Texturized Geriatric Footwear Design for Balance-enhancing and Pressure Management

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Contents

Section	Contents	Page
1	Descriptor	03
2	Research Questions	04
3	The Research Outputs	05
4	Research Fields & Key Words Referenced	08
5	Research Methods and Materials	10
6	Research Conclusion	36
7	Dissemination	37
8	Appendices	46

Descriptor

This research offers exciting new ways of addressing the complexities of ergonomic footwear design for older people to improve stability in terms of walking, pain reduction, and the risks of falling. Taking into consideration the age-related impairment of plantar sensitivity and declining musculoskeletal systems, this work involves strategic footwear design to augment the plantar feedback system for enhancing balance control and redistributing excessive plantar pressure for reducing foot pain.

This project incorporates foot biomechanics, foot anthropometry and material analyses to design protrusions (textures) on the insole for site-specific stimulation. The texturized footwear enhances the body balance of older people, hence yielding new insights and high tech solutions in footwear design and engineering for improving health and wellbeing. As the first research work of this kind on care footwear design for the Chinese elderly, over 300 elderly people participated in 3D foot scanning, evaluations of plantar pressures, and posture stability during walking, as well as wear trials of footwear prototypes for subjective perception. On the basis of the established findings, the optimised footwear design includes site-specific protrusions, 3D articulated midsole and arch support, open-toed and adjustable front strap, a flexible heel counter, and outsole materials that can be comfortably and safely worn at home. The new footwear has improved muscle co-contraction, plantar sensitivity for better body balance during walking, and for the reduction of underfoot pressure. With collaboration with centres for the elderly, a participative co-creation approach was adopted to encourage the engagement of older people in the footwear design process that enhances both the value and the uses of footwear. The design patent is filed in both US and China and the results have been published in five journals, at five conferences (with a best student paper award), in an academic book, and at four exhibitions and two workshops.

Dr. YICK KL (Short biography)

Dr. Yick's research focus is on the ergonomic design for wellbeing including patient clothing and footwear development. Based on analyses of 3D anthropometry measurements, human locomotion, models of contact interactions and material behaviour, the projects not only advance the fit and comfort of the designs, but also improve patients' compliance and quality of life.

Research Questions

Balance is a complex problem for elderly. Although footwear has been linked to falls in older people, little is known about the design of geriatric footwear. The research questions of this project include:

a) What are the needs and response of the elderly in relation to degenerative foot changes and associated foot problems with the practical use of indoor footwear for reducing pain and improving walking stability in daily activities?

b) How do foot anthropometric measurements, morphologies and deformities, and distribution of plantar pressure and dynamic body balance change with ageing?

c) How do properties and placement of protrusions (surface textured materials) and footwear materials affect plantar pressure distribution, posture stability and comfort sensation of older people?

d) On the basis of foot biomechanics, foot anthropometry and material sciences and analyses, optimally fitting indoor footwear for the elderly, what are the key design features in footwear design to enhance walking stability and comfort?

Research Outputs

- An ergonomic footwear design that can flexibly fit the foot shape geometry of the elderly due to foot deformities and swollen feet
- Design of flexible heel counter, deep tread grooves and adjustable front strap with the use of highly breathable materials to improve foot protection and mobility of the elderly
- Suitable design, fabrication and placement of protrusions that can augment declines in plantar sensory ability and feedback system to improve stability during walking
- Adequate 3D design and fabrication of footbed that can redistribute excessive plantar pressures during walking to reduce foot pain and wearing comfort

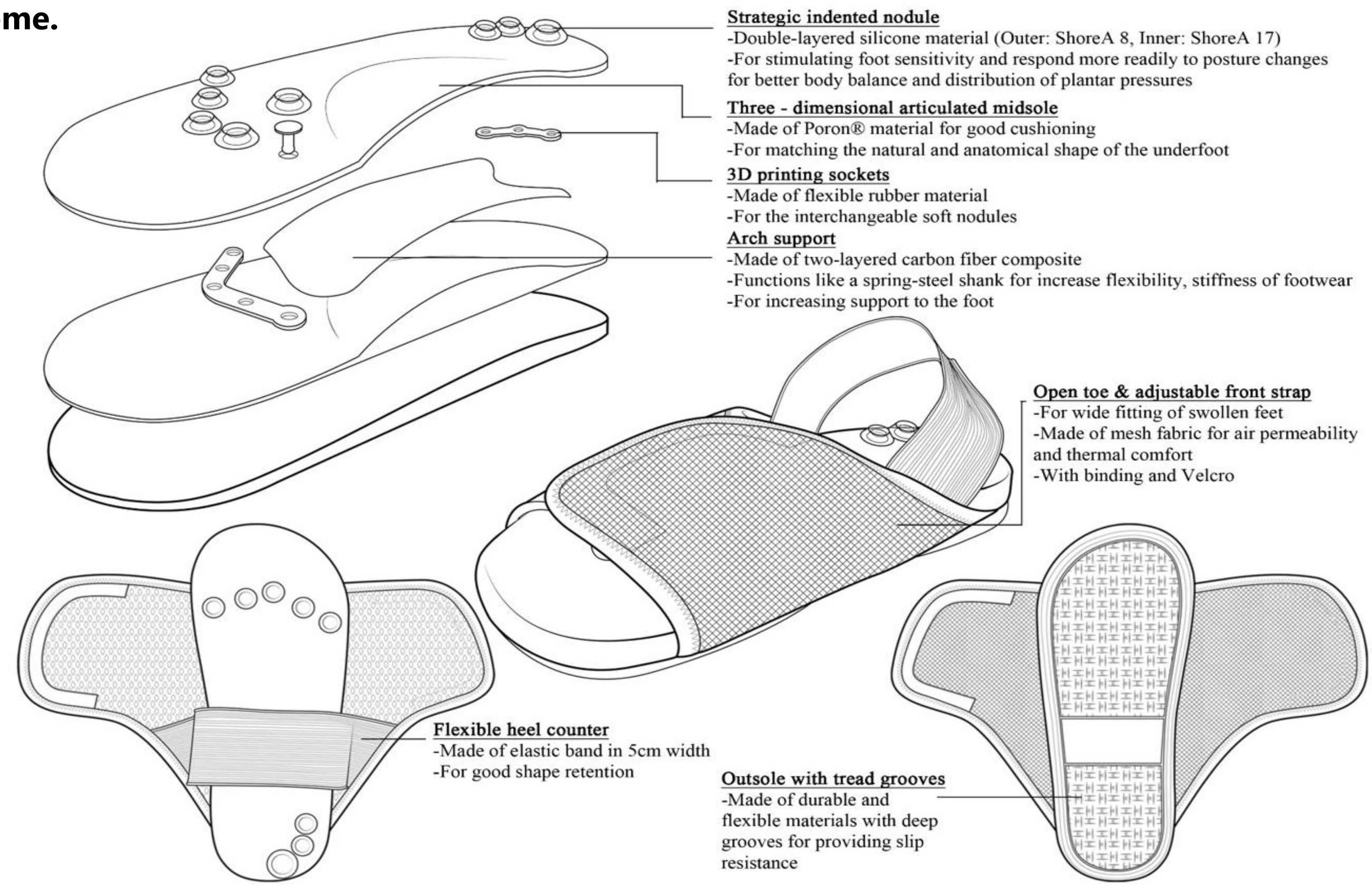
The design is filed in both US and China patents in 2016 and 2018 respectively. The results have been published in 5 top-tier journals, academic book and 5 conference papers (with a best student paper awards) during the period of 2014-19. In 2017 and 2018, footwear prototypes were showcased in 4 exhibitions, an open forum, a teaching laboratory and 2 co-design workshops in local elderly centres.

Yick's contribution to the research are:

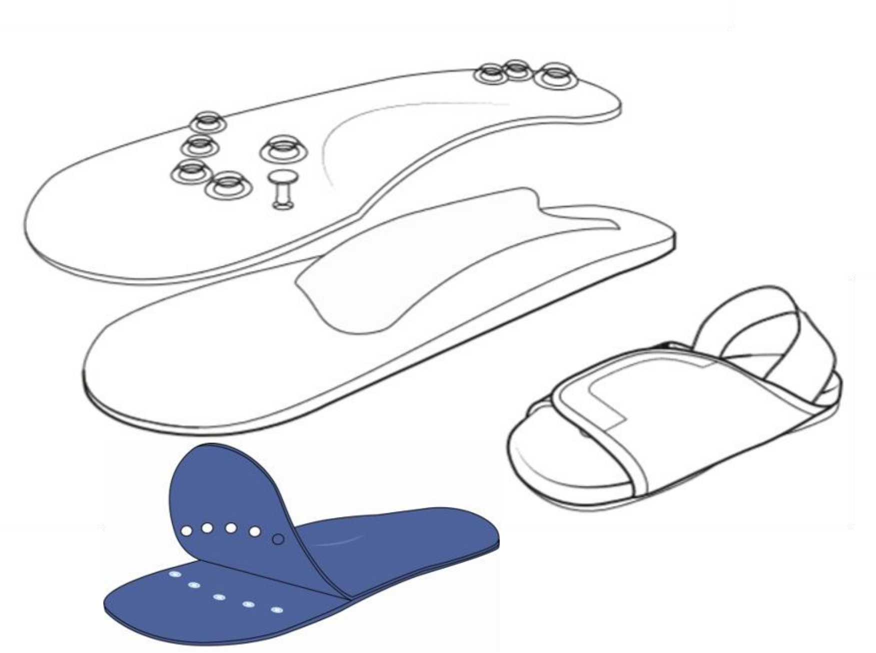
- Define design criteria to address the needs of the elderly with various forms of foot deformities and problems.
- Suggest solutions in design modifications and production of footwear prototypes
- Formulate scientific and systematic methods to evaluate footwear performance, including evaluations of balance, plantar pressure, muscle activity of lower limbs, subjective perception, etc.

Schematic Diagram of the Footwear Prototype

It addresses the intricacies of footwear design for older people that could be comfortably and safely worn at home.



Final Footwear Design



- Color combo (Red) and outsole pattern of size 36/37
- Color combo (Blue) and outsole pattern of size 38/39
- Color combo (Grey) and outsole pattern of size 40/41
- Color combo (Green) and outsole pattern of size 42/43

Nodules are detachable and compressible for comfort.

Research Field and Key Works Referenced

- About 40% of the elderly (age ≥ 65) living at home will fall at least once each year, in which about 25% of them will be hospitalized. *(Paiva de Castro et al., 2010)*
- Foot deformities and poorly fitting shoes are commonly found in older people. *(Mickle et al., 2010; Saghazadeh et al., 2015; Menz & Morris, 2005)*
- Ageing and inappropriate footwear lead to increased plantar pressure, postural sway, poor balance control & higher risks of falling. *(Paiva de Castro et al., 2010; Lorimer et al., 2002)*
- Textured insoles for enhancing underfoot sensitivity demonstrated positive effects on improving postural stability in older people. *(Aruin & Kanekar, 2013; Palluel, 2008)*
- Plantar cutaneous sensation and somatosensory feedback could be improved by suitable footwear features and/or designs. *(Qiu et al., 2012; Hatton et al., 2012)*

Aruin & Kanekar (2013). Effect of a textured insole on balance and gait symmetry. *Exp.Brain Res.* 231 (2), 201-208.

Hatton *et al. (*2012). Altering gait by way of stimulation of the plantar surface of the foot: the immediate effect of wearing textured insoles in older fallers. *J Foot & Ankle Res,* 5, 21.

Lorimer et al. (2002). *Neale's Disorders of the Foot.* Churchill Livingstone, Harcourt Publishers Limited.

Menz & Morris (2005). Footwear characteristics and foot problems in older people. *Gerontology*, 51 (5), 346-351.

