risk increases. Many of them are internally assumed, they are known and common, so it is not necessary to refer to them. If it had to do so, it would be clear that the person in question is not qualified to be user of the building itself.

As an example, the risk of a user is increased if he or she uses the building, or its exteriors, in inadequate conditions of footwear, clothing, or according to individual circumstances, even if they are temporary. The latter case is illustrated by examples such as the increased risk of walking while talking on the mobile phone, which decrease the sense of hearing, and can even cancel it in the case of wearing headphones. The same applies to wearing sunglasses in poorly lit environments or being under the influence of medical substances, or other, to name a few examples. In fact, this type of bad habits are beginning to be regulated as risky and out of good practice.

Returning to the simile of driving, it is considered negligent to drive with inappropriate footwear: flip flops, platforms, large heels, stiff boots, ... which should make us think over the importance that footwear acquires since it is the fundamental element of agreement between us and our tactile environment.

4. NEED TO BALANCE THIS BINOMY

If we want to intervene in any situation to improve it, first thing is to know as much as possible all the factors involved in it.

If our goal is to minimize accidents due to slips, trips or falls in which people and pavements are involved, first thing that is detected today is a clear imbalance between the level of knowledge and awareness of society towards pavements against to the other party involved: the users. Consequently, we must act to balance this situation, which implies increasing society's awareness in this regard and their level of knowledge of people as users.

This communication wants to help reverse this imbalance by presenting the biomechanical research work carried out at Instituto de Biomecánica (IBV) on people and their circumstances, as well as the achievements they have already obtained.

This line of research must continue to get to know people better, their behavior and ability to react, which will undoubtedly contribute to reversing the current situation by minimizing the risk of slips, trips or falls.

5. IBV HAS STARTED A RESEARCH LINE ON PHYSICAL PARAMETERS

Instituto de Biomecánica, as a research and technological development center focused on the care of people's quality of life (www.ibv.org), has been deploying, for more than 40 years, various lines of work aimed at the dynamic study of the human body, with special emphasis on the development of simple methodologies for assessing the state of physical and functional capabilities of the locomotor system.

In this sense, prevention and fall risk assessment has been, and currently is, one of the main lines of interest of the center, not only because of the real possibility of preventing them, but also because of the need to face a health and social global challenge. To understand the magnitude of it, it is enough to point out that one in three adults over 65 years of age suffers at least one fall per year, constituting one of the main geriatric syndromes and assuming the second worldwide cause of accidental or unintentional death (Source World Organization of Health "WHO").

From a scientific point of view, it is possible to study and analyze the individual biomechanical aspects most closely related to the risk of falls. Those factors are, the ability to walk, maintain posture, perform movements or the reaction to external stimuli.

Thus, for example, in scientific publications it is described how a greater variability of gait is related to the greater risk of falls. Similarly, other studies point out to the close relationship between biomechanical variables that describe the ability to maintain balance with the risk of falling; greater postural oscillation, greater risk of falling.

Likewise, many recently papers support the importance of identifying biomechanical variables related to the strength and muscular power of the lower limbs, since these are parameters closely related to the ability to overcome tripping and / or slipping, as well as to guarantee the correct repositioning of the body.

6. “FALLSKIP” RESULT

As a result of the work deployed by IBV in this area, at the beginning of 2018 a new methodology called FallSkip was defined to assess not only the risk of a person to fall, but the physical aspects or capabilities that may be affecting that risk. This methodology is based on a biomechanical application that allows the healthcare professional to obtain, in a simple way and in just over two minutes, a complete objective assessment of the risk of a person to suffer a fall attributable to their functional status. The system, composed of an Android portable device, analyzes the subject's biomechanical response by performing a modified “Timed up & Go” Test (TUG) protocol, which is developed in four consecutive phases and according to the protocol that can be seen in the following video:

https://youtu.be/Gf7A034LcUE

The device, located in the lumbar area of the adult, records the accelerations generated by the movement of the subject throughout the test. From a detailed analysis of the measured accelerations, the system performs a segmentation of each phase of the test and a parameterization that allows to calculate the biomechanical variables associated with the risk of falling:

- Balance assessment, by analyzing center of mass displacement during the standing phase.
- Gait assessment, by analyzing the center of mass displacement during the 3 meters walk period.

- Lower limb strength assessment, by analyzing power during the movement of sitting and getting up.
- Reaction time assessment to a sound stimulus, in the transition between the first and second phase of the test.

7. LESSONS LEARNED OF THE TRAVELED ROAD

As result of the application of this assessment methodology and considering the recommendations of the WHO, the evaluation of older adults' fall risk, as well as the state of the biomechanical variables that define it, enables the implementation of preventive measurements that help to reduce the risk of falling. In fact, according to the WHO itself, the implementation of risk monitoring systems allows for a 30-40% decrease in their incidence, which demonstrates the personal and health benefits of the implementation of surveillance and protection programs for the population.

The main beneficiaries of lessons learned from this work are, in the first instance, the group of older adults and people with reduced mobility. The identification of risk, as well as the implementation of specific interventions, allows to improve the quality of life and independence, of those having this risk and their families and caregivers

On the other hand, professionals responsible for prescribing resources for the care of people with high risk rates will find a new tool for the development of their work. This will have a positive long-term impact on the sustainability of social and health services.

Finally, it is also worth highlighting the possibilities that are open to professionals in architectural design and construction. The detailed knowledge of the physical and functional characteristics of people living and moving through the buildings makes possible to take *a priori* decisions regarding the construction materials and designs that minimize the risks.

8. SAMPLES OF INTEREST BY THIRD PARTIES

Throughout the time that the investigation and development of FallSkip methodology has lasted, the IBV has received numerous samples of interest from public and private entities sensitive to the problem of falls. Some of them include the Business Associations of Residences and Services for Dependents, Physical Medicine and Hospital Rehabilitation Services, Professional Societies, Hospital Entities, Municipalities and Public Administrations.

ASSESSMENT AND TRAINING OF FALL-RESISTING SKILLS FOR OCCUPATIONAL HEALTH CARE

Matthias König[1], Gaspar Epro[1], Julian Werth[1], Christoph Wetzel[2], Wolfgang Potthast[3], Kiros Karamanidis[1]

[1] Sport and Exercise Science Research Centre, School of Applied Sciences, London South Bank University, United Kingdom

[2] Expert Committee Trade and Logistics, German Social Accident Insurance, Germany

[3] Institute of Biomechanics and Orthopaedics, German Sport University Cologne, Germany

koenigm@lsbu.ac.uk

ABSTRACT

Trips and slips are common causes for falls in the public or working environment leading to various clinical conditions, disability or even death. Thus, developing effective fall prevention interventions beneficial to a wide range of age groups is vital for public health. As a departure from common approaches minimising environmental fall risk factors, we asked whether training of repeated simulated gait-trips facilitates one's ability to cope with sudden gait disturbances (so-called fall-resisting skills). Twelve young, thirteen middle-aged and ten older adults (average ages 24, 52 and 71 years respectively) performed a single perturbation training session (eight simulated trips during treadmill walking) with a repeated training session after a 14-week retention period. Tripping resulted from a resistance unexpectedly applied to the swing phase of the leg via an ankle strap connected to a custom-built brake-and-release system. Although older adults compared to both younger age groups showed a diminished ability to recover from tripping during the initial trial, we found a similar adaptive improvement in the balance recovery response to the repeated trip exposure among all age groups with a minor decay over 14 weeks ($p < 0.05$). Such single session gait perturbation training, therefore, appears to be a promising approach to effectively develop retainable balance control strategies in a time-efficient and safe manner among various age groups, which may benefit one's daily life resistance to falls.

