ORIGINAL ARTICLE

Do you get value for money when you buy an expensive pair of running shoes?

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Objective: This investigation aims to determine if more expensive running shoes provide better cushioning of plantar pressure and are more comfortable than low-cost alternatives from the same brand.
Methods: Three pairs of running shoes were purchased from three different manufacturers at three different price ranges: low (£40–45), medium (£60–65) and high (£70–75). Plantar pressure was recorded with the Pedar® in-shoe pressure measurement system. Comfort was assessed with a 100 mm visual analogue scale. A follow-on study was conducted to ascertain if shoe cushioning and comfort were comparable to walking while running on a treadmill. Forty-three and 9 male subjects participated in the main and follow-on studies, respectively. The main outcome measure was the evaluation of plantar pressure and comfort.
Results: Plantar pressure measurements were recorded from under the heel, across the forefoot and under the great toe. Differences in plantar pressure were recorded between models and between brands in relation to cost. Shoe performance was comparable between walking and running trials on a treadmill. No significant difference was observed between shoes and test occasions in terms of comfort.
Conclusions: Low- and medium-cost running shoes in each of the three brands tested provided the same (if not better) cushioning of plantar pressure as high-cost running shoes. Cushioning was comparable when walking and running on a treadmill. Comfort is a subjective sensation based on individual preferences and was not related to either the distribution of plantar pressure or cost.

Running is a high-impact activity. Middle-distance runners experience impact forces (ground reaction force) upwards of 2.5 times bodyweight with each footfall.[1] Impact force increases with speed[2] and fatigue.[3] The latter also reduces the stabilising capacity of the musculoskeletal structures surrounding the ankle.[4] The ground reaction force produces vibrations (shock waves) that are transmitted by the bones of the foot to the rest of the body.[5] The intensity of this shock wave has been linked to the development of running-related injuries.[6] Running has been associated with the occurrence of knee pain, shin splints, plantar fasciitis, stress fractures,[7] and the development of degenerative conditions (primary osteoarthrosis, achilles tendonitis) and muscle tears.[8] It has been suggested that running injuries are the result of training error, anatomical factors (such as excessive pronation), accumulated impact loading and chronic overuse.[7] Impact force is substantially reduced by appropriate joint alignment.[9] The viscoelastic properties of the heel tissues provide significant shock absorption.[10 11] Athletic footwear reduces impact force peaks and shock wave intensity by approximately 33% and 36%, respectively, compared with measurements recorded walking barefoot. Shoes with a more elastic mid-sole offer better cushioning, thus providing improved impact force attenuation.[12]

Better cushioning materials, found in more expensive running shoes, have been reported to attenuate impact force to a greater extent than less expensive alternatives.[3] However, it has been suggested that the advertising of advanced safety features and protective devices of these more expensive running shoes is deceptive; runners subconsciously subject themselves to greater impact forces, thereby increasing the risk of injury. This accounted for a 123% greater injury frequency observed amongst runners who trained in expensive running shoes compared with those running in less expensive models or brands.[13]

Comfort is becoming an increasingly important aspect of running shoe design as it may be related to fatigue, injury development and athletic performance.[14] It has been suggested that perceptions of comfort are based on previous stimuli.[15] Many factors, including plantar pressure distribution, foot accommodation and skeletal alignment, may influence the perception of comfort.[14] Other influencing factors include whether an individual is walking or running, and the flexibility and hardness of the mid-sole.[16] Ultimately, comfort relates to a multitude of mechanical, neuro-physiological and psychological attributes, unique to the individual.[14]

This investigation aims to determine whether more expensive running shoes provide better cushioning of plantar pressure (and therefore improve pressure attenuation) and whether these are more comfortable than less expensive alternatives from the same brand.

METHODS

Test shoes

Nine pairs of neutral running shoes (male fittings) UK sizes 8 and 10 were purchased in the UK. These sizes were considered to be the most common male shoe sizes, and would thus allow the optimum number of subjects to participate. As no standardisation of shoe size exists amongst manufacturers, shoes were bought based on their actual size, rather than their marked size. The size of the shoe was determined with a calibrated shoe size ruler, which correlates length of shoe to its size. Three pairs of shoes were bought from three different manufacturers (Brands A, B, C). The price ranges were low (£40–45), medium (£60–65) and high (£70–75) as shown in table 1. No manufacturer involvement was established during the trials, ensuring that testing was completely independent. All manufacturer-specific features and company logos were concealed with adhesive tape to ensure blinding. One pair in each size were chosen from a leisure brand to act as controls.

Abbreviation: VAS, visual analogue scale

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Table 1 Shoes tested

Manufacturer	Price (£)	Price range	Shoe code
Brand A	40	Low	A_l
	60	Medium	A_m
	70	High	A_h
Brand B	40	Low	B_l
	60	Medium	B_m
	70	High	B_h
Brand C	40	Low	C_l
	65	Medium	C_m
	75	High	C_h
Control first trial			X_1
Control last trial			X_2

Subjects

This study was conducted in the Institute of Motion Analysis and Research, Ninewells Hospital and Medical School, Dundee, UK, and was approved by the Tayside Committee on Medical Research Ethics. Subjects were selected provided they had size 8 or 10 feet, and had no gait abnormality or previous or current history of lower limb pathology, no foot or leg length discrepancy, or any other disability that might in some way affect their gait (eg, visual impairment, walking aid).