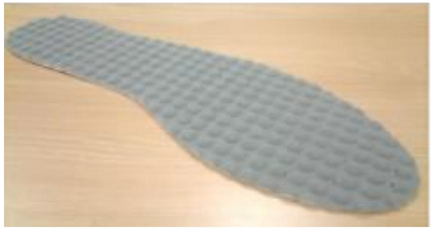
Mickle, et al., (2010). Foot shape of older people: Implications for shoe design. *Footwear Sci.* 2 (3), 131-139.

Paiva de Castro, et al. (2010). The relationship between foot pain, anthropometric variables and footwear among older people. *Appl.Erg.* 41 (1), 93-97.

Palluel, et al. (2008). Do spike insoles enhance postural stability and plantar-surface cutaneous sensitivity in the elderly?. *Age,* 30 (1), 53-61.

Qiu, et al. (2012). Enhanced somatosensory information decreases postural sway in older people. *Gait & Posture*, 35 (4), 630-635.

Saghazadeh, et al. (2015). Gender differences of foot characteristics in older Japanese adults using a 3D foot scanner. *J. Foot & Ankle Res.* 8 (1).

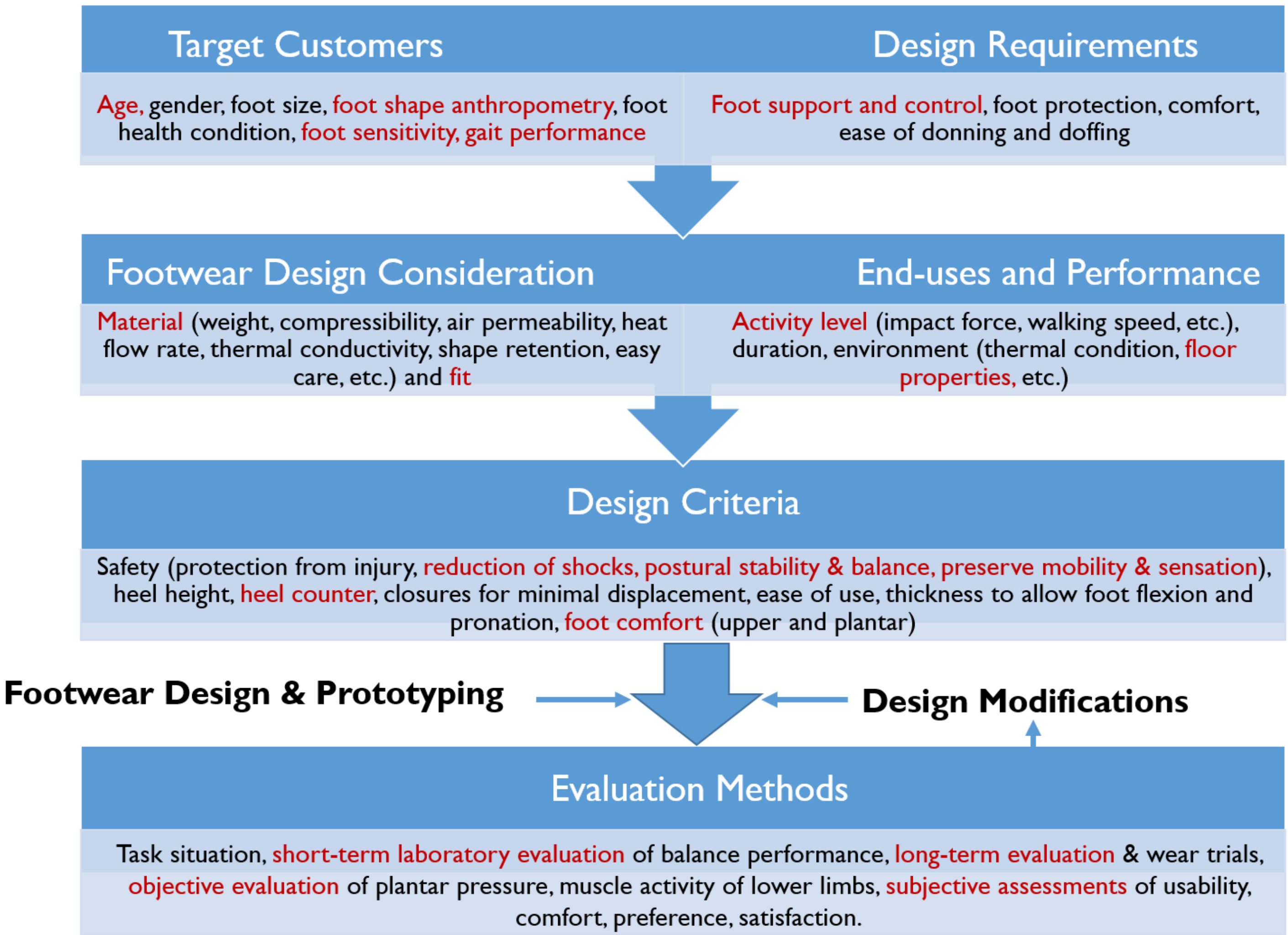


Knowledge Gap

Footwear for the elderly must be appropriate for the location and activity being undertaken. However, there has been a scarcity of scientific work for suitable indoor footwear.

- Few investigations have been carried out on the foot anthropometry in older Chinese adults to improve fit and design of footwear.
- The design requirements and criteria of indoor footwear for enhancing balance of older people have not been reported.
- Effects of design features and material properties of indoor footwear on improving body stability and plantar pressure distribution have not been analysed.
- The strategic design and properties of texturing materials for improving plantar sensation and balance control of older people have not been reported.
- Information on indoor footwear fit, wearing comfort and their practical use amongst older people is missing.

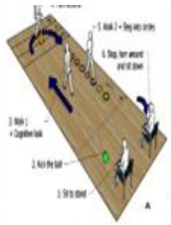
Research Methods & Materials

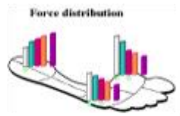


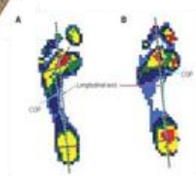
Research Context

Muscle Activity

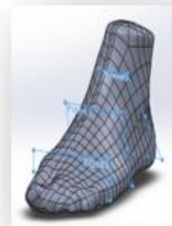
Balance Performance & Predict Fall Risk



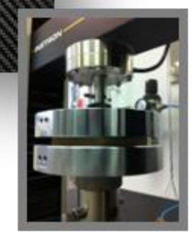




Postural Stability & Plantar Pressure



3D Foot Image Analysis



Material Fabrication & Evaluation

Footwear Design & Prototyping Technologies

The research incorporates foot biomechanics and foot anthropometry analysis into the design of footwear for improving fit and mobility of the elderly. Ergonomic design considerations such as material properties, durability, ease of donning, condition of use, task requirements and comfort are taken into consideration.

Multi-disciplinary Research

Dr. Yick specialises in body anthropometry measurements, and evaluations of materials, fit and pressures for anatomical engineered design for well-being. In this project, she works intensively on 3D foot scanning, material characterisation, and body motion analysis to advance the design of footwear. She also closely works with various elderly centres and formulates suitable approach to address the needs of older people.

This study is a multi-disciplinary research project led by **Dr. Yick** which involves physiotherapist, mechanical engineer, garment technologist and textile expert. With the support of elderly centers, in-depth investigations on footwear needs and foot care workshops were conducted. Activity profiles of older people and their daily foot-care routines, indoor footwear requirements, and practical uses of footwear and slippers in and around the home were also investigated.

Based on extensive analysis of 3D foot shapes, an anatomically engineered footwear for older people was designed. To provide adequate support for body weight and maintain consistent foot-footwear interface pressures and the contact conditions of footwear across the plantar foot surface, the team has established a systematic methodology to quantitatively assess the key properties of footwear materials. With regards to the practical use of footwear, instrumentations for measuring force reduction performance of footwear material were also developed. The change of plantar pressures, centre of pressures and muscle activity of the lower limbs in response to different design and fabrication of footwear were identified and analysed. The research findings also provide basis for future research on footwear sizing system and design that could improve foot protection in accordance with various activities and advance the design of functional footwear.

Supporting Partners

Health Care Sectors

Helping Hand 伸手助人協會

HKSB 香港盲人輔導會

Institute of Active Ageing 活齡學院

香港鞋業商會
HONG KONG FOOTWEAR ASSOCIATION

Hong Kong Government

創新科技署
Innovation and Technology Commission

Footwear Association & Commercial Companies

PROACTIVE ASIA CO LTD

Goddess International Limited

Apart from Government funding, supporting partners of this project include Hong Kong Footwear Association, footwear manufacturers, and health care sectors, such as Helping Hand (Po Lam Jockey Club Housing for Elderly, Siu Sai Wan Jockey Club Housing for Elderly and Chuk Yuen Jockey Club Housing for Elderly), Hong Kong Sheng Kung Hui Lok Man Alice Kwok Integrated Service Centre, Hong Kong Christian Mutual Improvement Society Chuang Chung Wen Centre for the Elderly, with over 500 elderly.

Phase I: Foot Care Programme

It aims to identify footwear problems of older people and formulate suitable design requirements to meet the specified needs of end-users.

Questionnaire

Identifying footwear requirements and preferences

Foot examination

Analysing foot deformity and sensitivity

Static footprint measurement

Examining foot pressure and using Podograph

Tinetti Performance-Oriented Mobility Assessment

Investigating mobility and dynamic stability of elderly

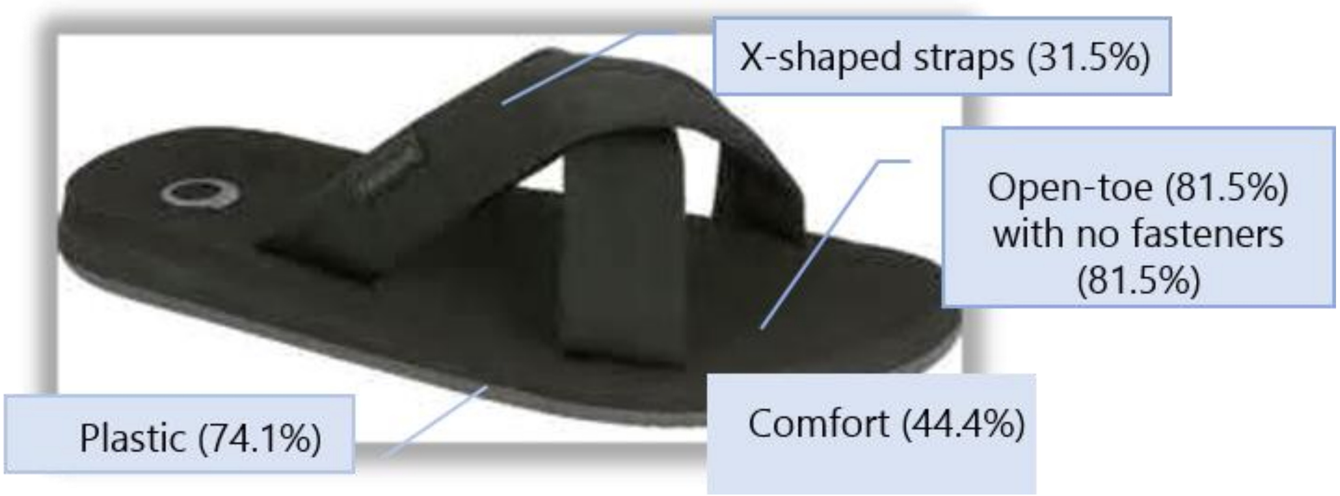
3D Foot Scanning and measurements

Analysing foot shape geometry and degenerative foot shape changes

Phase I: Foot Care Programme

- No. of participants: 54 elderly (mean of 81.76 years old)
- Discomfort area: medial (14.8%) and plantar sides (14.8%)
- Design features and requirements of indoor footwear:

Questionnaire



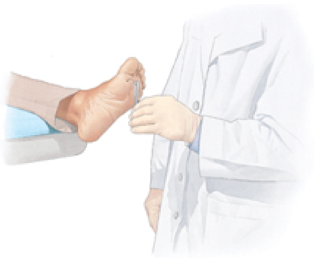
A typical indoor footwear adopted by the elderly in Hong Kong