Keywords: falls, aged, perturbation training, reactive balance, occupational health care

Topic: Falls prevention

1. INTRODUCTION

Falls in the working environment due to slipping or tripping are a serious problem worldwide, causing various clinical conditions, disability and major financial burden (Chang et al., 2016). According to the most recent report on 'causes and circumstances of accidents at work' of the European Commission (2009), such 'falls on the same level' are the most common cause (14.4%) of all non-fatal accidents in the EU. Notably, the frequency and/or severity (i.e. the number of working days lost) of work-related falls is higher with increasing age (Bentley, 1998; Buck & Coleman, 1985; Kemmlert & Lundholm, 1998; Yeoh et al., 2013). This is alarming given the demographic transition towards an expanded older population (EU, 2015) and, hence, work force in most industrialised countries and the recent suggestions to expand the working life span on over 70 years of age (Vaupel and Loichinger, 2006). Ilmarinen (2001) prognosticated that by the year 2025 the EU's work force will attain its oldest age, with twice as many workers at the age of ≥ 50 years as those aged ≤ 25 years, a trend that is underpinned by the actual employment rates in the EU (EU, 2010). Thus the development of effective and efficient strategies aiming at the prevention of work-related falls, seems mandatory for future occupational health care.

Common approaches for the prevention of slip and trip-related falls on the same level circle around a comprehensive environmental risk assessment and management (Bell et al., 2008; Haslam and Stubbs, 2005). In other words, the focus of these interventions lies on the elimination or mitigation of specific hazards associated with slipping or tripping (e.g. proper selection of footwear and flooring; Verma et al., 2011). In their 10-year longitudinal study, Bell et al. (2008) showed that by a combination of different prevention measures to control such *extrinsic* risk factors together with a general awareness campaign, slip and trip-related falls could be reduced by over 50% in a hospital setting. However, despite a general reduction of non-fatal work-related injuries in the EU over the last decade (in-between 2008 and 2017 by about 13%; European Statistical Office, 2019a), the relative proportion of fall-related accidents (including falls to a lower level) remained relatively stable (European Statistical Office, 2016, 2019b). Similar observations can be made for the U.S. (Bureau of Labor Statistics, 2017). These results suggest that, despite the numerous attempts to control for external risk factors, slip and trip-related falls remain a primary cause for injury among different occupations. Thus we propose that new approaches may be needed focussing more on the individual in the context of its interaction with the mechanical environment.

Promising results stem from falls prevention in geriatric practice. It has been shown by our group and others that the ability to cope with a sudden slip or trip (so-called fall-resisting skills) can improve after exposure to repeated simulated slipping and/or tripping events in the laboratory (McCrum et al., 2014; Okubo et al., 2019; Pai et al., 2010). Furthermore, these training effects seem to last up to several years (Epro et al., 2018) and to cause a reduction of older adults' daily life falls risk (Rosenblatt et al., 2013). As a departure from common approaches targeting environmental fall risk factors, here we asked for the practicability of such training interventions in an occupational context, comprising employees of different fitness levels and age groups.

2. METHODS

Twelve young, thirteen middle-aged and ten older adults (average ages 24, 52 and 71 years respectively) were recruited, allowing for an age group comparison across the working life span and early retirement stage. All age groups performed a single perturbation training session (eight simulated trips in total) on the treadmill (Epro et al., 2018). After 3.5 months the three groups returned to our laboratory for a single trip on the treadmill to examine potential long-term training effects. A typical trip perturbation and subsequent balance recovery behaviour for our applied setup is illustrated in Figure 1.

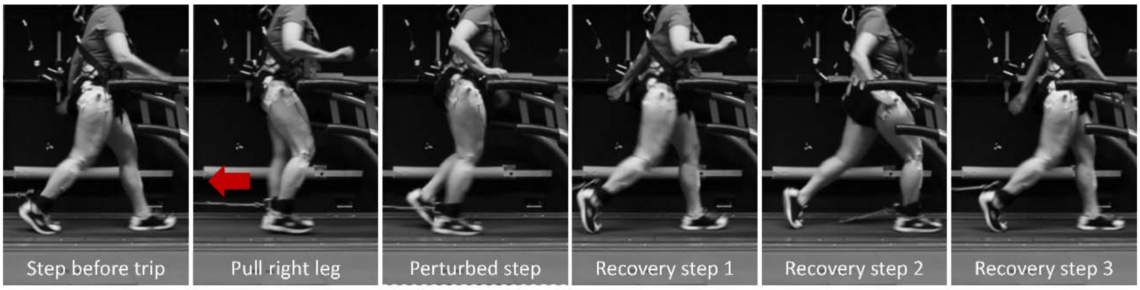


Figure 1: Applied trip perturbation setup. Tripping was unexpectedly induced by pulling the right leg behind during swing phase via an ankle strap and custom-built break-and-release system. The stability of the body was analysed during this perturbed step and subsequent balance recovery steps.

The participants walked on a treadmill at a given velocity of 1.4 m s^{-1} wearing two ankle straps connected via Teflon ropes to a custom-built break-and-release system. Tripping was induced by pulling the right leg behind while the leg was in the air (i.e. swing phase; Figure 1). The trip was unexpected to the participants, though they were informed prior to the training that at some point their gait is going to be perturbed. Before the next trip was applied, a 2-3 min resting period of normal walking was given to the participants. For any of the eight trips the stability of the body was analysed for the step during which the leg was pulled behind (in the following referred to as the perturbed step) and the subsequent balance recovery steps (Figure 1).

Body stability during walking and tripping was calculated using the so-called ‘margin of stability’ according to Hof et al. (2005):

$$MoS = BoS_{anteriorMax} - CoM_{extrapolated} \quad (1)$$

The margin of stability (usually described in centimetres or metres; MoS) can be positive or negative, saying whether the extrapolated centre of mass (i.e. the centre of mass position of the body under consideration of its movement velocity; $CoM_{extrapolated}$; Hof et al., 2005) lies in front of or behind the most anterior point of the body’s base of support (i.e. the leading foot; $BoS_{anteriorMax}$; Figure 2). If the margin of stability is positive, the body is stable, whereas negative margin of stability values indicate an unstable body configuration, requiring further movements (e.g. stepping or grasping) to avoid a fall. To calculate the position and velocity of the body’s centre of mass and base of support over the course of the training, we placed five reflective markers to different body positions (namely the hips, toes and the most prominent cervical vertebra; Süptitz et al., 2013) and captured their trajectories by ten infrared cameras operating at 120 Hz.