Pedar® System

Plantar pressure was recorded with the Pedar® in-shoe pressure measurement system (Novel$_{gmbh}$, Munich, Germany). This consists of a synchronisation box that is attached by a set of cables to a pair of specially made insoles placed in the test shoes. Each lightweight insole is composed of a matrix of 99 capacitive sensors with an effective area of about 2 cm^2. These sensors detect changes in pressure application and send electrical signals to the synchronisation box, which in turn relays them via a Bluetooth wireless radio link to an electronic database. Prior to testing, the insoles were calibrated in accordance with the manufacturer's instructions. This ensures accurate readings are recorded.[17] A rucksack was constructed to house the synchronisation box on the subject's back (fig 1). The Pedar® system was shown to have good repeatability in a concurrent study.[18]

Assessment of comfort

Comfort was assessed with a visual analogue scale (VAS). A 100 mm scale was adapted where the left-hand side was labelled ''least comfortable imaginable'', and the opposite end ''most comfortable imaginable''. This method of assessing comfort has been shown to be reliable[15] when used in this context.

Test protocol

The study was explained to each subject, and consent for participation was gained. Height, weight, foot dimensions and lower limb length were recorded prior to the Pedar® equipment being attached. Each subject was then shown a pair of shoes and asked to provide a score on the VAS for expected comfort. A second score (immediate comfort) was recorded when standing in the shoes. To investigate the possibility that shearing forces between the Pedar® insole, the mid-sole and the foot altered plantar pressure measurements, a pilot study was conducted to determine whether insoles would conform to a position where they would no longer slip. This was achieved within a few steps by asking each subject to walk to the start of the walkway. Plantar pressure was recorded over approximately 15 steps along a 20 m walkway. Nine steps or more ensured reliable results were recorded.[19] The final VAS was recorded for each shoe after walking. The control shoes were always worn as the first and last trials. The order of the shoes was randomised.

Each subject was asked to estimate the cost of the shoes (low/medium/high) based on their perception of comfort alone. Subjects walked barefoot between each trial. This acted as a standard condition between trials, and was done in an attempt to reduce any confounding effect of the perception of comfort between shoes.[15]

Follow-on study

Subjects with previous running and treadmill experience were selected to take part in a follow-on study. This was intended primarily to compare the pressure distribution patterns under the foot while walking and running. In addition, it provided information on variability needed for a power calculation in a further study. Each subject walked at his natural speed and ran (3.13 ms^{-1}) on a treadmill. Comfort scores were collected as before for each walking and running trial, for each pair of shoes.

Data validation

Erroneous readings were removed with the Novel step analysis programme. Masks were constructed (with the Novel creation of any masks program) to analyse plantar pressure measurements under eight areas of the foot including medial, and lateral heel (M1–M2), 1st–5th metatarsals (M3–M7) and great toe (M8) (fig 2). These are the main regions of load-bearing areas under the foot.[20] Pressure recorded under the lesser toes was incorporated into the follow-on study, as this area tends to bear more weight whilst running.[2]

Statistical analysis

A power study suggested that 39 subjects would be required to enable a difference of 80 kPa to be detected between groups. Power was set at 80% and significance at 5%. The estimate of standard deviation was obtained from a pilot study conducted within the department. General linear model, repeated measures analysis of variance was applied to investigate relationships between models and the effects of brand and cost on plantar pressure and comfort. Brand and cost were within-subjects factors. The Bonferroni correction for multiple comparisons was applied to means post hoc and the Huynh–Feldt adjustment for non-sphericity made when appropriate. In an attempt to standardise comfort scores between subjects the average comfort rating for each subject across all shoes and occasions was calculated. Individual comfort scores (for three occasions and 11 shoes) were divided by this average. Cohen's kappa statistic was used to assess agreement between actual and estimated costs (low, medium, high in each shoe). The relationship between comfort score and plantar pressure readings was investigated using scatter plots and Pearson's product moment correlation coefficient.

RESULTS

Forty-three male subjects (mean age 28.9 years, SD 9.3) participated in this investigation. The results are presented as Venn diagrams (fig 3). Mean plantar pressures recorded under each foot region were arranged in increasing order of plantar pressure. Shoes within the same ring were not significantly different ($p>0.05$). For example (fig 3: left medial heel), mean plantar pressures between shoes A_m, A_h, B_h and C_l were not significantly different. Likewise, mean plantar pressures between shoes C_l and B_m were not significantly different. Shoe B_m provided significantly poorer cushioning under the left medial heel than shoes A_m, A_h and B_h.