Phase I: Foot Care Programme

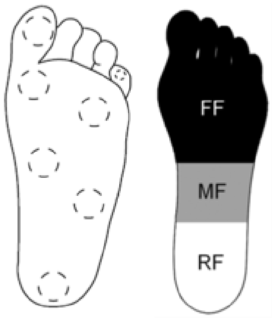
Foot examination

Foot Region	Left Foot	Right Foot
	Mean (SD)	Mean (SD)
Forefoot	5.21 (0.36)	5.21 (0.36)*
Midfoot	5.19 (0.33)*	5.14 (0.27)*
Rearfoot	5.34 (0.46)*	5.41 (0.49)*
*Significant difference at P<0.05		

Foot sensitivity scores (expressed in filaments markings) of elderly across three foot regions



A **5.07** monofilament as cut off for normal sensation

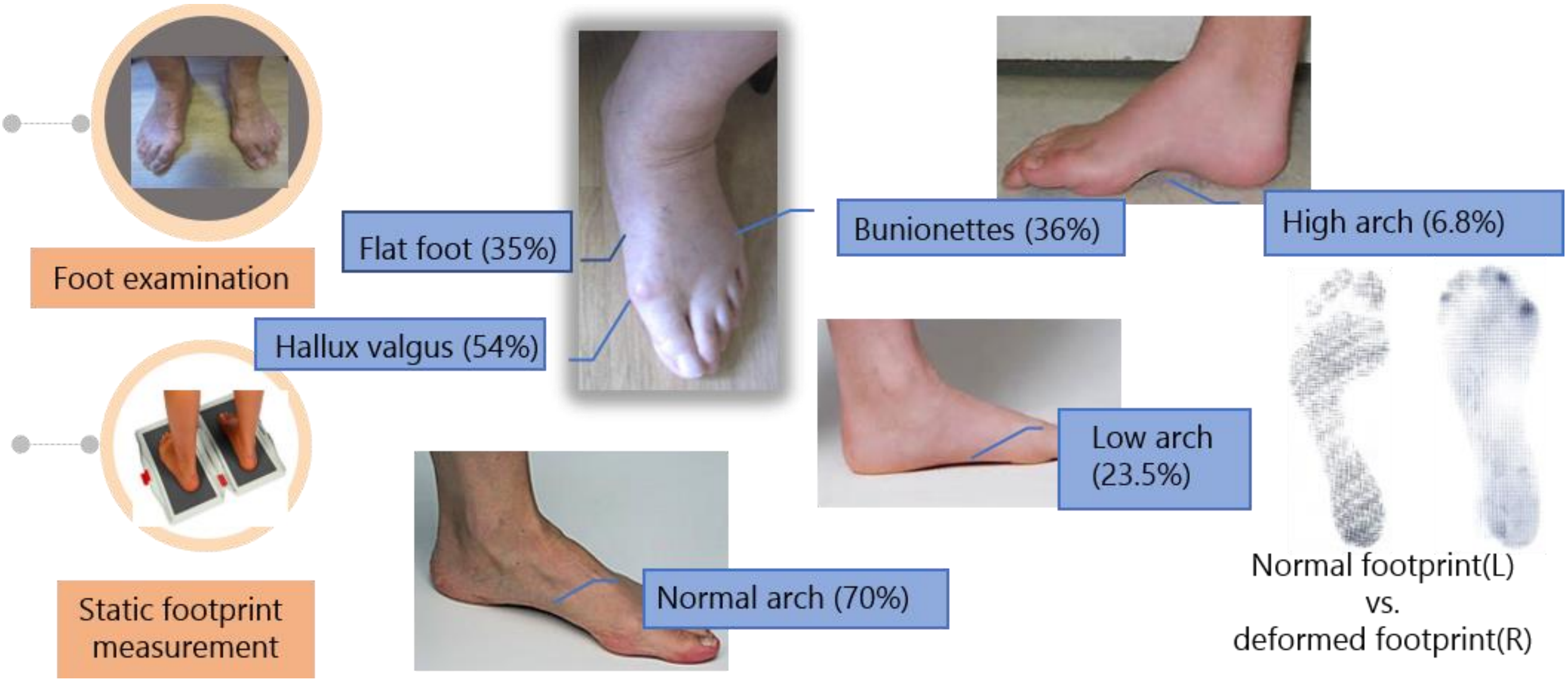


7 sensitive points and different foot regions considered - FF: forefoot; MF: midfoot; RF: rearfoot

Touch sensitivity test by using Semmes–Weinstein monofilaments

- Around 28.6% of the subjects are diagnosed with low underfoot sensation (low sensation in ≥2 foot areas).
- Midfoot has higher sensitivity as compared to forefoot and rearfoot regions (consistent with Brazilian elderly)
- No significant differences are found for both right and left feet, as well as gender

Phase I: Foot Care Programme



Foot condition and footprint results

- Majority (78.8%): at least one foot deformity problem
- Amongst the 54 subjects studied, only 11 have a healthy foot.
- The incidences and patterns of foot deformities are very similar to those in previous studies of elderly people in Hong Kong and Thailand.

Phase I: Foot Care Programme

Tinetti Performance-Oriented Mobility Assessment

	Male	Female	Overall (SD)
Balance POMA (0-16)	14.75 (1.39)	15.17 (1.41)	15.10 (1.40)
Gait POMA (0-12)	11.50 (1.51)	11.56 (0.92)	11.55 (1.02)
Tinetti POMA (0-28)	26.3 (1.60)	26.7 (1.9)	26.7 (1.80)
Risk of Falling (Tinetti POMA)			
High (0-17)	0 (0%)	0 (0%)	0 (0%)
Medium (18-24)	1 (12.5%)	7 (17.07%)	8 (16.33%)
Low (25-28)	7 (87.5%)	34 (82.93%)	41 (83.67%)

Related Conference Paper:

Lo W.T., Yeung K.L., Li P.L., Yick K.L., Chan K.C. (2016). Mobility performance and foot problems in older people. CPCE Health Conference 2016, 11-12 January 2016, Hong Kong.

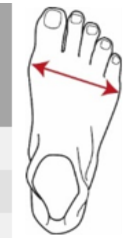
- Amongst the 49 subjects, 41 (83.7%) perform satisfactorily with a POMA score of 25 or above (i.e. low risk of falls), whilst none are diagnosed with a high risk of falling.
- Amongst those with a medium risk of falls, the percentage of female subjects is slightly higher than that of the male subjects.
- There is no significant difference for gender in both balance and gait performance.

Phase I: Foot Care Programme

Foot Scanning and measurements

Female	Healthy Foot (n=20)	Deformed Foot (n=62)	Mean Difference (%)
	Mean (SD)	Mean (SD)	
Foot Length (mm)	230.39 (8.06)	229.29 (11.79)	-0.48
Heel Length (mm)	58.00 (5.59)	59.88 (4.62)	3.24
Ball Length (mm)	169.40 (5.97)	170.91 (8.64)	0.89
Foot Width (mm)	90.15 (6.14)	92.56 (5.16)	2.67
Ball Width (mm)	92.11 (6.12)*	94.95 (5.02)*	3.08
Bimalleolar width (mm)	64.52 (3.66)	64.49 (6.39)	-0.05
Ball Girth (mm)	142.66 (9.56)	142.72 (9.45)	0.04
Instep Girth (mm)	159.31 (9.84)	161.15 (11.20)	1.15
Instep Height (mm)	61.16 (4.06)	60.44 (5.49)	-1.18
Degree of Hallux Valgus Deformity (○)	7.58 (3.67)*	15.82 (10.27)*	108.71
Valgus Index (%)	-1.67 (5.66)	-1.36 (7.35)	0.19

*Significant difference at P<0.05 (2-tailed)



Ball Width

Degree of Hallux Valgus Deformity

Related Journal & Conference Papers:

- Li P.L., Yick K.L., Ng S.P., Yip J. (2016). Foot anthropometric measurements of Hong Kong elderly: implications for footwear design. *Journal of Fiber Bioengineering and Informatics*, 9:3(2016), 133-143.
- Li P.L., Yick K.L., Ng S.P., Yip J. (2016). Foot anthropometric measurements of Hong Kong elderly: implications for footwear design. The 9th Textile Bioengineering Informatics Symposium & The 6th Asian Protective Clothing Conference, RMIT University, Melbourne, Australia, 12-15 July 2016. (Best Student Paper Award)

- Amongst the female subjects, as compared to healthy foot, significant differences are shown in Ball Width (BW) and the degree of hallux valgus deformity (HVD) (p=0.040, p=0.000 respectively)
- The results are consistent with older Japanese women that significant difference is found in the first toe angle (hallux valgus), leading to a significant increase of BG and BW.

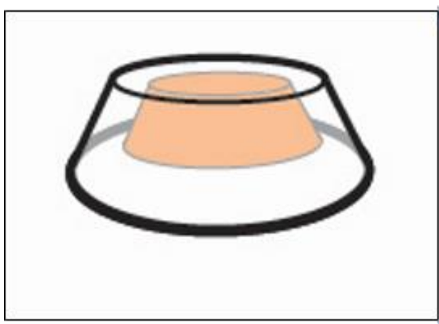
Phase II: Footwear Design Considerations on Materials & End-use

Indented textures

Aim to stimulate foot sensitivity and respond more readily to posture changes for better body balance and distribution of plantar pressures.

Problems: it will inevitably increase plantar pressure due to reduction of the supporting surface directly in contact with the plantar soles. It will also cause wearing discomfort.

Focus of study: fabrication (comfort & durable with suitable compression properties) & location sites of insole textures.



Phase II: Footwear Design Considerations on Materials & End-use

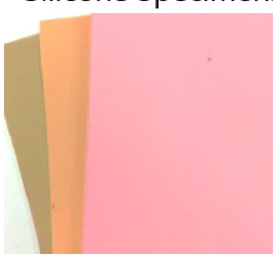
A. Fabrication of textured (nodules) materials

- Objective: Evaluate and select suitable nodule materials for adequately stimulation of tactile sensitivity with optimal comfort
- Testing Materials of Single-Layer

Specifications of nodule materials:

Brand/Name	Sample	Ratio			Density (g/cm^3)	Hardness (Shore A)	Thickness (mm)
		Silicone	Silicone Oil	Catalyst			
Silicone_0	A	1	0	0.1	1.09	41	12
Silicone_0.25	B	1	0.25	0.1	1.04	27	11.5
Silicone_0.5	C	1	0.5	0.1	1.06	17	11.5
Silicone_0.75	D	1	0.75	0.1	1.05	11	12
Silicone_1	E	1	1	0.1	1.02	8	11.5
lora®Lunairmed	F	N/A	N/A	N/A	0.16	20	3
High Density EVA 1	G	N/A	N/A	N/A	0.08	36	3.65
High Density EVA 2	H	N/A	N/A	N/A	0.17	32	1.5

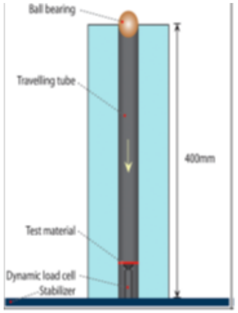

Silicone Specimen

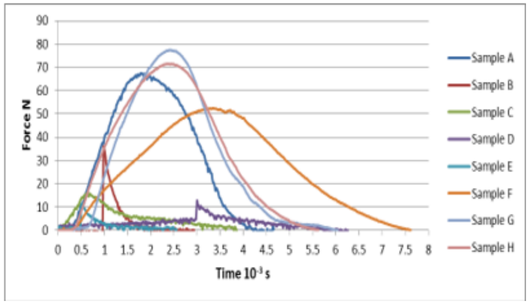

EVA Specimens

Phase II: Footwear Design Considerations on Materials & End-use

- Sample E shows excellent energy absorption (>96%), short reaction time for absorption of impact forces.
- Sample E shows the largest deformity (compressed by 17.43%), whereas Sample H (High density EVA 2) has the least amount of deformity (compressed by 9.31%).