3. RESULTS

All age groups completed the training without reporting any physical or mental stress. The total average training time over all participants was 25 min. During normal walking all participants showed stable body configurations (i.e. positive margin of stability values). For all age groups the onset of the trip caused a remarkable instability, which required further stepping to avoid a fall (Figure 1). Notably, after the first trip older compared to the two younger age groups needed one more step to recover balance ($p < 0.05$), indicating lower capabilities to cope with sudden gait disturbances with ageing. This trend could also be observed for many of the middle-aged adults, though the difference reached no statistically significance.

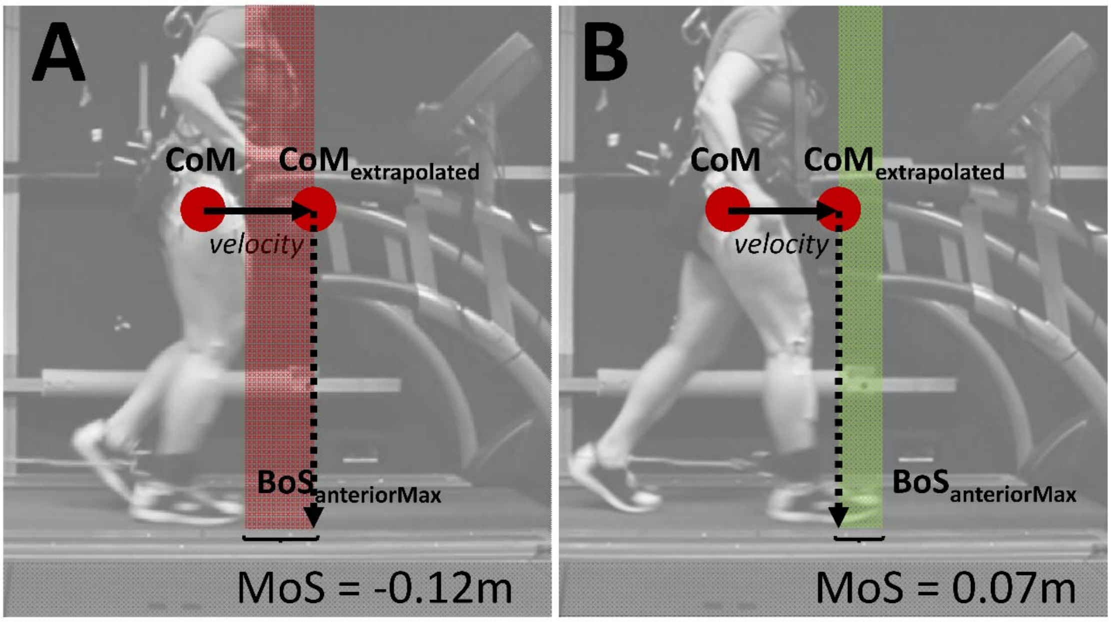


Figure 2: Schematic illustration of our stability calculation during walking and tripping for a representative middle-aged participant (59 years). **A:** Margin of stability (MoS) during the perturbed step for the first trip; **B:** MoS during the perturbed step for the eighth trip. MoS was calculated as the difference between the most anterior point of the body's base of support (i.e. the leading foot; $BoS_{anteriorMax}$) and the extrapolated centre of mass (i.e. the centre of mass position of the body under consideration of its movement velocity; $CoM_{extrapolated}$; Hof et al., 2005). Negative values indicate an unstable body configuration ($CoM_{extrapolated} > BoS_{anteriorMax}$) requiring further movements to avoid a fall, whereas positive values indicate a stable body configuration ($CoM_{extrapolated} < BoS_{anteriorMax}$).

However, over the course of the eight tripping trials all age groups were able to significantly improve their margin of stability (i.e. more positive values) during the perturbed step (Figure 2) and subsequent balance recovery steps up to 70% and were able to recover balance within a single step. More importantly we found these margin of stability values to remain significantly improved ($p < 0.05$) in all three age groups even after a 3.5 months period without any ancillary training. However, it is mandatory to address the fact, that there was a slight but significant decay in training effects over time, which was more pronounced in older adults ($p < 0.05$).

4. DISCUSSION

Maintenance of health across working life is a central aspect not only for an individual's quality of life, but is also a major concern for public health. Here we presented a novel approach in the context of occupational health care, aiming at the strengthening of one's *intrinsic* capabilities to cope with sudden external daily-life disturbances to gait (e.g. a trip over a curb) to reduce fall risk. The results of our training intervention* are demonstrating clearly that such fall-resisting skills can be sustainably improved within merely a single 25-min-session of repeated trip practice. Moreover, these long-term training effects over several months could be observed among different age groups, representing the whole working life span from career entrant to early retirement stage.

Whereas the longstanding view on work-related falls in general was, that when all potential external hazards were removed, the majority of falls could be prevented (Bell et al., 2008; Haslam and Stubbs, 2005), we argue that the individual with its specific characteristics needs to be added to this equation. Our results demonstrate that, while younger workers may cope easily with sudden disturbances to balance from slippery or raised floors, increasing age seems to be a tremendous risk factor for a fall for that very same condition. The pressing need for a rethinking in occupational falls prevention is reflected also in the reportedly constant numbers of work-related falls over the last years (Bureau of Labor Statistics, 2017; European Commission, 2016, 2019b). Thus, training interventions as the one presented here could be an effective and time-efficient (average training time: 25 min) add-on to the existing prevention measures by strengthening one's capacities against unavoidable or overseen external risk factors. Support for this is provided by the data from geriatric fall prevention programmes, that show not only remarkable improvements of one's ability to resist a fall in the laboratory after such slipping or tripping training interventions (Epro et al., 2018; McCrum et al., 2014, Okubo et al., 2019; Pai et al., 2010), but also a reduction of real-life falls (Rosenblatt et al., 2013). Given the demographic shift towards an increasingly older workforce in most industrialised countries (EU, 2010; Ilmarinen, 2001), these findings are transferable to occupational health care more as it seems at first glance.

We conclude that such single session gait perturbation training may be a promising approach for future occupational health care to effectively reduce slip and trip-related falls at work. The present results, in combination with the previous findings on older adults, demonstrate beneficial effects of slip and trip training on one's daily life resistance to falls. We recommend single training sessions on a yearly basis (e.g. in the context of a regular occupational health check) in particular for workers ≥ 50 years of age showing greater susceptibility to falling. Middle-aged and older workers may profit from a single ancillary session after half a year to overcome the slightly greater decay in training effects.

*The results of this Conference Paper have been published in *König, M., Epro, G., Seeley, J., Potthast, W., & Karamanidis, K. (2019). Retention and generalizability of balance recovery response adaptations from trip perturbations across the adult life span. Journal of Neurophysiology, 122(5), 1884-1893*.

5. REFERENCES

Bell, J. L., Collins, J. W., Wolf, L., Grönqvist, R., Chiou, S., Chang, W. R., Sorock, G. S., Courtney, T. K., Lombardi, D. A., & Evanoff, B. (2008). Evaluation of a comprehensive slip, trip and fall prevention programme for hospital employees*. Ergonomics, 51*(12), 1906-1925.

