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Elite to high street footwear: the role of anthropometric data

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ABSTRACT
Rapid manufacturing has been revolutionary allowing the production of personalised design components for products like footwear to the final customer. Foot shape plays an important role in the development of injuries in runners, therefore any footwear should take into account an individuals mass, foot shape and other measures to provide unique support, balance, and comfort to the wearer. Despite the obvious potential in footwear products, it is not known how best to measure feet in this context nor even whether a personalised shoe can positively affect comfort, performance and prevent risk from injury. A challenge for anthropometry is the collection of detailed anthropometric measurements of the foot which can then be used to specify the design of personalised footwear. A pilot study is being conducted to assess the feasibility of personalising the design of insoles for running shoes. Rear striker, recreational runners (n=6) were selected to take part in the study. They were 18-64 years old, had no reported musculoskeletal pain or injury in the last 12 months. If they had any known lower limb abnormality they were excluded from the study. The plantar surface of the feet were scanned and detailed anthropometric measurements taken. Using these data insoles for a running shoe were rapid manufactured for comparison with the standard running shoe. Participants then returned to the laboratory to be fitted with a running shoe under two experimental conditions (personalised and standard footwear). For each experimental condition, the footwear was evaluated in terms of comfort (visual analogue scales), performance (running economy on a treadmill) and injury risk (knee and ankle torque, ground reaction force and plantar pressure distribution). This paper will present and discuss the detailed methodology for this research.

1. INTRODUCTION
Rapid manufacturing (RM) is potentially revolutionary in developing high performance, personalised footwear. This technology can benefit not only elite runners but any individual who wishes to be more active, such as recreational joggers and older individuals. As RM works without any tooling, it can significantly reduce unit costs as products can be produced near the location where they will be used, minimising transportation and stock space (Hopkinson & Dickens, 2001). RM can also allow the production of unique elements allowing industry to provide personalised components.

Foot shape plays an important role in the development of many types of injury (James et al, 1978, McKenzie et al, 1985, Cowan et al, 1993). According to Williams III et al (2001a), low arched runners tend to have greater evasion/tibial internal rotation ratio, in comparison with high arch runners, which leads to more soft tissue and knee injuries. High arch runners tend to have more bony foot and ankle injuries (William III, 2001b). Moreover, the high arch foot tends to experience more ankle sprains because of higher lateral loading, peak pressure and supination of the foot (Morag & Cavenagh, 1999, William III, 2001b). In terms of comfort, low arch individuals prefer harder insoles whereas those with a high arch tend to choose softer ones.

Personalising footwear can decrease the magnitude of impact force, provide stability and traction for different terrains, protect the foot and provide comfort to maintain aerobic work over a longer period. Generally, when an individual purchases footwear, only two measurements are taken (length and width), but there are other measures considered crucial. These include, metatarsophalangeal joint girth, heel height, arch height and toe box space (Cheng & Perng, 1999, Witana et al, 2004).

Studies have indicated that ‘fit’ is the most important component of footwear not only because it is strongly correlated to comfort, but because it is speculated to be linked to injury and damage prevention (Cheng & Perng, 1999; Wunderlich & Cavanagh, 2001; Luximon et al, 2003). Too little or too much space in a shoe can be perceived as tight or loose respectively (Witana et al, 2004). Too tight a shoe will compress tissues leading to discomfort whereas too loose a shoe will lead to tissue friction because of the slippage between the foot and the shoe both causing blisters (Cheskin et al, 1987).

Despite the obvious potential in footwear products, it is not known how best to measure feet in this context nor even whether a personalised shoe can positively affect comfort, performance and prevent risk from injury. A challenge for anthropometry is the collection of detailed anthropometric measurements of the foot which can then be used to specify the design of personalised footwear. This paper describes the design of a pilot study to determine the most effective methods of measuring comfort, performance and injury risk.

2. METHOD
2.1 Aims and objectives
The main aim of the research is to develop high performance personalised footwear for high street individuals using rapid manufacturing (RM). It is expected that this research will ultimately benefit a diverse sample of people, for example, the

1 If necessary, you may place some address information in a footnote, or in a named section at the end of your paper.
over 65s, people with conditions effecting foot shape such as diabetes and arthritis and anyone who wishes to be more active.

In order to start to define the measurement techniques for specifying such personalised footwear, a pilot study was conducted. The main objectives of this study were:

1. To develop and refine anthropometric measurement techniques for specifying personalised footwear.
2. To evaluate the effectiveness of these techniques in terms of measuring footwear comfort, performance and injury risk.
3. To understand the rapid manufacturing process in this context e.g. time required, reliability of hardware and software, materials available.

2.2 Sampling

For this pilot study, it was decided to focus on participants who have some experience of wearing sports footwear, therefore a convenience sample of six recreational runners was recruited. Inclusion criteria were: 18-65 years old, some experience running (at least 5km/week), that they were rear foot strikers, no reported musculoskeletal pain or injury in the last 6 months, and had not used an orthosis in the last 12 months.

It was intended to use leg length discrepancy and Quadriceps angle to judge whether to exclude participants who might be at risk of injury, but early pilot trials revealed that the bony landmarks needed are difficult to find leading to inaccuracies. For example, leg length is measured as the distance between the anterior superior iliac spine to the inferior edge of the medial malleolus.

2.3 Procedure

A repeated measures experimental design was used, with a balanced presentation of two conditions: insole (shoe + personalised insole) and control (standard shoe). The time of day was standardised for each participant to take part in the experimental sessions. It was proposed that the two conditions would be compared in terms of comfort, performance and injury risks. Ethical clearance was received for the study in July 2008.