Sample	Density (g/cm³)	Hardness (Shore A)	Force Reduction (%)	Compressive Stress (kPa)	Young's modulus (MPa)	Compressive Strain
A	1.09	41	79.33	4098	27.14	12.64
B	1.04	27	87.93	1748	11.01	13.66
C	1.06	17	94.62	1186	7.78	12.79
D	1.05	11	96.80	914	5.70	11.57
E	1.02	8	96.40	521	3.22	17.43
F	0.16	20	82.79	170	0.65	12.69
G	0.08	36	74.57	413	1.79	17.28
H	0.17	32	76.42	404	1.51	9.31





Phase II: Footwear Design Considerations on Materials & End-use

Sample J is *soft, elastic and comfortable*. It also achieves good compressive stress and stiffness, with the best performance in energy absorption and short reaction time.

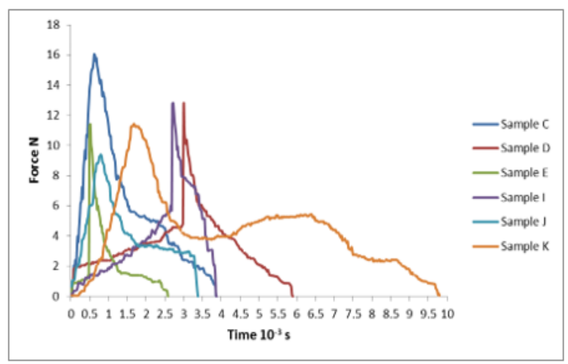
Sample	Density (g/cm³)	Hardness (Shore A)	Energy absorption (%)	Compressive Stress (kPa)	Young's modulus (MPa)	Compressive Strain
I	1.11	8	94.65	1081	6.37	11.33
J	1.12	8	96.98	1007	6.44	11.88
K	1.13	12	96.73	1079	7.21	11.55

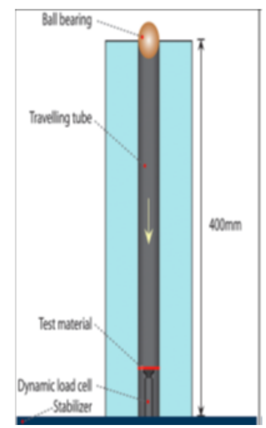
RESULTS:

Double-layered Silicone Nodules:

Orange (Harder) – *silicone 1: silicone oil 0.5: catalyst 0.1*

White (Softer) – *silicone 1: silicone oil 1: catalyst 0.1*





Related Journal Paper:

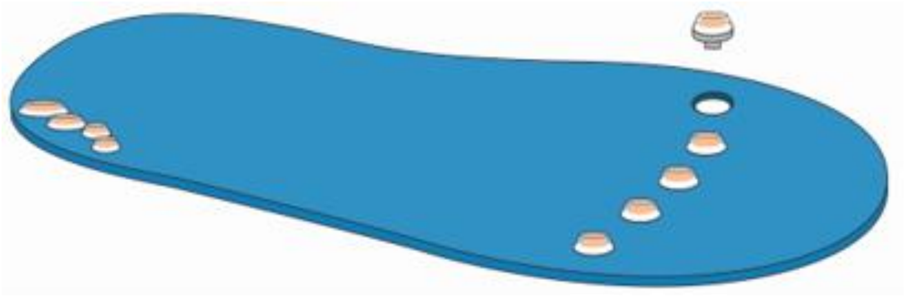
Lo W.T., Yick K.L., Ng S.P., Yip J. (2014). New methods for evaluating physical and thermal comfort properties of orthotic materials used in insoles for patients with diabetes. Journal of Rehabilitation and Research Development, 51(2):311-24.

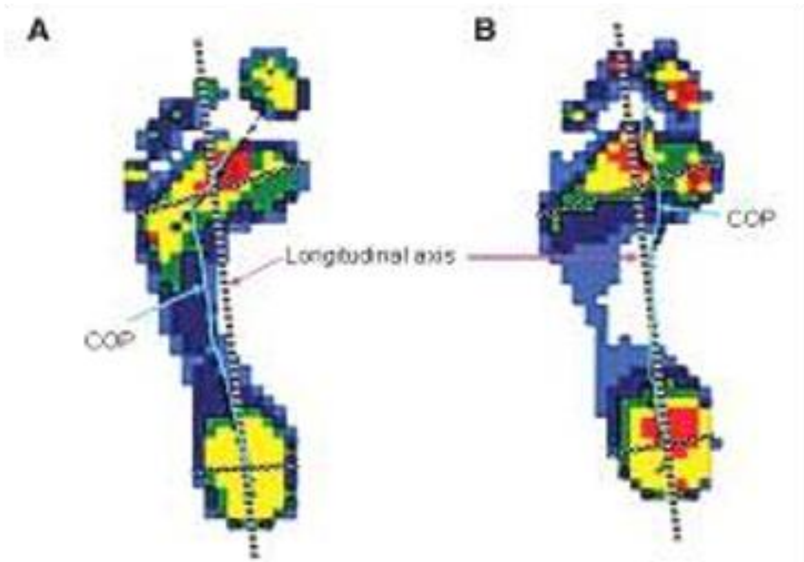
Phase III: Footwear Design Criteria & Related Evaluation

Aim to identify the location sites of indented textures to stimulate suitable underfoot sensation, whilst excessive plantar pressures and discomfort should be avoided.

Proposed solutions:

- Minimal number of indented nodules (improve comfort and foot-insole contact area)
- On the basis of the COP trajectory (body stability evaluation) during dynamic walking, indented nodules are located at heel and MTHs
- Nodules can flexibly be changed or removed





RESULTS:

Related Journal Papers:

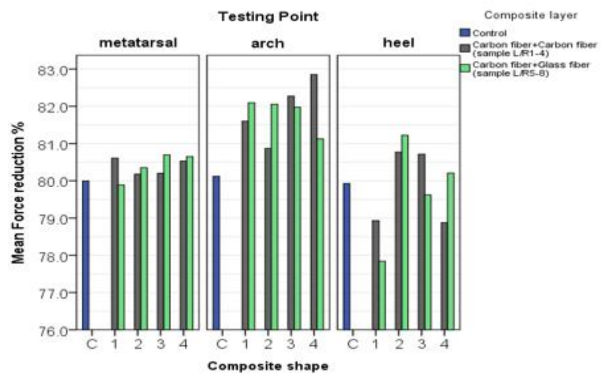
- Lo, et al. (2018). The biomechanical effects and perceived comfort of textile-fabricated insoles during straight line walking. Prosthetics & Orthotics International, 42(2):153-162.
- Lo, et al. (2017). Effects of slipper features and properties on walking and sit-to-stand tasks in older women. Journal of Aging and Physical Activity 25(4), 587-595.

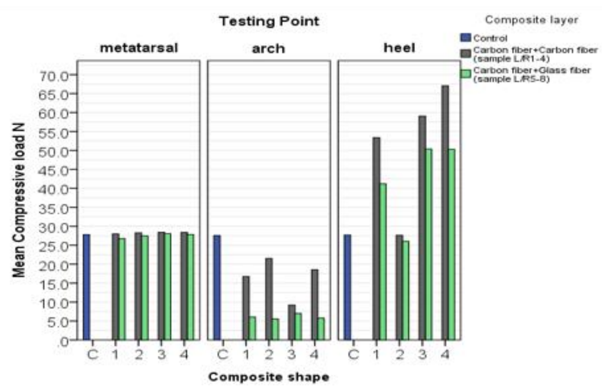
Phase III: Footwear Design Criteria & Related Evaluation

Aim to formulate a suitable 3D architectural design of supportive midsole for plantar pressure management

Results indicated that the reinforcement composites have major improvements on the compression load, with small reductions in energy absorption performance of midsole.

The compressive load of midsole could be improved by the increased length of the reinforcement composite layer and its fabrication materials.

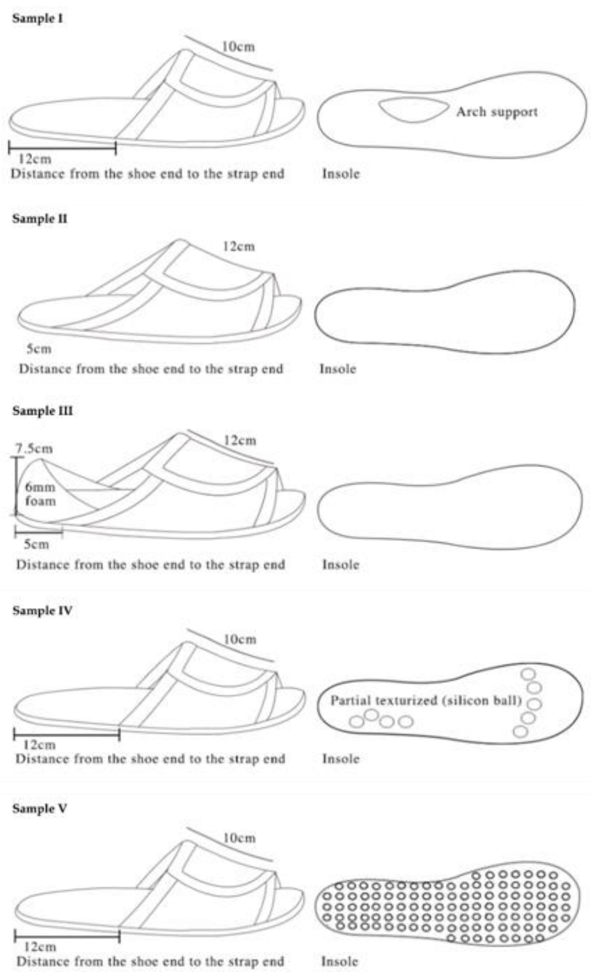




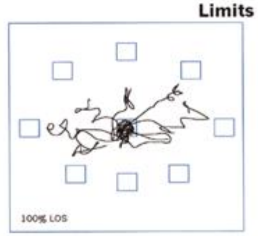
A series of midsole design made of carbon fibres and fibreglass are developed and evaluated.

Phase III: Footwear Design Criteria & Related Evaluation

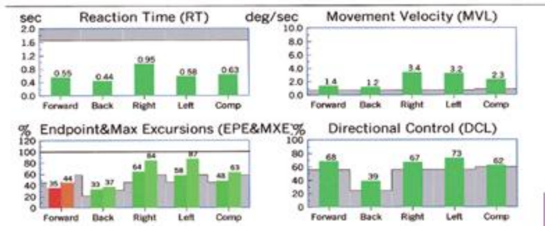
Aim to compare various footwear features such as arch support, strap length, heel counter, textured insole surface in relation to postural stability are evaluated by using Computerized Dynamic Posturography (EquiTest).