Bentley, T. A. (1998). Slip, trip and fall accidents occurring during the delivery of mail. *Ergonomics, 41*(12), 1859-1872.

Buck, P. C., & Coleman, V. P. (1985). Slipping, tripping and falling accidents at work: a national picture. *Ergonomics, 28*(7), 949-958.

Bureau of Labor Statistics (2017). *2016 survey of occupational injuries & illnesses*. Accessed November 28, 2019. https://www.bls.gov/iif/soii-chart-data-2016.htm

Chang, W. R., Leclercq, S., Lockhart, T. E., & Haslam, R. (2016). State of science: occupational slips, trips and falls on the same level. *Ergonomics, 59*(7), 861-883.

Epro, G., Mierau, A., McCrum, C., Leyendecker, M., Brüggemann, G.-P., & Karamanidis, K. (2018). Retention of gait stability improvements over 1.5 years in older adults: effects of perturbation exposure and triceps surae neuromuscular exercise. *Journal of Neurophysiology, 119*(6), 2229-2240.

European Commission (2009). *Causes and circumstances of accidents at work in the EU*. Luxembourg: Office for Official Publications of the European Communities.

European Statistical Office (2016). *Percentage distribution of accidents at work by deviation, NACE Rev. 1.1 activity, sex, age and severity*. Accessed November 28, 2019. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_aw_de3&lang=en

European Statistical Office (2019a). *Non-fatal accidents at work by NACE Rev. 2 activity and age*. Accessed November 28, 2019. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_n2_03&lang=en

European Statistical Office (2019b). *Accidents at work by sex, age, severity, NACE Rev. 2 activity and deviation*. Accessed November 28, 2019. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hsw_ph3_06&lang=en

European Union (2010). *Health and safety at work in Europe (1999–2007) – A statistical portrait*. Luxembourg: Publications Office of the European Union.

European Union (2015). *Demography Report*. Luxembourg: Publications Office of the European Union.

Haslam, R., & Stubbs, D. (2005). Preventing falls. In: Haslam, R. and Stubbs, D. (Eds). *Understanding and Preventing Falls: An Ergonomics Approach* (196-203). Boca Raton, Florida: CRC Press.

Ilmarinen, J. E. (2001). Aging workers. *Occupational and Environmental Medicine, 58*(8), 546-552.

Kemmlert, K., & Lundholm, L. (1998). Slips, trips and falls in different work groups with reference to age. *Safety Science, 28*(1), 59-75.

McCrum, C., Eysel-Gosepath, K., Epro, G., Meijer, K., Savelberg, H. H., Brüggemann, G.-P., & Karamanidis, K. (2014). Deficient recovery response and adaptive feedback potential in dynamic gait stability in unilateral peripheral vestibular disorder patients. *Physiological Reports, 2*(12), e12222.

Okubo, Y., Sturnieks, D. L., Brodie, M. A., Duran, L., & Lord, S. R. (2019). Effect of reactive balance training involving repeated slips and trips on balance recovery among older adults: A blinded randomized controlled trial. *The Journals of Gerontology: Series A, 74*(9), 1489-1496.

Pai, Y.-C., Bhatt, T., Wang, E., Espy, D., & Pavol, M. J. (2010). Inoculation against falls: rapid adaptation by young and older adults to slips during daily activities. *Archives of Physical Medicine and Rehabilitation, 91*(3), 452-459.

Rosenblatt, N. J., Marone, J., & Grabiner, M. D. (2013). Preventing Trip-Related Falls by Community-Dwelling Adults: A Prospective Study. *Journal of the American Geriatrics Society, 61*(9), 1629-1631.

Süptitz, F., Moreno Catalá, M., Brüggemann, G.-P., & Karamanidis, K. (2013). Dynamic stability control during perturbed walking can be assessed by a reduced kinematic model across the adult female lifespan. *Human Movement Science, 32*(6), 1404-1414.

Vaupel, J. W., & Loichinger, E. (2006). Redistributing work in aging Europe. *Science, 312*(5782), 1911-1913.

Verma, S. K., Chang, W. R., Courtney, T. K., Lombardi, D. A., Huang, Y. H., Brennan, M. J., .Mittleman, M. A., Ware, J. H., & Perry, M. J. (2011). A prospective study of floor surface, shoes, floor cleaning and slipping in US limited-service restaurant workers. *Occupational and Environmental Medicine, 68*(4), 279-285.

Yeoh, H. T., Lockhart, T. E., & Wu, X. (2013). Non-fatal occupational falls on the same level. *Ergonomics, 56*(2), 153-165.

ELECTROMECHANICAL TRAINING SYSTEM DEVELOPMENT FOR THE PREVENTION OF FALLS AND THE IMPROVE OF POSTURAL STABILITY

Kostas Gianikellis[1], Rafael Gutierrez-Horrillo[1], Miguel Rodal[1]

[1]*BioẼrgon Research Group, University of Extremadura, Cáceres, Spain.*

kgiannik@unex.es

ABSTRACT

Slips and falls are one of most important problems in people of the Third Age. Several studies have showed until a 30% of falls per year in people over 65 and until a 45% in people over 70. Furthermore, the death rate as a result of a fall, or of repeated falls in a short period of time, is very high; According to the World Health Organization, the death rate in Spain caused directly by a fall in people over 75 is 40 deaths per 100,000 inhabitants. On the other hand, many other older people voluntarily limit their independent activity for fear of falling. Autonomy and self-sufficiency in the elderly are two of the most important factors in achieving a good quality of life. This problem shows the great need that exists in the society of development of new technologies that help prevent the risks of falls. For this, BioẼrgon research group have developed a novel electromechanical system for the quantitative assessment of proprioception and training of postural balance. This technological innovation allows standardized balance training, which favors the reduction of the risk of falls. This manuscript has been supported by the Government of the Community of Extremadura, Grant Ref. GR18191 and project Grant Ref. IB16198; and the project "Centro de Tecnificación del Deporte Paralímpico – DEPATECH 2014-2015".

Keywords: biomechanics, balance, falls, innovation, technological development

Topic: Prevention falls

1. INTRODUCTION

The maintenance of dynamic stability is an essential task in everyday life, especially for elderly people. The problem of slips and falls is one of the most serious in this group, numerous studies reveal up to 30% of falls per year in adults over 65 years and up to 45% in people over 70 years (Lord, Sherrington, Menz, & Close, 2007). In addition, the death rate as a result of a fall, or of repeated falls in a short period of time, is very high. On the other hand, many other elderly people voluntarily limit their independent activity for fear of falling, and autonomy and self-sufficiency in the elderly are two of the most important factors in achieving a good quality of life (Imms & Edholm, 1981). With advanced age there is a progressive degeneration of the mechanical and neuronal system of the body. The functional decrease in the capacity of the musculoskeletal system is an obvious cause of deficits in age-related stability control

On the other hand, aging develops gradually, and consequently, degeneration occurs slowly, allowing the motor system to have time to adapt to it. This adaptation incorporates modifications in the organization of motor tasks using sensory feedback information until efferent sensory information and afferent motor actions reach a new equilibrium that compensates for the decrease in the capacities of the nervous and musculoskeletal system.

