Texturized Geriatric Footwear Design for Balance-enhancing and Pressure Management

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ITC PolyU – Center 20
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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.

- **Strategic indented nodule**
  - Double-layered silicone material (Outer: Shore A 8, Inner: Shore A 17)
  - For stimulating foot sensitivity and respond more readily to posture changes for better body balance and distribution of plantar pressures

- **Three-dimensional articulated midsole**
  - Made of Poron® material for good cushioning
  - For matching the natural and anatomical shape of the underfoot

- **3D printing sockets**
  - Made of flexible rubber material
  - For the interchangeable soft nodules

- **Arch support**
  - Made of two-layered carbon fiber composite
  - Functions like a spring-steel shank for increased flexibility, stiffness of footwear
  - For increasing support to the foot

- **Flexible heel counter**
  - Made of elastic band in 5 cm width
  - For good shape retention

- **Outsole with tread grooves**
  - Made of durable and flexible materials with deep grooves for providing slip resistance

- **Open toe & adjustable front strap**
  - For wide fitting of swollen feet
  - Made of mesh fabric for air permeability and thermal comfort
  - With binding and Velcro
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)


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

<table>
<thead>
<tr>
<th>Target Customers</th>
<th>Design Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, gender, foot size, foot shape anthropometry, foot health condition, foot sensitivity, gait performance</td>
<td>Foot support and control, foot protection, comfort, ease of donning and doffing</td>
</tr>
</tbody>
</table>

Footwear Design Consideration

<table>
<thead>
<tr>
<th>Material (weight, compressibility, air permeability, heat flow rate, thermal conductivity, shape retention, easy care, etc.) and fit</th>
<th>End-uses and Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity level (impact force, walking speed, etc.), duration, environment (thermal condition, floor properties, etc.)</td>
<td></td>
</tr>
</tbody>
</table>

Design Criteria

| Safety (protection from injury, reduction of shocks, postural stability & balance, preserve mobility & sensation), heel height, heel counter, closures for minimal displacement, ease of use, thickness to allow foot flexion and pronation, foot comfort (upper and plantar) |

Footwear Design & Prototyping

| Design Modifications |

Evaluation Methods

| Task situation, short-term laboratory evaluation of balance performance, long-term evaluation & wear trials, objective evaluation of plantar pressure, muscle activity of lower limbs, subjective assessments of usability, comfort, preference, satisfaction. |
Research Context

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

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:

A typical indoor footwear adopted by the elderly in Hong Kong
Phase I: Foot Care Programme

<table>
<thead>
<tr>
<th>Foot Region</th>
<th>Left Foot</th>
<th>Right Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forefoot</td>
<td>5.21 (0.36)</td>
<td>5.21 (0.36)*</td>
</tr>
<tr>
<td>Midfoot</td>
<td>5.19 (0.33)*</td>
<td>5.14 (0.27)*</td>
</tr>
<tr>
<td>Rearfoot</td>
<td>5.34 (0.46)*</td>
<td>5.41 (0.49)*</td>
</tr>
</tbody>
</table>

*Significant difference at P<0.05

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

**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

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

- 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.

Related Conference Paper:
Phase I: Foot Care Programme

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

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

Related Journal & Conference Papers:


* 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:

<table>
<thead>
<tr>
<th>Brand/Name</th>
<th>Sample</th>
<th>Ratio</th>
<th>Density (g/cm³)</th>
<th>Hardness (Shore A)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Silicone</td>
<td>Silicone Oil</td>
<td>Catalyst</td>
<td></td>
</tr>
<tr>
<td>Silicone_0</td>
<td>A</td>
<td>1</td>
<td>0</td>
<td>0.1</td>
<td>1.09</td>
</tr>
<tr>
<td>Silicone_0.25</td>
<td>B</td>
<td>1</td>
<td>0.25</td>
<td>0.1</td>
<td>1.04</td>
</tr>
<tr>
<td>Silicone_0.5</td>
<td>C</td>
<td>1</td>
<td>0.5</td>
<td>0.1</td>
<td>1.06</td>
</tr>
<tr>
<td>Silicone_0.75</td>
<td>D</td>
<td>1</td>
<td>0.75</td>
<td>0.1</td>
<td>1.05</td>
</tr>
<tr>
<td>Silicone_1</td>
<td>E</td>
<td>1</td>
<td>1</td>
<td>0.1</td>
<td>1.02</td>
</tr>
<tr>
<td>Iora® Lunairme d</td>
<td>F</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.16</td>
</tr>
<tr>
<td>High Density EVA 1</td>
<td>G</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.08</td>
</tr>
<tr>
<td>High Density EVA 2</td>
<td>H</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>0.17</td>
</tr>
</tbody>
</table>
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%).

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

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

**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:**

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:**

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).
Phase III: Footwear Design Criteria & Related Evaluation

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

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

Flexible heel counter
Terry upper (superior comfort)
Insufficient foot support
Footwear Prototype II

June 2017

- Rounding off the edge
- Improved midsole support
- Leather footbed
- More breathable and colorful front strap
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

Nodules are detachable and compressible for comfort.

Embedded socket design

Improved front strap design

3D articulated midsole
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**

*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.
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.

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.
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.

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.
Dissemination 05

Journal Papers


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.


• 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)


• 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.
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.
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.

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.

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