Table 1: Anthropometric measurements based on Williams & McClay (2000)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navicular height</td>
<td>Floor to the most anterior-inferior portion of the navicular</td>
</tr>
<tr>
<td>Dorsum height</td>
<td>Dorsum height at 50% foot length</td>
</tr>
<tr>
<td>Foot length</td>
<td>The most posterior portion of the calcaneous to the end of the longest toe</td>
</tr>
<tr>
<td>Truncated foot length</td>
<td>The most posterior portion of the calcaneous to the centre of the 1st MTP</td>
</tr>
</tbody>
</table>

Initial contact was made with participants with a brief explanation of the study. The research can be divided into four clear stages which are described as follows:

In session 1 (40 minutes) detailed anthropometric measurements were taken, following Williams & McClay (2000) to classify the foot type, and measurements based on Hawes & Sovak (1994), to capture dimensional aspects of the foot (Tables 1 and 2). Following guidelines by Williams & McClay (2000), dorsum height was measured under two weight bearing conditions (10% and 90% of weight bearing). The other foot ‘height’ measures described in Table 2 were measured with 50% weight bearing on each foot. Scales and a block were used to facilitate these (Figure 1). Arch ratio, arch index and relative arch deformation were calculated from these measures following Williams and McClay (2000). In addition, a 3D scan was made of the plantar surface of both feet in an non weight bearing position (Figure 2). Stature and weight were also captured for each participant.

Table 2: Anthropometric measurements based on Hawes & Sovak (1994)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot length (1st digit)</td>
<td>The most posterior portion of the calcaneous to the end of the 1st digit (hallux)</td>
</tr>
<tr>
<td>Foot length (2nd digit)</td>
<td>The most posterior portion of the calcaneous to the end of the 2nd digit</td>
</tr>
<tr>
<td>Foot length (5th digit)</td>
<td>The most posterior portion of the calcaneous to the end of the 5th digit</td>
</tr>
<tr>
<td>Metatarsal fibulare length</td>
<td>The most posterior portion of the calcaneous to the centre of the 5th MPJ</td>
</tr>
<tr>
<td>Hallux height</td>
<td>Floor to the superior surface of the hallux</td>
</tr>
<tr>
<td>MPJ height</td>
<td>Floor to the superior point of the 1st joint</td>
</tr>
<tr>
<td>Navicular height</td>
<td>Floor to the most anterior-inferior portion of the navicular</td>
</tr>
<tr>
<td>Foot breadth</td>
<td>Between the metatarsal tibiale and fibulare</td>
</tr>
<tr>
<td>Heel breadth</td>
<td>Measured with compression to the bony surface and the point of maximum heel width</td>
</tr>
<tr>
<td>MPJ girth</td>
<td>Measured encompassing the metatarsal tibiale and fibulare.</td>
</tr>
<tr>
<td>Mid arch girth</td>
<td>Measured in the frontal plane passing through the dorsum</td>
</tr>
<tr>
<td>Heel girth</td>
<td>Measured encompassing the dorsum and the point of distal heel contact on the standing surface</td>
</tr>
</tbody>
</table>

Scanned data were first ‘cleaned’ and then personalised insoles were manufactured from Polymide using a selective laser sintering...
RP process technology. These were to be fitted to the trainers for the experimental sessions.

In the second session (75 minutes), in-shoe plantar pressure (Nm/cm²) was measured to quantify pressure distribution by placing a sensor inside each shoe. Participants were asked to run at the same speed as a normal training session, 5 x 10 metres under each condition whilst planter pressure distribution was recorded. To estimate running economy (performance), after a short warm up in their own trainers, participants ran for 4 minutes on a treadmill to reach a steady rate and then 2 minutes for analysis of gases (under each condition). The lower the volume of oxygen consumed per unit of body mass per time, the more efficient the runner and thus a better performance. The treadmill was set at 1% gradient as this has been shown in the literature as most accurately reflecting the energy ‘cost’ of outdoor running. At least a five minute break was given between runs. Foot comfort in each condition was measured using a visual analogue scale (the most comfortable imaginable to not comfortable at all). Six regions of the foot were assessed, the heel, midfoot, forefoot, fit, arch height, and overall (Mundermann et al, 2002). Thermal comfort was measured using a 7 point (from hot to cold) Predicted Mean Vote scale.

In session 3 (75 minutes), participants were first asked to do five practice ‘runs’ in their own trainers for 10 metres to gain experience of landing on a force platform. This would allow the capture of vertical peak ground reaction force (N); high values of peak vertical impact forces are positively related to increased injury risk (Mundermann et al, 2004; Yung-Hui and Wei-Hsien, 2005). The footwear (under both conditions) were fitted (in a balanced order) and reflective markers placed on landmarks on the lower limb for tracking 3D movement. Participants were asked to run 5 x 10 metres under each condition, while the kinematic data were collected using the Vicon Motion System (Oxford, UK). The collection of ground reaction force and kinematic data were synchronised. The kinematic data were used to assess knee and ankle torques (Nm). High values of peak joint torques are associated with increased risk of injury. Finally, the body landmarks were removed and participants performed another running economy test under each condition following the procedures described in the previous session. Ideally session 3 would take place 2 days after the previous session.

3. SUMMARY
Data collection started in October 2008. Detailed anthropometric data have been taken for all six participants, personalised insoles have been manufactured and the trials have commenced. It is likely that the findings of this pilot study will be published in 2009. This pilot work is the pre-cursor for a longitudinal study involving a broader sample of the population and which will commence in 2009.

4. ACKNOWLEDGEMENTS
We would like to acknowledge the Innovative Manufacturing and Construction Research Centre at Loughborough University who provided funding for this research.

5. REFERENCES

Figure 2: Example of scanned plantar surface of the foot