A very important research topic in the line of action of stability is the understanding of the mechanisms by which the Central Nervous System (CNS) regulates these movements and their stability. A loss of balance occurs when the center of mass (CoM) of the body exceeds the established stability limits with respect to the base of support. The CNS can make adaptive adjustments in advance to improve the stability of the CoM, as well as integrating afferent signals from different sources to control and update the status of the CoM at any time and compare it with the internal representation of the corresponding stability limits. Therefore, an adaptive improvement of the internal representation of postural stability in the presence of disturbances would help to improve the ability of the CNS to prevent loss of balance. The CNS must achieve this thanks to a continuous adaptation process; it seems that these adaptations are guided by modifications (updates) of the internal representation of the stability limits (a reflection of what happens in reality). Thus, it seems logical to state that the CNS is able to quantify the probability of loss of balance based on previous experiences and records in memory. The defended theory is that the internal representation of the stability limits can be rapidly updated through exposure to repeated disturbances.

In this way, knowing the postural motor control strategies carried out by the central nervous system of each individual for the maintenance of the equilibrium in standing position is an important proposition oriented by and for people since it gives the possibility to characterize and individualize the physical work programs to prevent falls, both in those programs aimed at neuromuscular rehabilitation, as in those that focus on the functional assessment of the user, understanding that assessment as the set of methodological procedures that aim to measure the dynamic characteristics of the individual's motor behavior, reflecting the quality of control of his motor skills at different stages of his life, clinical pictures and environmental conditions (Gianikellis, Gálvez, Bote, & Moreno, 2011).

2. AIMS

Given the evidence that motor stability can be improved in older people through repeated exposure to situations of destabilization, so that it is produced a reduction in loss of balance and accidents and an adaptation of the subject by adopting optimal strategies of movement to avoid the loss of balance (Pai, Wening, Runtz, Iqbal, & Pavol, 2003), in the present work we propose the design of a prototype of electromechanical sensorized platform. The system presents, in addition to the technical characteristics of a force plate, unique capabilities as a mobile force plate that makes it possible to measure the corresponding biomechanical parameters, while considering a controlled imbalance through the modification of the inclination and / or the orientation of the platform itself. The concept of this mobile smart platform is based on the fact that the recording and analysis of the orientation and angular acceleration of the platform, together with the information associated with the dynamics centre of preasure, known as the point of application of the resulting normal force to the surface (Latash & Zatsiorsky, 2016), and the distribution of the pressure allows to evaluate the postural control of the subject, as well as to plan the training of the proprioceptive qualities as part of the process of its rehabilitation. Therefore, this intelligent platform is integrated into the field of Biomechatronics applied to rehabilitation and proprioceptive training, understanding Biomechatronics as the science that includes aspects of biology, mechanics and electronics, covering the fields of robotics and neuroscience (Ponsa & Català, 2001).

3. METHODS

The system developed consists of a mechatronic balance disturbance platform that provides disturbances based on movements of two of the three axes of rotation. To the mechanical development of the disturbance platform, sensorization has been added by collecting information from the engines and triaxial load cells that allow the measurement of the system state at any time (information related to the kinematic properties of the platform) and user reactions (in this case the interaction forces between the platform and the user). All this information is collected by the acquisition system that allows the analysis of aformentioned information and the generation of disturbances to achieve the final objective of obtaining a system that allows users to evaluate and train postural control. In addition, the analysis module allows the visualization of the information.

4. RESULTS

Once the tests have been carried out, the information is stored in a file with the raw data collected by the sensors. The file includes the information recorded regarding the kinematics of the platform and the user's response. For each measurement made there will be a row of values in the file, the first column being the time stamp of the measurement and the following: angular positions of the platform (vertical axis and horizontal axis respectively), force on the three X, Y axes , Z and center of pressures (figure 1).

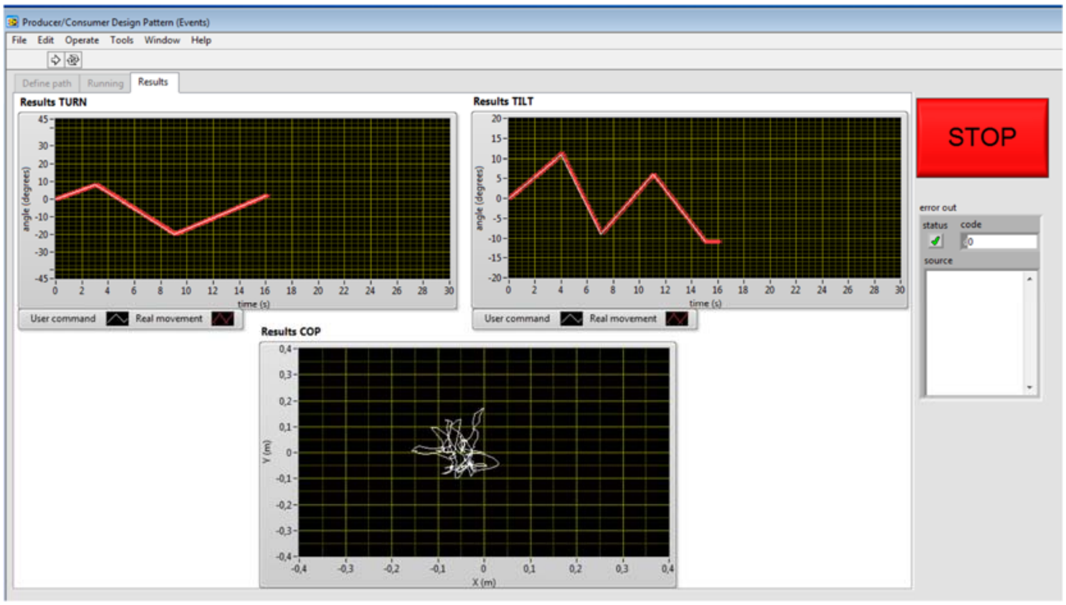


Figure 1: Results obtained with the mechatronic platform.

5. CONCLUSIONS

In conclusion, the elderly have deficiencies in the use of the mechanisms responsible for controlling dynamic stability after an imbalance; as a consequence of a series of factors that come into play in the restoration of stability in the event of a balance disturbance. Re-stabilization in case of disturbance is a trainable mechanism, so it needs to be improved in a controlled and monitored environment. Therefore, a technological tool has been developed that allows: to analyze and quantify the risk factors of falling, to issue individualized reports for the rehabilitation and assessment of each patient, to train proprioception in a controlled and monitored environment.

6. REFERENCES

Gianikellis, K., Gálvez, A., Bote, A., & Moreno, A. (2011). *Relevancia del problema de control motor y reconsideración del protocolo NIOSH en las tareas con manipulación manual de cargas*.

Imms, F., & Edholm, O. (1981). Studies of gait and mobility in the elderly. *Age and ageing*, *10*(3), 147-156.

Latash, M. L., & Zatsiorsky, V. M. (2016). *Biomechanics and motor control: Defining central concepts*. London, UK ; San Diego, CA, USA: Elsevier/AP, Academic Press is an imprint of Elsevier.