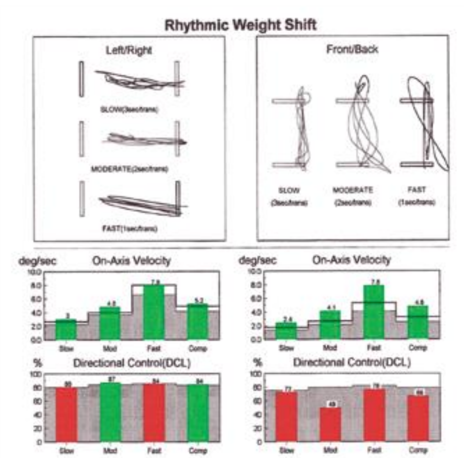


Limits Of Stability



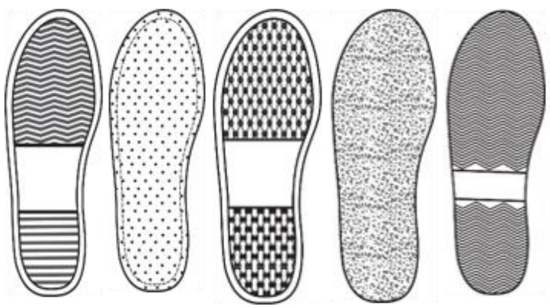
Transition	RT (sec)	MVL (deg/sec)	EPE (%)	MXE (%)	DCL (%)
1 (F)	0.26	1.3	43	52	63
2 (RF)	1.19	2.9	62	79	86
3 (R)	1.04	3.5	49	84	65
4 (RB)	0.52	2.4	58	58	53
5 (B)	0.25	1.3	37	37	23
6 (LB)	0.72	2.3	62	83	57
7 (L)	0.54	2.8	53	82	87
8 (LF)	0.50	2.9	32	55	61



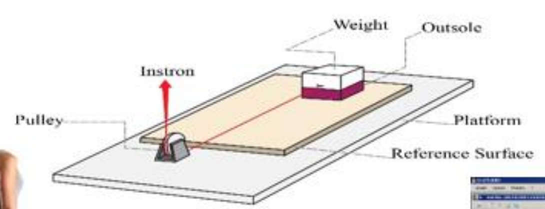


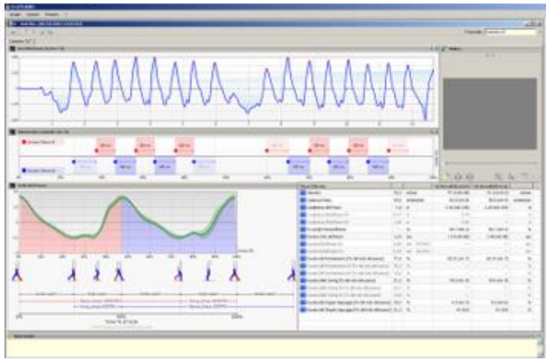
Phase III: Footwear Design Criteria & Related Evaluation

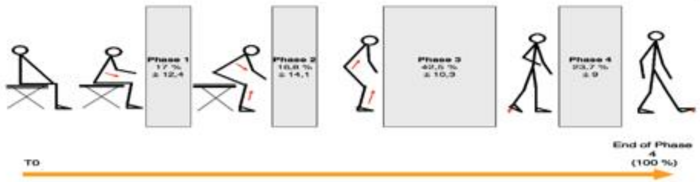
Aim to compare gait performance in response to different footwear outsole tread groove designs & flooring conditions

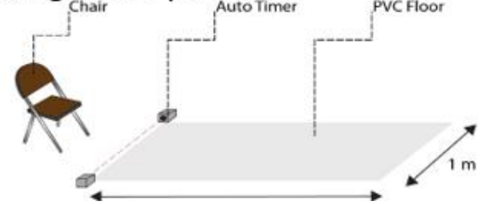


Fabric, PVC and EVA insoles with different tread groove patterns





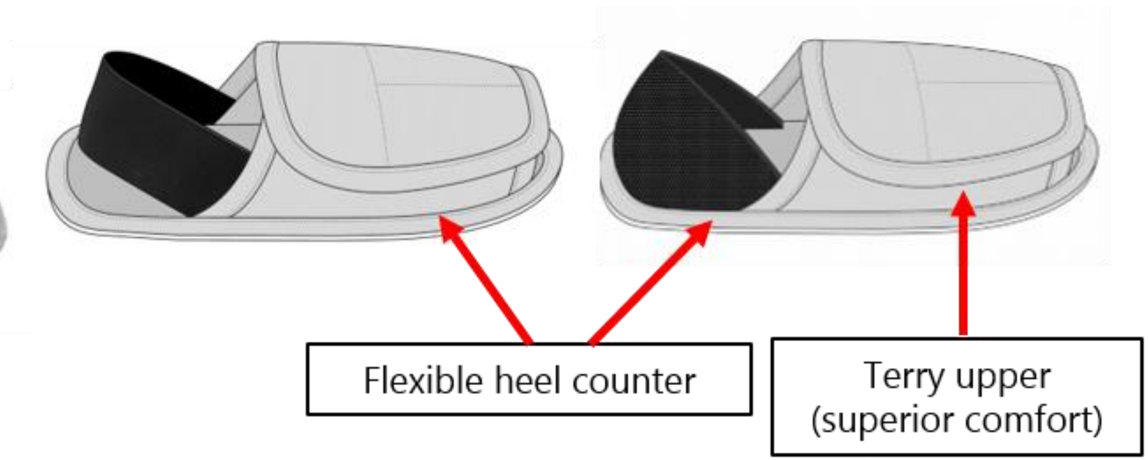


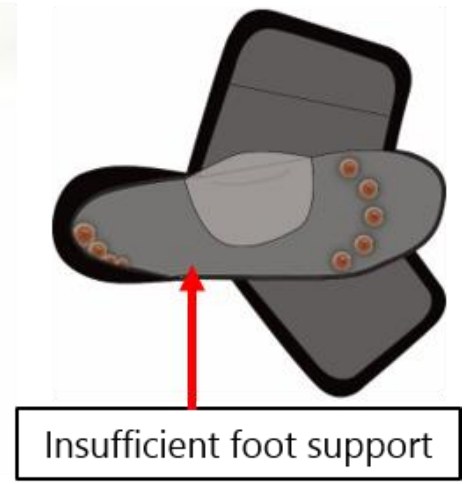


The influence of outsole tread groove designs to walking kinematics (viz., speed, cadence, step length, gait cycle duration, stance duration, etc.) in relation to flooring conditions are evaluated by using BTS G-WALK.