Lord, S. R., Sherrington, C., Menz, H. B., & Close, J. C. (2007). *Falls in older people: Risk factors and strategies for prevention*. Cambridge University Press.

Pai, Y.-C., Wening, J., Runtz, E., Iqbal, K., & Pavol, M. (2003). Role of feedforward control of movement stability in reducing slip-related balance loss and falls among older adults. *Journal of Neurophysiology*, *90*(2), 755-762.

Ponsa, P., & Català, A. (2001). Actividades docentes en mecatrónica. *XXII Jornadas de Automática*.

ACKNOWLEDGMENTS

This manuscript has been partially supported by the Government of the Community of Extremadura, Grant Ref. GR15161, project Grant. Ref. IB16198 and GR18191; and the project “Centro de Tecnificación del Deporte Paralímpico – DEPATECH 2014-2015”.

STABILOMETRY APPLIED TO FALL PREVENTION

Kostas Gianikellis[1], Miguel Rodal[1], Rafael Gutierrez-Horrillo[1]

[1]BioẼrgon Research Group, University of Extremadura, Cáceres, Spain.

kgiannik@unex.es

ABSTRACT

Vertical posture mantainance can be consider as a stability problem of inverted pendulum or as a stability problem of rigid articulated segments system. System stabilization entails the provision of information to feedback controller respect oscillation of those rigid segments. In general, postural balancing is perceived through sensory, visual, vestibular and proprioceptive systems, and this information is transmitted by afferent ways to CNS' control centers, evoking the activation of muscles by afferent ways to variate the ground reaction forces distribution with the aim of vertical posture mantainance. Stabilometry is a methodology for the evaluation of the ability to stabilize the posture using force plates to measure the displacements of the pressure center on the support surface. A loss of balance occurs when the center of mass (CoM) of the body exceeds the established stability limits with respect to the lift base. The CNS can perform adaptative adjust in advance to improve the stability of CoM, likewise, it can integrate afferent signals from different sources to control and update the CoM status at each moment and compare it with the internal representation of the corresponding stability limits. Therefore, an adaptive improvement of the internal representation of postural stability in the presence of disturbances would help to improve the ability of the CNS to prevent loss of balance.

Keywords: biomechanics, stabilometry, postural balance, prevention, falls

Topic: Prevention falls

1. INTRODUCTION

The maintenance of the vertical posture is one of the most important characteristics of human nature. This justifies that both its external manifestation and the control mechanisms (that intervene and are responsible for its regulation) have been the subject of many scientific studies. From the point of view of the biomechanics of human movement, the maintenance of the vertical posture can be considered as a problem of reducing the number of degrees of freedom of movement of the body segments in the joints under the direction of the central nervous system (CNS). The oscillatory movements of the body segments in the standing position that lead to postural balancing are of small amplitude and low frequency and, although they are always present, they are not normally perceived by the human eye. However, it is a dynamic activity of the human locomotor system that can be registered using electronic instruments such as force plates.

The behavior of the human body, both in quasi-static conditions of standing as in conditions of small controlled imbalances, introduced during experimentation, is studied assuming that it is an inverted pendulum with its mass concentrated at the upper end that pivots with respect to the articulation of the ankle in a plane (DeHart, 2019; Gurfinkel & Shik, 1973), or of a set of bars and hinges that make up a mechanical model of articulated rigid solids that rest on one another and oscillate with respect to an equilibrium position (Baroudi, Giorgio, Battista, Turco, & Igumnov, 2019; Nashner & McCollum, 1985).

These types of problems are known in the field of systems control engineering and the desired response of the system is achieved by applying forces directed properly towards the end of the pendulum. For such forces to occur, it is necessary to have information regarding the rotations of the segments and their magnitudes derived from time. In other words, the stabilization of the system means to provide to the controller some “feedback” regarding the oscillations of the rigid segments. Although the functioning of the human body is much more complex, these relatively simple mechanical models allow, at least, mechanical descriptions of the intervention of the mechanisms that govern the maintenance of the vertical posture. Balance depends on the normal development of the physiological functions of the central nervous system (CNS). In general, the postural balance, which is always present, is perceived through visual, vestibular and proprioceptive sensory systems, and this information is transmitted through the afferent pathways to the CNS control centers, evoking the activation of the muscles through the efferent pathways to vary the distribution of reactions forces on the support surface in order to maintain the vertical posture.

2. AIMS.

The aim of this paper is to propose a methodological solution based on the biomechanics of the human movement, which helps to prevent falls in different contexts from obtaining accurate information about the quality of each person's motor control.

3. METHODS

Stabilometry is a methodology that allows the evaluation of man's ability to stabilize his posture using force plates to measure the displacements of the center of pressure (CoP) on the support surface (Terekhov, 1978). CoP is defined as the point of application of the result of the external forces exerted on the base of support (BS) at every moment of time. Margin of Stability (MS) is defined as the instantaneous difference between the extrapolated center of mass (ECM) and the limits of the BS, being positive when the position of the subject is stable (ECM within the BS) and negative when It is unstable (ECM outside the BS), therefore the Margin of Stability (MS) is considered as the best variable to measure stability.

$$MS\ ap = \ BS\ anterior\ limit - \left(Pcmx + \frac{Vcmx}{\sqrt{l/g}}\right): \quad (1)$$

Margin of Stability, for a two-dimensional example, can be calculated as the minimum perpendicular distance between the position of r + (v / ω0) (ECM) and the limits of the BS. This variable can also be interpreted as the minimum "linear momentum" necessary to cause imbalance. It can be seen that ECM would reach the limits of the BS if extra speed was added in the appropriate direction; therefore, the Margin of Stability is proportional to the momentum needed to cause instability in a subject.

For an effective training of CNS in the readjustment of these limits, and of the position and speed of the CM we must expose the body to situations of instability that, thanks to the application of the mechanism of increase of the BS, going to positive values of the MS.

The instrumental technique par excellence for conducting stabilometry studies is the force plate. The force plate consist of a system instrumented by extensometric or piezoelectric force sensors that is used to measure the reaction forces that are developed between the subject and the support surface. The information obtained by a force plate refers to the temporal evolution of the components of the reaction forces $(Fx, Fy, Fz)^t$, the mechanical impulse components $(Ix, Iy, Iz)^t$, the components of torque $(Mx, My, Mz)^t$ and the coordinates $(x, z)^t$ of the center of pressure, so that the measurements obtained provide information regarding the dynamics of the body as a whole. These data are usually related to kinematic and anthropometric parameters to calculate through the model of the articulated rigid segments, a procedure known as inverse dynamics analysis, the mechanical stresses to which the joints are subjected. One of the most used tests to assess the ability to maintain vertical posture is the Romberg test. Today, stabilometry has numerous applications in the fields of rehabilitation, neurology, ergonomics, industry and sports.

4. RESULTS

Once the dynamic data has been recorded, the information can be presented through the stabilogram. The stabilogram represents the displacements of the pressure center on the force platform and reflects the neuromuscular response to postural imbalances that introduce the continuous oscillations of the body segments during each specific task.

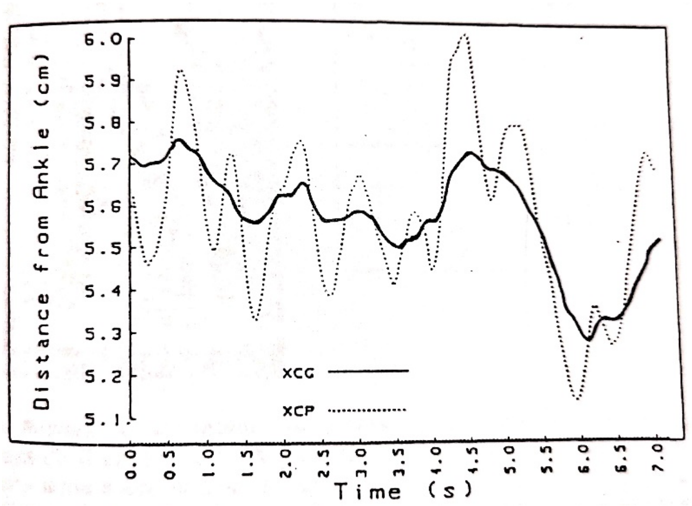


Figure 1: Representation of the trajectories described by the pressure center (...) and the center of mass (---) while the subject maintains the vertical posture. The trajectory of (CP) is wider and more frequent. Adapted from (Winter, 2009).

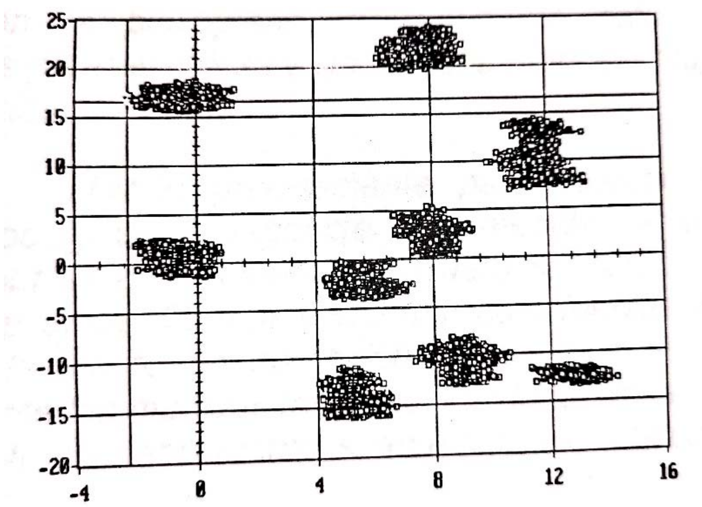


Figure 2: Representation of the trajectories described by the pressure center during different repetitions.

Next, the movement performed by the subjects through the stabilometric variables calculated for the antero-posterior direction in single step (single step) and multipass (forward sequence of steps) forward movements are described.

Simple Step Strategy:

Figure 3 shows the curves that define the Margin of Stability, and that express the clear trend followed by each of the subjects in the last stabilization step in all the exercises.

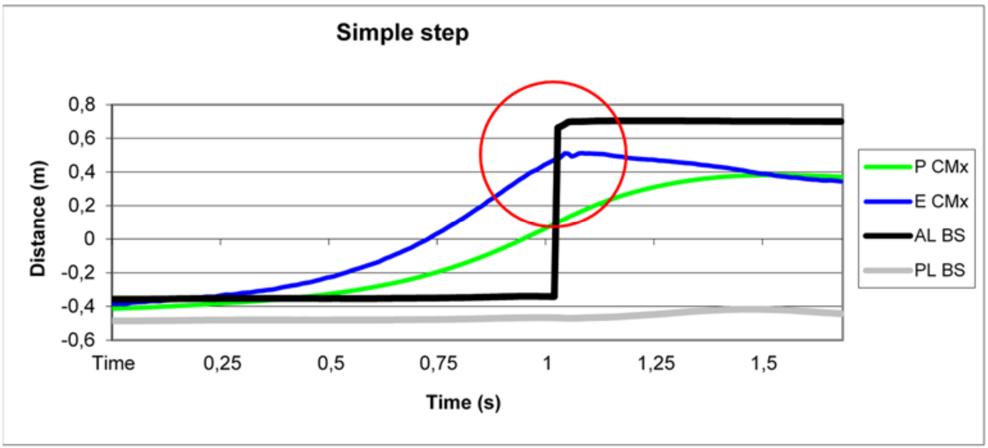


Figure 3: Behavior of the position of the projected center of mass (P CMx), of the extrapolated center of mass (E CMx), of the anterior limit of the support base (AL BS) and of the posterior limit of the support base (PL BS) during performing the task simple step forward.

Figure 3 shows a clearly stable position between 0 and 0.25 seconds, which corresponds to a static state of the subject's foot, shown below as the proyection of center of mass (PCM) as well as the extrapolated center of mas (ECM) evolve out of the stability limits, due to the voluntary inclination of the trunk forward, to exceed the limit of stability manageable by the musculoskeletal units of the plantar flexors of the foot, where take off is produced, around 0.6 seconds. While the foot moves forward in an attempt to recover stability, the PCM and the ECM continue to move away from the limits of stability, as it can be seen, the ECM with a much steeper trend than the PCM, because this is influenced by the speed that the CM acquires as a result of the imbalance. It is at the time of the Touch down (TD), or contact of the foot with the ground, where the Support Base is increased causing the ECM to enter within the limits and the balance is recovered (about 1 second), so this phase allows that the horizontal speed of the CM was reduced until zero, when the ECM coincides with the PCM. The subject remains stable because thanks to his action he has been able to readjust his stability limits and the position of his PCM and ECM.

Multipass strartergy:

In figure 4 the characteristic curves of the movement can be observed in the performance of multiple steps for the recovery of stability after a disturbance.

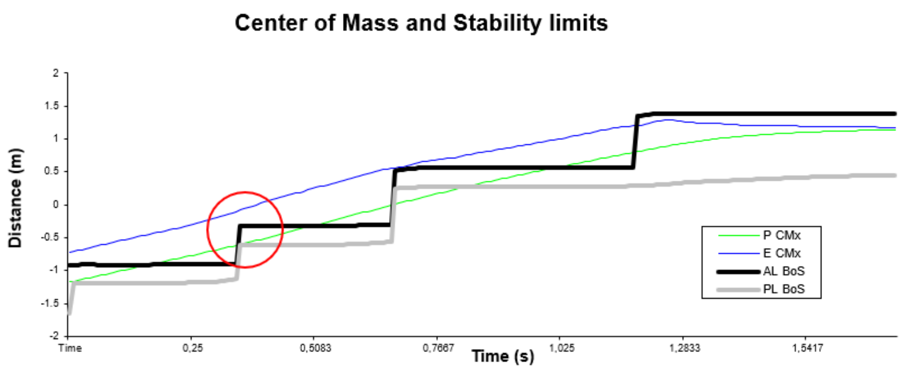


Figure 4: Behavior of the position of the projected center of mass (PCMx), of the extrapolated center of mass (E CMx), of the previous boundary of the base of support (AL BoS) and of the back boundary of the base of support (PLBoS) during performing the multipass task forward.