Footwear Prototype I

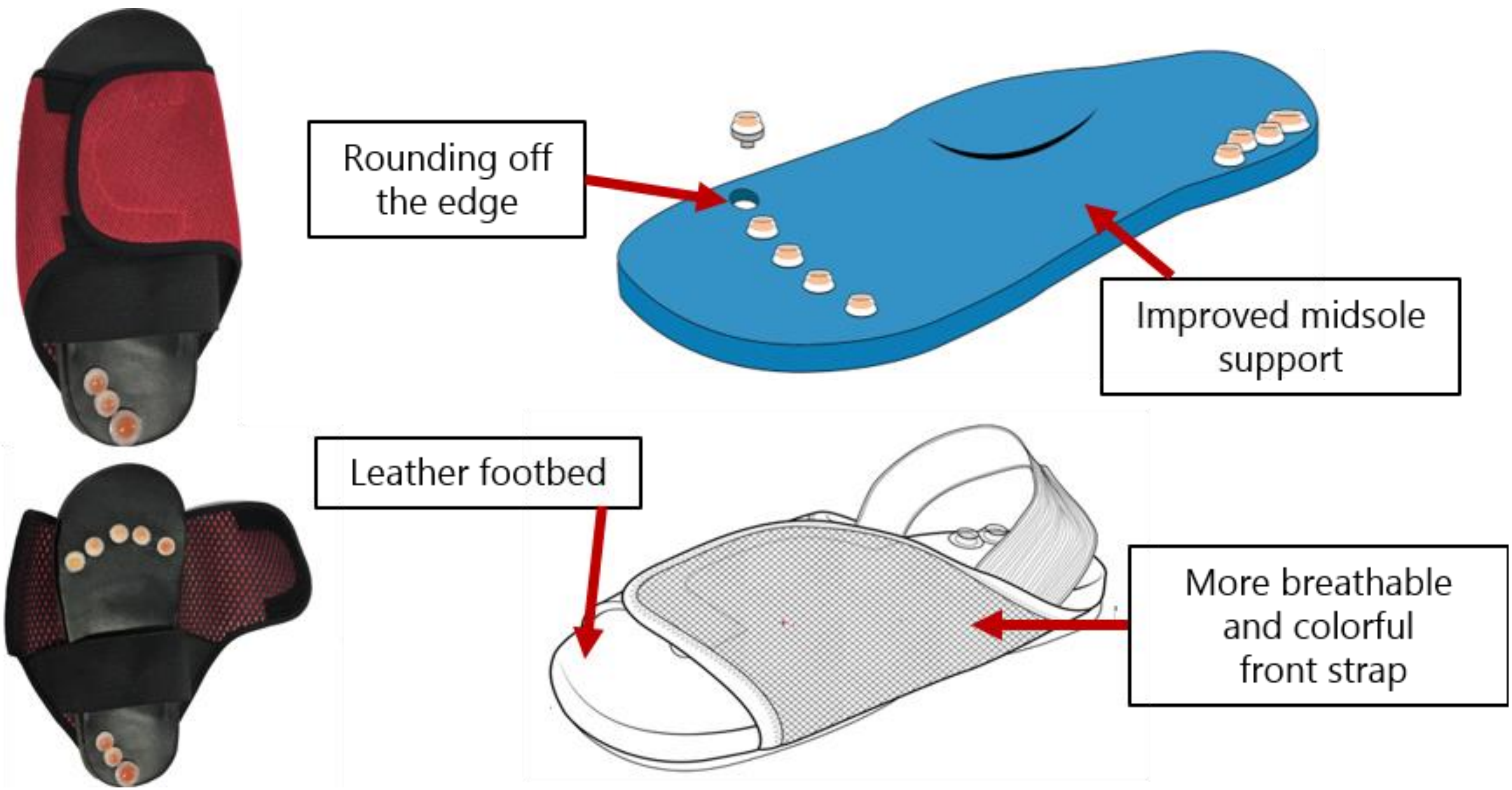
Oct 2016





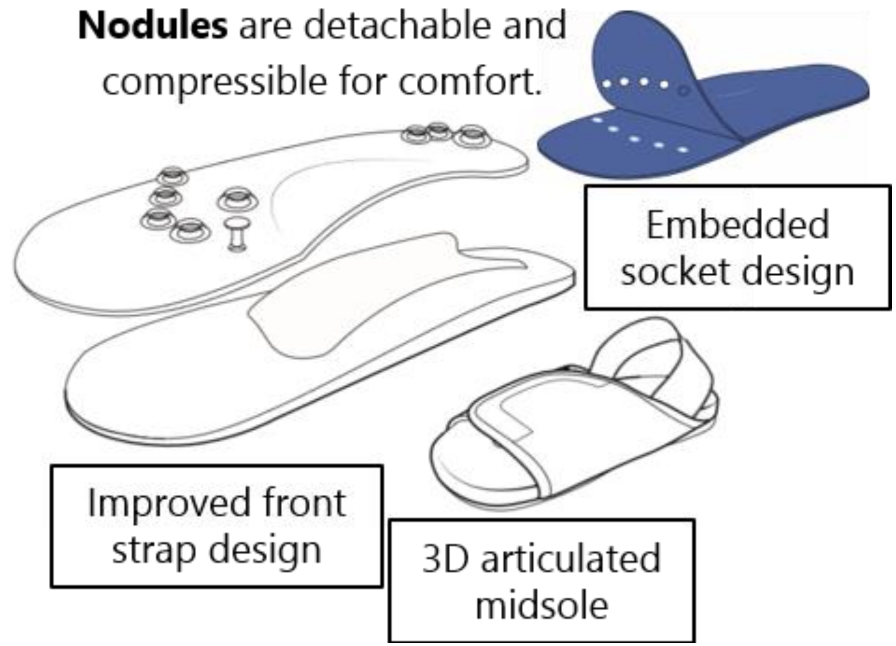
Footwear Prototype II

June 2017



Footwear Prototype III

June 2018



4 colour codes for different footwear sizes

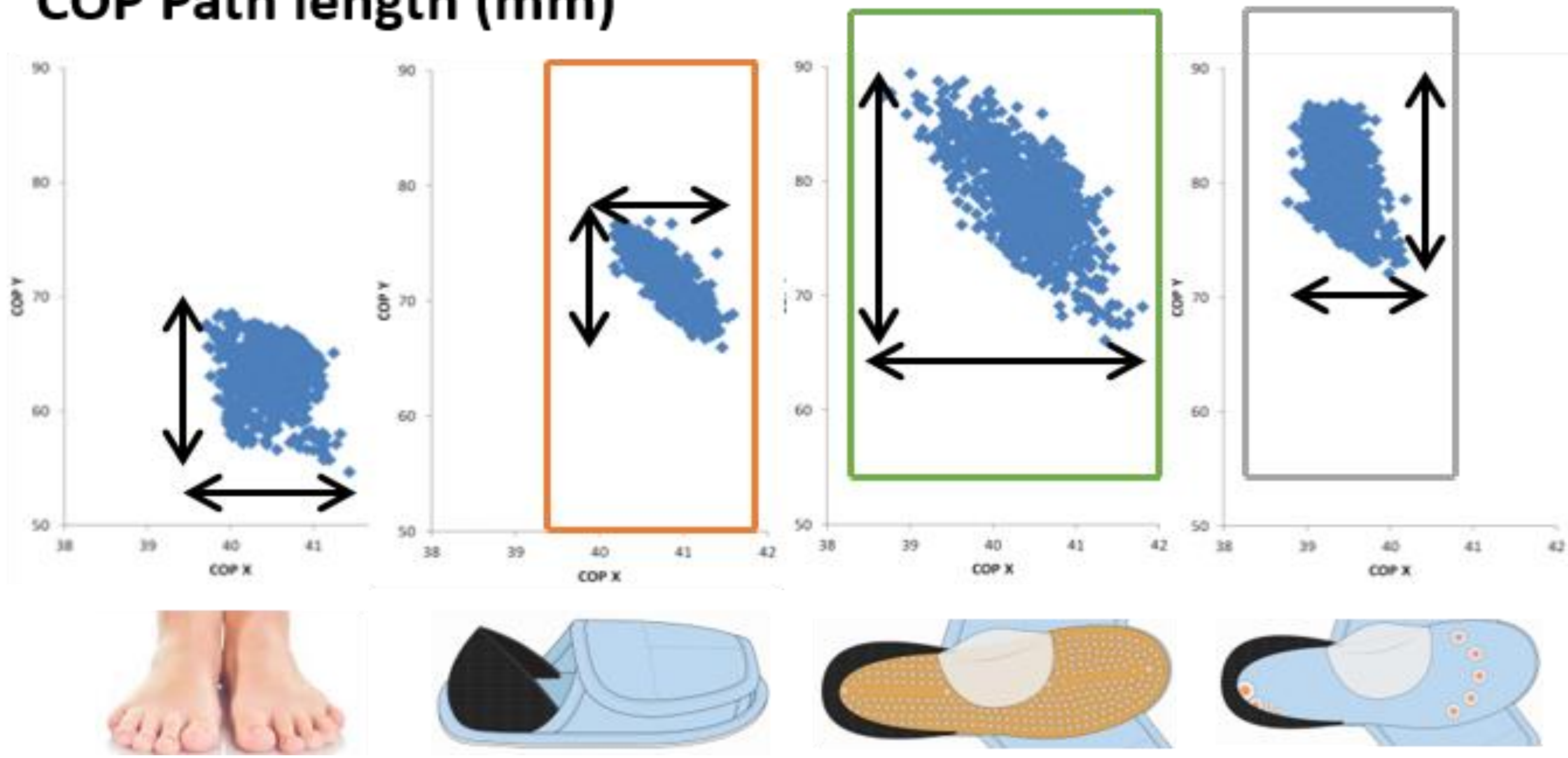
- Color combo (Red) and outsole pattern of size 36/37
- Color combo (Blue) and outsole pattern of size 38/39
- Color combo (Grey) and outsole pattern of size 40/41
- Color combo (Green) and outsole pattern of size 42/43

Phase III: Footwear Design Criteria & Related Evaluation

Aim to evaluate the impact of footwear on postural stability at quiet standing condition.

- Raised nodules & Full textured with arch support slightly shifted anteriorly
- Raised nodules with arch support slightly shifted medially

COP Path length (mm)

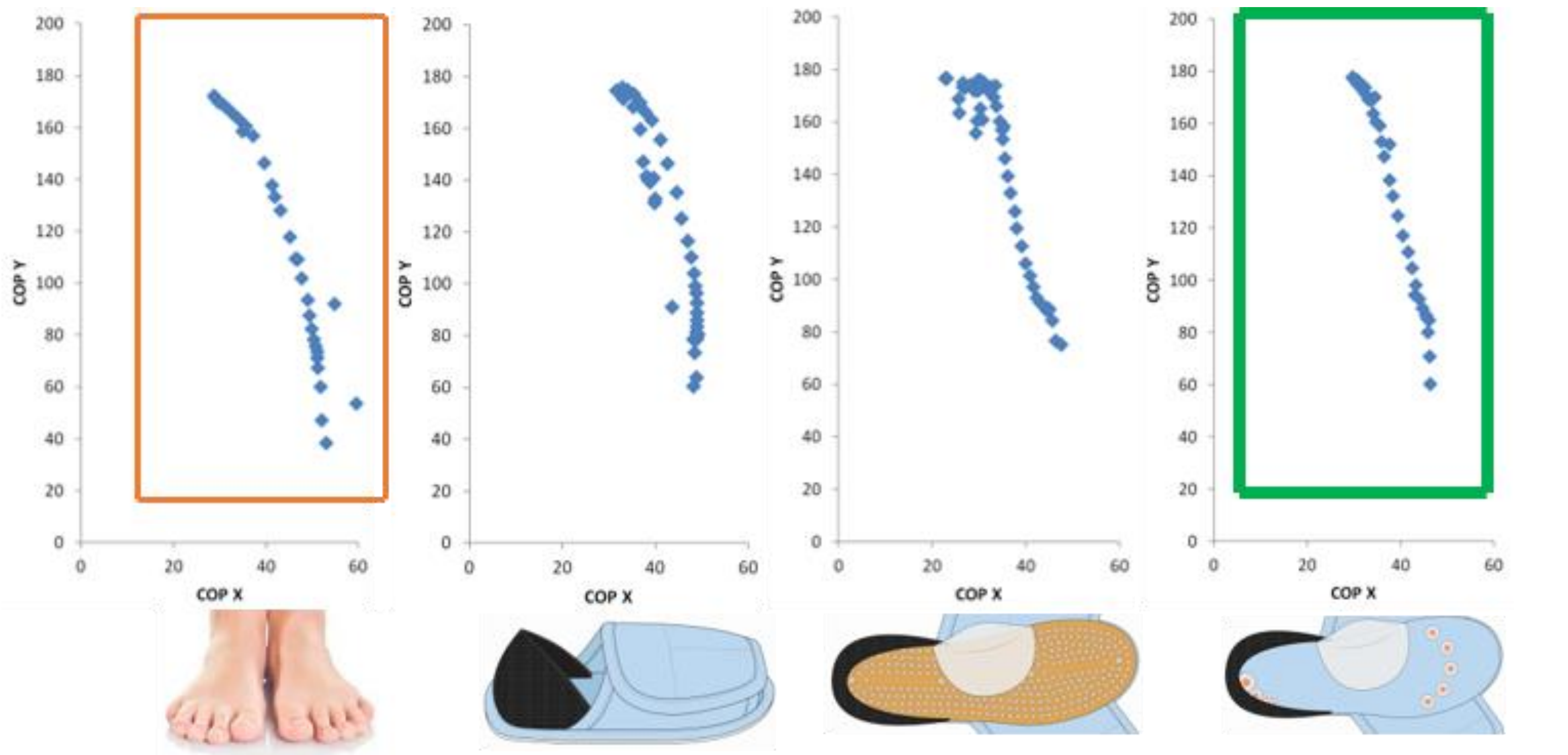


A typical example of COP trajectory during static test on the ground

Phase III: Footwear Design Criteria & Related Evaluation

Aim to evaluate the impact of footwear on postural stability at dynamic walking condition.

- Raised nodules with arch support resulted in similar COP trajectory as barefoot (the most desirable and natural gait).

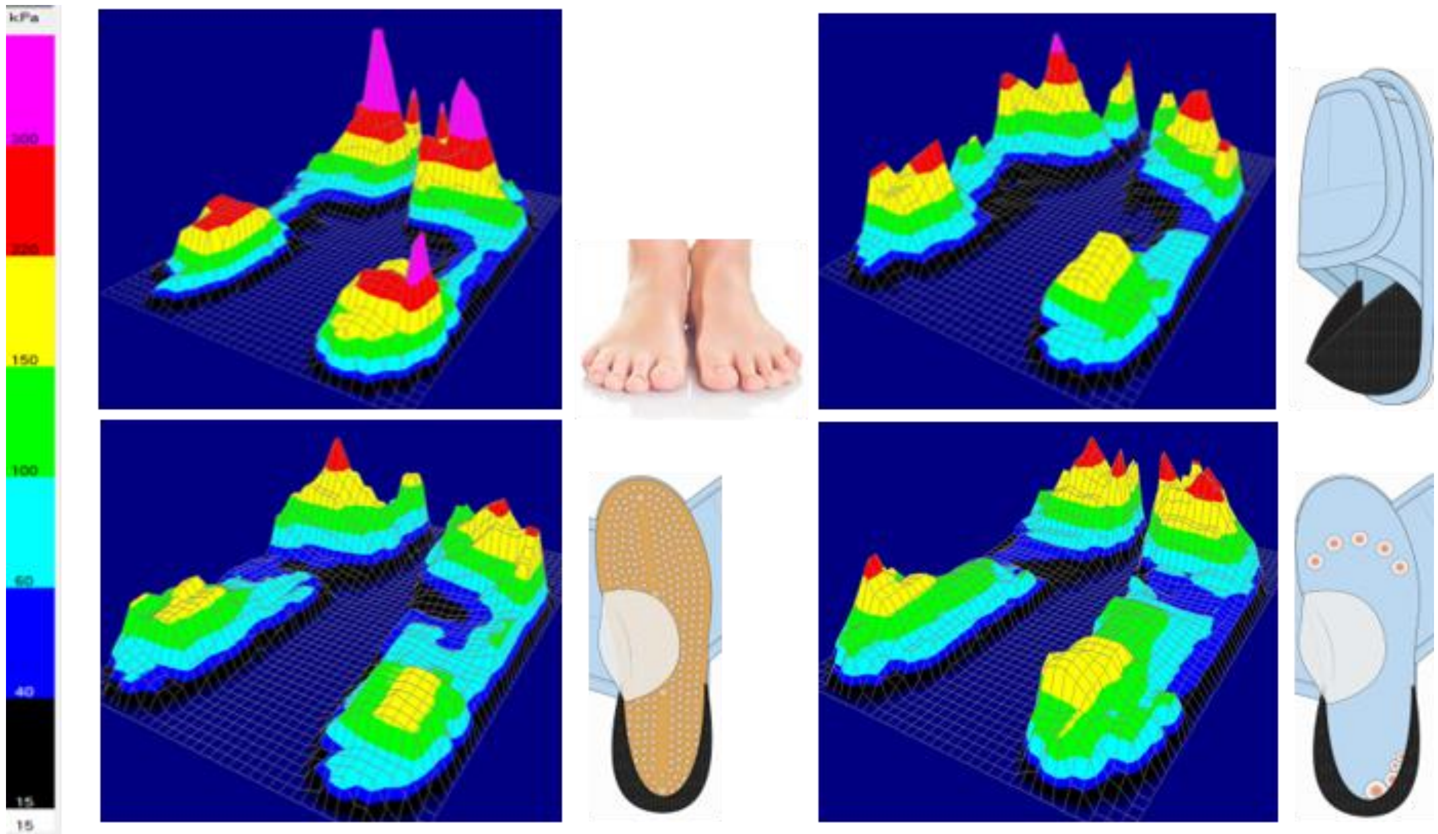


A typical example of COP trajectory during dynamic walking test

Phase III: Footwear Design Criteria & Related Evaluation

Aim to evaluate the plantar pressure distribution at various footwear conditions.

Results: Raised nodules with arch support resulted in reduced underfoot peak pressure, as compared to barefoot and control walking.

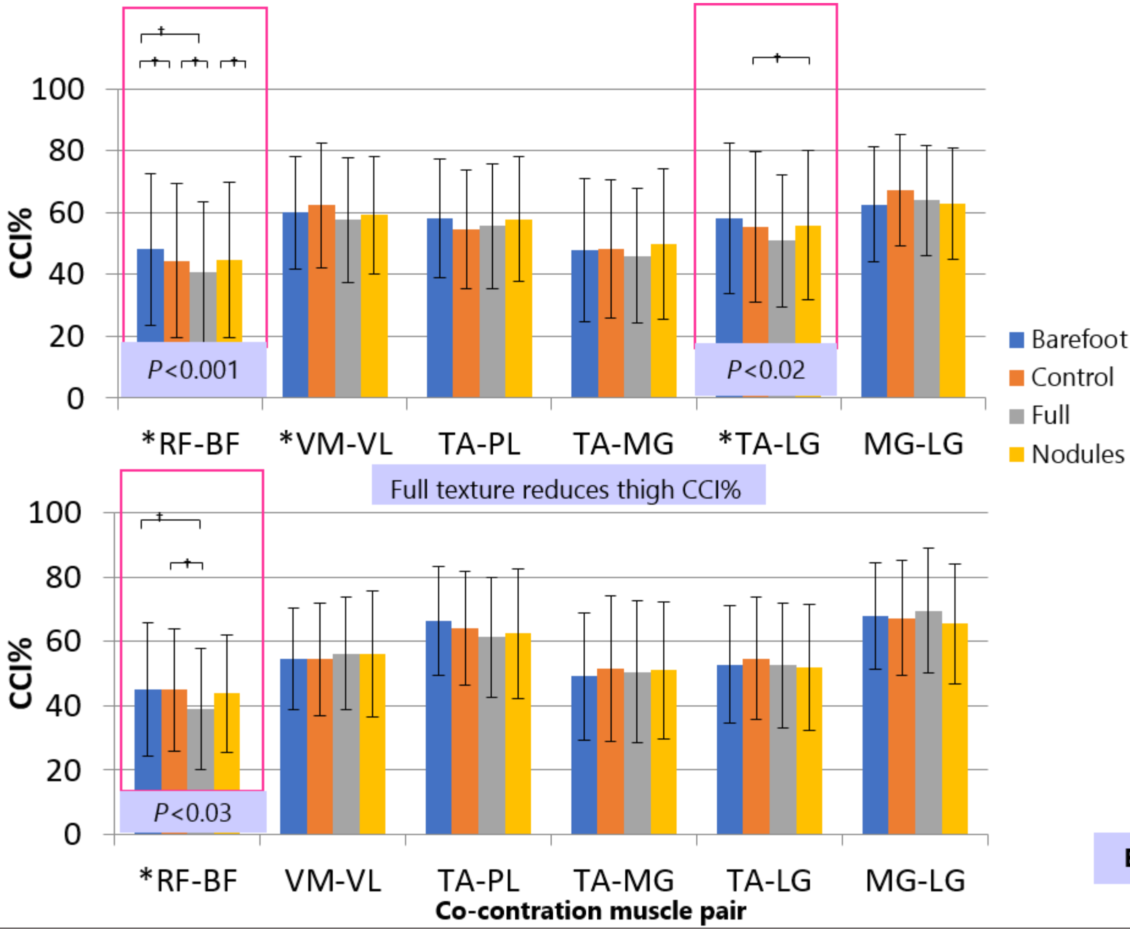


A typical example of pressure distribution during dynamic walking test

Phase III: Footwear Design Criteria & Related Evaluation

Aim to evaluate the muscle activity of lower limbs at various footwear conditions.

Results: Wearing footwear significantly decreased the VL and TA muscle activation, especially for the nodulous shoes



Ground

Balance Pad

Phase IV: Co-creation Footwear Workshop

The workshops encouraged the engagement of users in the footwear design process. It offered a highly meaningful activity for older women to further enhance the footwear design, and improve personal, spiritual and social satisfactions. With challenges on mix-and-match of the trimmings and use of materials, the workshops promoted sense of success in the co-design process and improved wellbeing.

Related Conference Paper:

Kwan MY, Yick KL, Wong YY. (2019). Impact of co-creation footwear workshops on older women in elderly centers in Hong Kong. CPCE Health Conference 2019, Hong Kong.

Asia-Pacific Journal of Health Management, 2019, 14(1):i205 (by invitation)

Research Conclusions

- The design features of the PROPOSED NEW indoor footwear (3D articulated arch support and midsole materials) could effectively increase the pressure contact area, especially in the midfoot region.
- Increased contact area not only allows the body load to be shared across a larger area, but also improves the plantar sensitivity by stimulating more sensory receptors situated in the sensitive medial midfoot region.
- The NEW indoor footwear could effectively shift the body load from high pressure areas (MTH and Heel) to the Midfoot region; hence relieving the pressure at major load bearing areas, the MTH and the Heel.
- The structural design and placement of the nodules could effectively provide stimulation to the plantar sensory receptors and thus increase the frequency of the regulatory body adjustments when maintaining standing balance.
- The balance performance, evaluated in terms of foot stability in the medio-lateral direction during walking, is significantly improved when wearing the current footwear prototypes.

Dissemination

Footwear prototypes were designed, developed and showcased in exhibitions, open forum and teaching laboratory. Through wear trials in laboratory and various elderly centres, the footwear demonstrated significant improvements in muscle co-contraction, postural stability during walking, and reduction of peak pressures by 25-35% in metatarsal heads and heel regions. The research outputs have been published in top-tier journals, academic book and conferences. As the first research work of this kind on care footwear design for the Chinese elderly, a participative co-creation approach was initiated to address the footwear needs of the elderly, and hence promoting footwear safety and caring relationships between the carers and the elderly.

01 Video of geriatric footwear design

02 Exhibitions

03 Academic book

04 US and Chinese Patents

05 Journal Papers

06 Conference Papers

07 Consultancy Projects

The research is supported by local Government funds (HK$2M). Based on large-scale anthropometric studies, clinical symptom screening and foot care programme, the design of the footwear was formulated.

Dissemination 01

Video of Footwear Design

Dissemination 02

Exhibitions

The research and footwear prototypes were showcased at various exhibitions, such as Hong Kong International Medical Devices and Supplies Fair (16-18 May 2017). A forum presentation was given on 18 May 2017 during the International Medical Devices and Supplies Fair, organized by Hong Kong Trade Development Council with 270 exhibitors and 10,793 buyers from different countries.

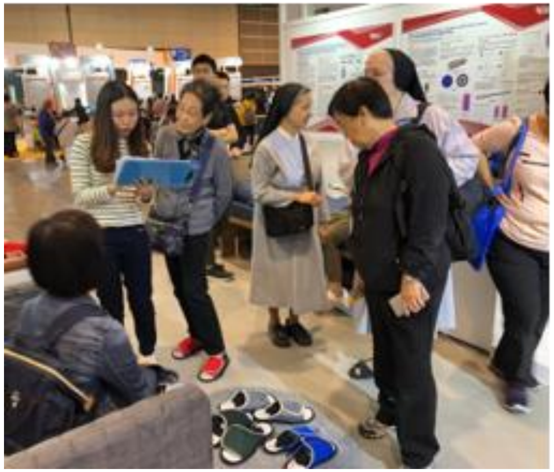
It was also exhibited in The Gerontech and Innovation Expo cum Summit 2017 (16-18 June 2017), organized by the Government of HKSAR, The Community Health Training Center of Hong Kong Institute of Vocational Education, PolyU 80th Anniversary Open Day in late 2017.

Visitors signed up for more information

Dissemination 02

Exhibitions

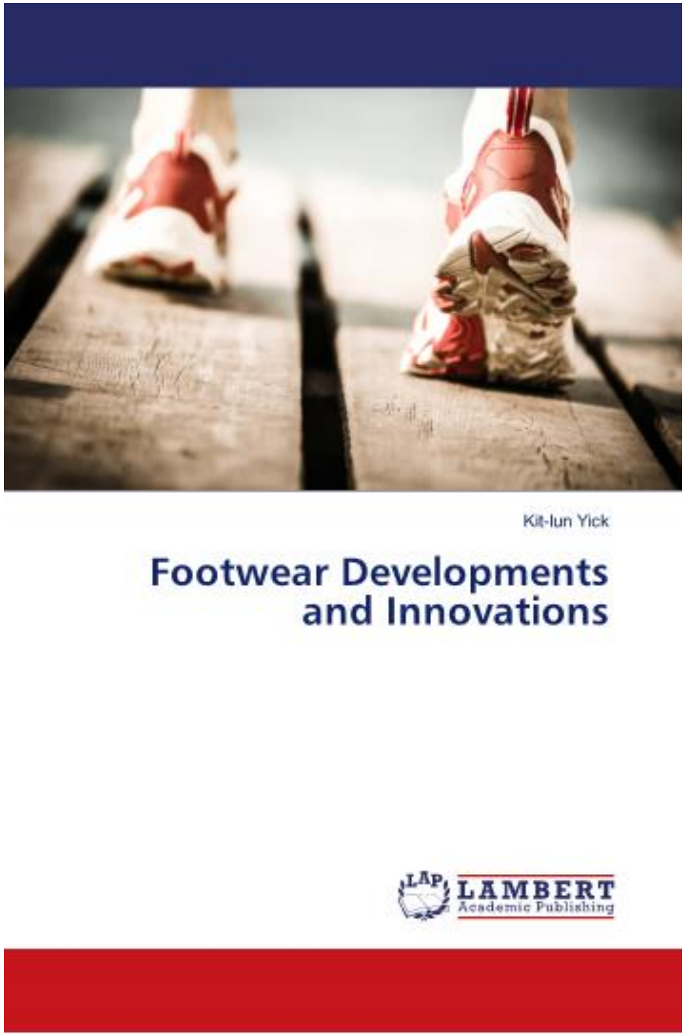
The research project and footwear prototypes were exhibited in The Gerontech and Innovation Expo cum Summit 2018 (22-25 November 2018), organized by the Government of HKSAR.



Dissemination 03

Academic Book

New designs and technologies in orthopaedic footwear and insoles, geriatric footwear, high heel shoes, minimalist footwear and unstable footwear for muscle toning and postural control were addressed.



Through Lambert Academic Publishing, an academic book entitled "Footwear Developments and Innovations" was published in 2016.

Dissemination 04

US and Chinese Patents

An US patent application (no. 15/205,955) has been filed in the US on 8th July 2016. The invention aims to provide an alternative and/ or improved insole assembly that enhances stimulation and tactile sensitivity of the sole of a foot. A Chinese patent application (no. 201710555192,6) has also been submitted.


UNITED STATES PATENT AND TRADEMARK OFFICE

15/205,955	07/08/2016	3765	1080	900220.404	27	3

CONFIRMATION NO. 2891
UPDATED FILING RECEIPT

500
SEED INTELLECTUAL PROPERTY LAW GROUP LLP
701 FIFTH AVE
SUITE 5400
SEATTLE, WA 98104

Date Mailed: 10/31/2016

Receipt is acknowledged of this non-provisional patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please submit a written request for a Filing Receipt Correction. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Inventor(s)

Kit-Lun Yick, Hong Kong, HONG KONG;
Sun-Pui Ng, Hong Kong, HONG KONG;
Yiu-Wan Joanne Yip, Hong Kong, HONG KONG;
Tsz-Hei Roy Cheung, Hong Kong, HONG KONG;

Applicant(s)

The Hong Kong Polytechnic University, Hong Kong, HONG KONG

Power of Attorney: None

Domestic Applications for which benefit is claimed - None.
A proper domestic benefit claim must be provided in an Application Data Sheet in order to constitute a claim for domestic benefit. See 37 CFR 1.76 and 1.78.