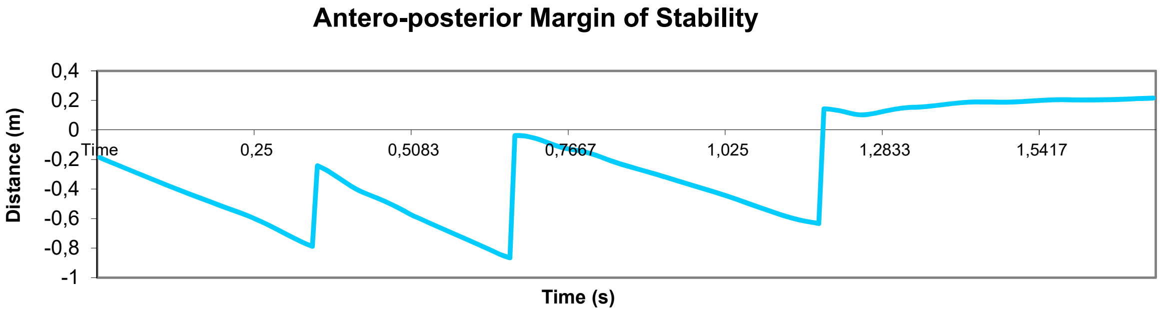


Figure 5: Evolution of the ECM during the task outside the stability limits.

In Figure 5 it can be seen how the ECM evolves during the exercise outside the stability limits, reaching negative MS values of average -0.51 ± 0.19 in the last stabilization step. The subject maintains this unstable state for 3 or 4 steps that have a duration around 1.5-2 seconds and prevents the fall thanks to the repeated action of increasing the BS in the direction of travel of the ECM (steps forward). This allows that ECM gets closer and closer to the previous limit of the BS until it is within the limits with a broader final step, a fact that normally occurs at the same time of TD, although in 3 of the subjects it occurred 0.05 ± 0.13 before the TD, an exception that indicates that the CNS is able to readjust not only the BS but also the position and speed of the CM in situations of imbalance before the motor gesture selected for the recovery of stability is completed.

In this way, it is observed how the subject is exposed to a very unstable dynamic situation and that he develops an effective strategy to solve the imbalance problem and recover stability through the Multipass strategy of the BS augmentation mechanism.

Comparison of simple step and multipass strategy:

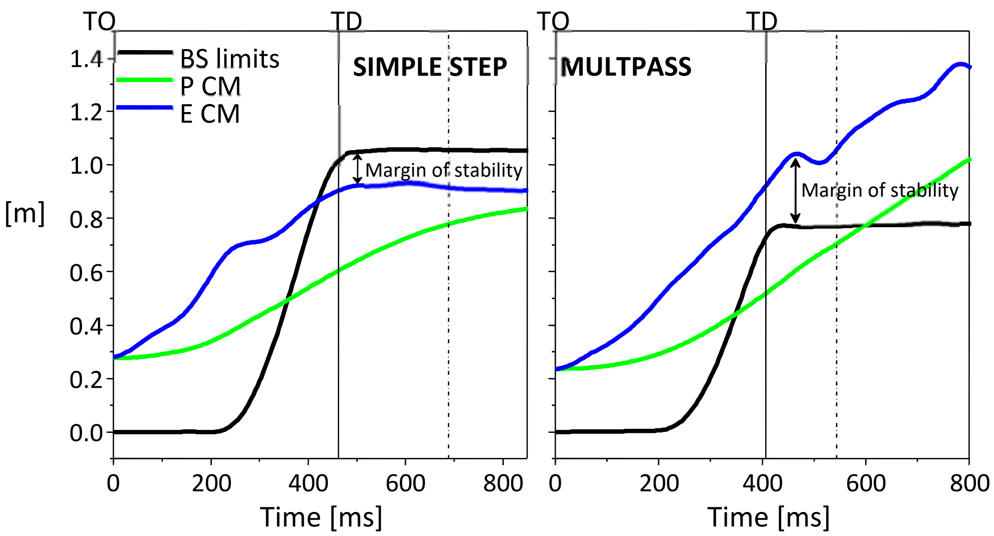


Figure 6: Comparison of the projection of the center of mass, of the extrapolated center of mass, and of the limits of the base of support behaviour during the accomplishment of the tasks simple step and multipasses forward.

Based on the inverted pendulum model and the concept of the ECM (Hof, Gazendam, & Sinke, 2005), in the first graph of figure 6, the subject's body is stable and no additional actions are needed to regain equilibrium, the ECM is within the BS and the MS value is positive, so the subject has only needed one step to regain stability. In the second graph of figure 6, the E CM is outside the BS (negative MS values), so the body is in an unstable situation and requires additional actions to regain stability.

5. CONCLUSIONS

The stability of this system, composed by bars and hinges, within the Earth's gravity field, in an upright position, is possible only with the active intervention of the neuromuscular system, provided that the projection of its center of mass belongs to the area of support for. The support area of humans is relatively small, so maintaining balance requires a high level of motor coordination. The coordination of movements and stabilization strategies of the body segments is developed through motor learning, a process that allows people to develop their ability to keep their vertical posture stable, as well as practitioners of the different modalities of precision sports reproduce correctly the motor patterns required to get good marks. In this sense, one of effectiveness criteria is the quality of control of the postural balance. The position of the pressure center reflects the neuromuscular response to postural imbalances that introduce the continuous oscillations of the center of mass of the body.

6. REFERENCES

Baroudi, D., Giorgio, I., Battista, A., Turco, E., & Igumnov, L. A. (2019). Nonlinear dynamics of uniformly loaded Elastica: Experimental and numerical evidence of motion around curled stable equilibrium configurations. *ZAMM-Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik*, e201800121.

DeHart, B. (2019). *Dynamic Balance and Gait Metrics for Robotic Bipeds*.

Gurfinkel, V., & Shik, M. (1973). The control of posture and locomotion. En *Motor control* (pp. 217-234). Springer.

Hof, A., Gazendam, M., & Sinke, W. (2005). The condition for dynamic stability. *Journal of biomechanics*, *38*(1), 1-8.

Nashner, L. M., & McCollum, G. (1985). The organization of human postural movements: A formal basis and experimental synthesis. *Behavioral and brain sciences*, *8*(1), 135-150.

Terekhov, Y. V. (1978). Instrumentation for automatic measurement and real-time evaluation of man's postural equilibrium. *Journal of Medical Engineering & Technology*, *2*(4), 182-186.

Winter, D. A. (2009). *Biomechanics and motor control of human movement* (4th ed). Hoboken, N.J: Wiley.

ACKNOWLEDGMENTS

This manuscript has been partially supported by the Government of the Community of Extremadura, Grant Ref. GR15161, project Grant. Ref. IB16198 and GR18191; and the project "Centro de Tecnificación del Deporte Paralímpico – DEPATECH 2014-2015".

SRGS
Slip Resistance Group Spain

COLLABORATORS

INSTITUTIONAL SUPPORT

SPONSORS