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: Yes

Permission to Access Search Results: Yes

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

page 1 of 3

Dissemination 05

Journal Papers

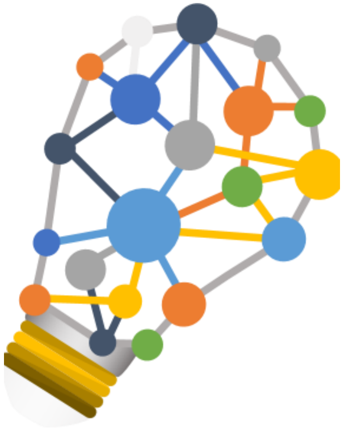
- Lo W.T., Wong D.P., Yick K.L., Ng S.P., Yip J. (2018). The biomechanical effects and perceived comfort of textile-fabricated insoles during straight line walking. Prosthetics & Orthotics International, 42(2):153-162.

- Lo, W.T., Yick, K.L., Lau, N.M.L, Tse, L.T., Ng, S.P., Yip, J. (2017). Effects of slipper features and properties on walking and sit-to-stand tasks in older women. Journal of Aging and Physical Activity 25(4), 587-595.

- Li P.L., Yick K.L., Ng S.P., Yip J. (2016). Foot anthropometric measurements of Hong Kong elderly: implications for footwear design. *Journal of Fiber Bioengineering and Informatics*, 9:3(2016), 133-143. **(invited by the Editorial Board)**

- Lo W.T., Yick K.L., Ng S.P., Yip J. (2014). New methods for evaluating physical and thermal comfort properties of orthotic materials used in insoles for patients with diabetes. Journal of Rehabilitation and Research Development, 51(2):311-24.

- Li PL, Yick KL, Ng SP, Yip J. (2019). Influence of textured indoor footwear on posture stability of older women based on center- of-pressure measurements. *Human Factors* (DOI: 10.1177/0018720819837414).



Dissemination 06

Conference Papers

Age-related changes of mobility performance, foot problems, foot anthropometric measurements were collected and statistically analysed. Results were consolidated and disseminated in international conferences.

The positive results of the participative **co-creation workshops** were also compiled and disseminated in a local conference in 2019, and invited for publication in Asia Pacific Journal of Health Management, 2019; 14(1):i205.

- Lo W.T., Yeung K.L., Li P.L., Yick K.L., Chan K.C. (2016). Mobility performance and foot problems in older people. CPCE Health Conference 2016, 11-12 January 2016, Hong Kong.
- Li P.L., Yick K.L., Ng S.P., Yip J. (2016). Foot anthropometric measurements of Hong Kong elderly: implications for footwear design. The 9th Textile Bioengineering Informatics Symposium & The 6th Asian Protective Clothing Conference, RMIT University, Melbourne, Australia, 12-15 July 2016. (Best Student Paper Award)
- Lo W.T., Yick K.L., Ng S.P., Yip J. (2016). Numerical simulation of sock-slipper and foot contact interaction for geriatric footwear design. International Conference on Medical and Health Sciences (ICMHS), 5-6 September 2016, Helsinki Finland.
- Yu A, Li PL, Yick KL, Ng SP, Yip J. (2018). Investigation of microclimate in sports shoes with the integration of human subjective sensations. The 8th International Conference on Advanced Materials Research, 2018, Fukuoka, Japan, 20-22 Jan 2018.
- Kwan MY, Yick KL, Wong YY. (2019). Impact of co-creation footwear workshops on older women in elderly centers in Hong Kong. CPCE Health Conference 2019, Hong Kong. As invited by conference organizer, the paper has further submitted to Asia Pacific Journal of Health Management.

The paper was awarded "**Best Student Paper Award**".


OUTSTANDING STUDENT PAPERS COMPETITION

Presented to

Pui-Ling Li, Kit-Lun Yick, Sun-Pui Ng, Joanne Yip

In recognition of your paper, entitled

Foot Anthropometric Measurements of Hong Kong Elderly: Implications for Footwear Design

TBIS-APCC 2016

Organized by

RMIT University

Textile Bioengineering and Informatics Society

Asian Society of Protective Clothing

July 12-15, 2016 Melbourne, Australia

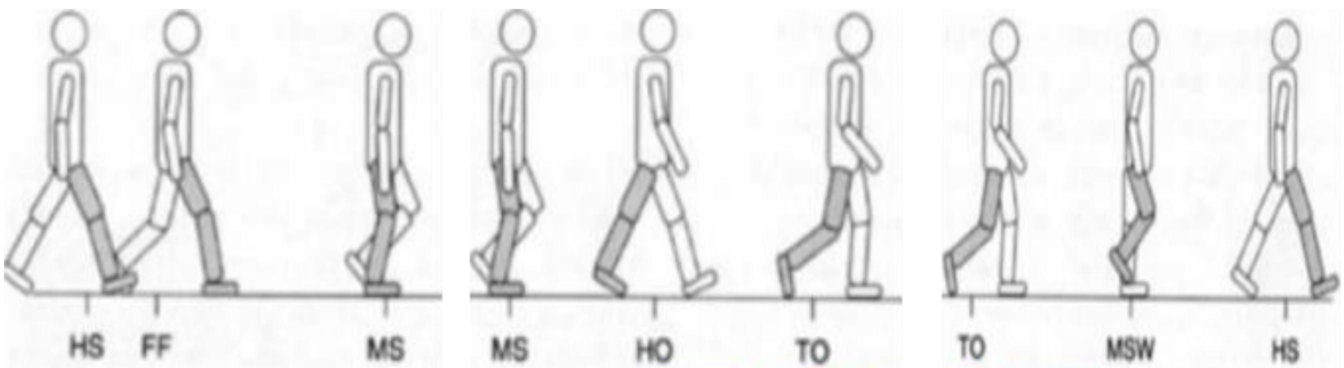
International Scientific Committee TBIS-APCC 2016

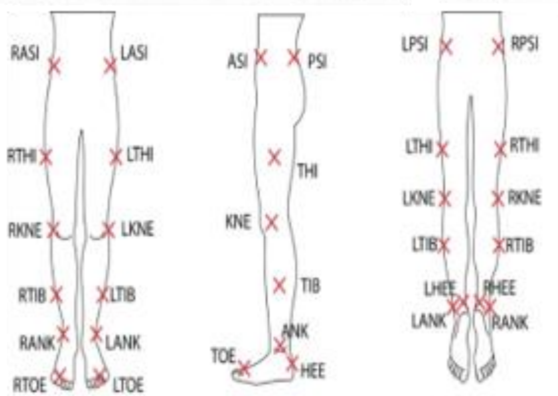
Organizing Committee TBIS-APCC 2016

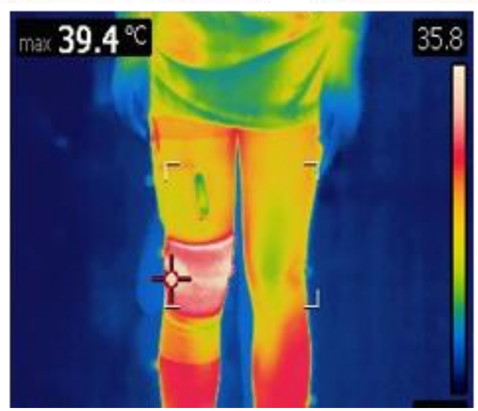
Dissemination 07

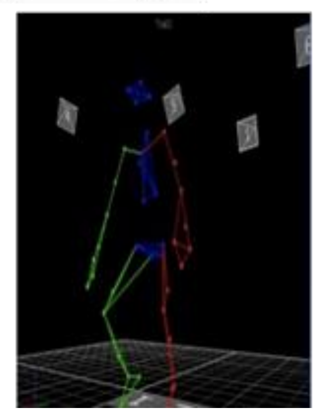
Consultancy Projects

Two funded consultancy projects in foot biomechanic analysis entitled “Gait Analysis of Knee Sleeves” and “Thermal Comfort Analysis and Evaluation of Knee Sleeves” from Hong Kong Design Institute were conducted in 2017 and 2018.









Appendix I – Testimonials from various elderly centres

As referring to the elderly centers, the foot care programme has increased the awareness of footwear safety at home.

香港基督教培道聯愛會 莊重文長者中心
HONG KONG CHRISTIAN MUTUAL IMPROVEMENT SOCIETY
CHUANG CHUNG WEN CENTRE FOR THE ELDERLY

10 August 2018

The Innovation and Technology Fund

Innovation and Technology Commission

TO WHOM IT MAY CONCERN

On behalf of Hong Kong Christian Mutual Improvement Society Chuang Chung Wen Centre for the Elderly, we would like to express our sincere thanks to Dr. KL Yick of Institute of Textiles and Clothing, The Hong Kong Polytechnic University and her project entitled "Total Pressure Management and Balance-enhancing Geriatric Footwear (Public Sector Scheme)" in preparing the foot care programme and the free-of-charge specially designed geriatric footwear for our elderly in June-August 2018.

During the programme, participants' foot measurements, foot degenerative changes, balance and gait performance were recorded and reported. The strategically developed geriatric footwear which aims to enhance tactile sensation for improving balance and stability in walking, provides total plantar pressure management for adequate support and protection, and thus preserves wearers' mobility and quality of life, was well received by eligible participants and wear trials were done with feedback collected.

We would like to convey our appreciation to those involved in the project.

Yours faithfully,

Wong Ka Man / Centre-in-charge

HONG KONG SHENG KUNG HUI
LOK MAN ALICE KWOK INTEGRATED SERVICE CENTRE

Our Ref.:
Your Ref.:

此致
創新及科技基金委員會

Helping Hand
伸手助人協會

敬啟者：

此致
創新及科技基金委員會

伸手助人協會
總幹事

二零一八年八月十三日

Appendix II – Feedbacks

It is proposed by the Service Director of Hong Kong Sheng Kung Hui Welfare Council for further collaborations of footwear & caring programmes for the coming 2-3 years under social services, hence promoting safety and caring relationships between the carers and the elderly.

Yick, Kit-lun [ITC]

From: Law Kit Ying <kylaw@skhwc.org.hk>
Sent: Monday, 19 November 2018 12:43 PM
To: Yick, Kit-lun [ITC]
Cc: LAW, Alice [DIS]; Tai Lo Wing; Andrew Ho
Subject: RE: Geriatric Footwear

Dear Dr Yick,

First of all, many thanks for your goodwill in promoting the well-beings of elderly.

As per our conversation, there are many possibilities for further developing and promoting the footwear.

I am pleased to tell that we received very positive feedback from elderly in the pilot research.
It is believed that both elders and carers would love to own and use the footwear, too.

I have a preliminary idea, that is, we can make use of the characteristics of the footwear, i.e. make own design, concern for safety,
for promoting caring relationships among carers and elders by the program "[illegible]".

The program can be launched by SKH social worker, and we can make two or three sets of protocols after running the groups for 2-3 years.
For students of POLYU, the program can provide them an service learning opportunity in preparing the accessories for elders and they may also get involve in the program if they want.
For elders and carers, they may make their own design of the footwear for themselves and /or each other.

It is hoped that after the protocols being set, such collaboration experience can be shared with other Community Service Centre and promoting the program and footwear.

May we have further discussion if you're also interested in the suggested program and I will make the meeting with our colleagues specialized in carers' service also.

Thanks and regards,
Ying

Ms Law Kit Ying

Service Director
Hong Kong Sheng Kung Hui Welfare Council Limited

Very positive feedbacks were received from the elderly (80 participants), particularly in comfort and breathability, as well as the overall design of the footwear (**with an average rating of 8.1, out of the max. of 10**)

Appendix III – Project Posters at Exhibitions

The exhibitions attracted over 100,000 people that over 200 visitors signed up for footwear trials.