Similar plantar pressure measurements were recorded under the heel in both left and right feet. Brands A and B provided better cushioning under the heel in the medium- and high-cost

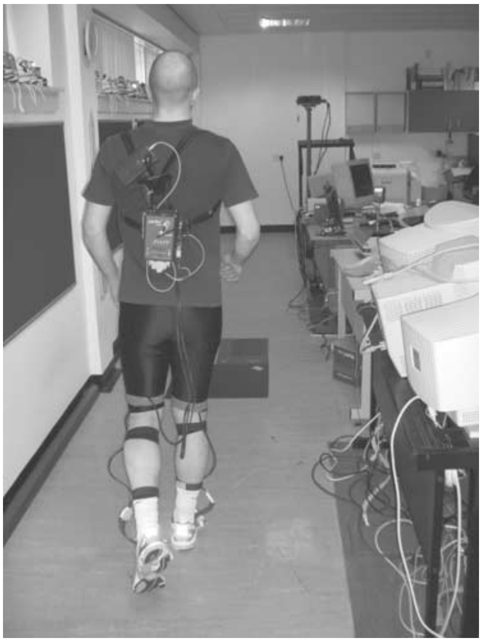

Figure 1 Pedar® Mobile system and one tested shoe. Informed consent was obtained for publication of this figure.

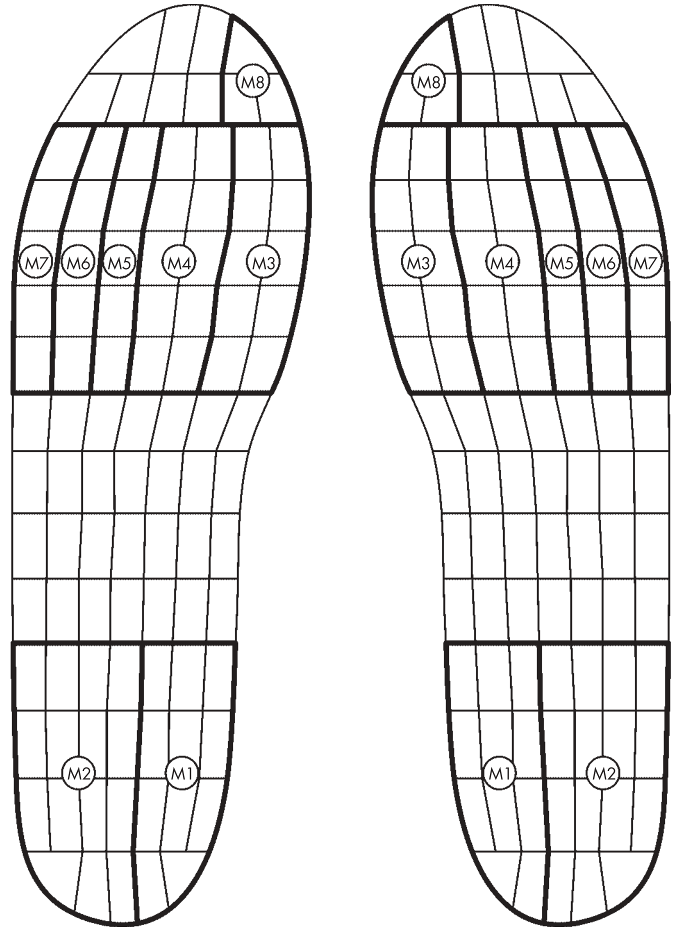

Figure 2 Study mask.

shoes rather than in the low-cost models. Overall, poorer under-heel cushioning was recorded in Brand C. Under-heel cushioning decreased with increasing cost in Brand C. Few significantly different values were observed under the 1st metatarsal between brands in relation to cost. Improved cushioning was recorded under the 2nd/3rd metatarsals with increasing cost from Brand A. The moderately priced models from Brands B and C provided better cushioning of plantar pressure than their low- and high-cost alternatives. The medium- and high-cost models from Brand C recorded significantly better cushioning under the 4th/5th metatarsals than all of the other shoes. However, this could have been the result of off-loading pressure from over this area by the medial forefoot. Cushioning from under the medial forefoot in the medium- and high-cost models from Brand C was poorer than the remaining shoes. Brand A provided relatively better cushioning under the 4th/5th metatarsals than Brand B. Enhanced cushioning under the great toe was observed in Brands A and B with rising cost. The opposite was found for in Brand C.

When plantar pressure was analysed under all the masked regions studied, there was no significant difference between shoes with regard to brand or cost. Mean plantar pressure was lower overall in low- and medium-cost shoes but not significantly so.

Standardised comfort ratings proved to be highly variable across all shoes investigated. No significant differences between shoes and test occasions were observed. There was negligible agreement between perceived comfort and predicted cost (0.081). No relationship was found between comfort score and plantar pressure recordings.

Nine subjects (mean age 24.8 years, SD 5.2) participated in the follow-on investigation. Similar pressure distribution patterns for each area under the foot were seen in the walking and running phases. As the study group was small, it was not possible to reliably detect differences between pressure in shoes from different brands and cost ranges.

DISCUSSION

Pressure attenuation under the heel reduces the potency of the shock wave experienced by the body. It has been suggested that increasing shock wave intensity perpetuates damage of the micro-composition of the musculoskeletal structures surrounding the foot and ankle. If the magnitude of accumulated impact force and the rate of impact loading exceed the tensile limit for a particular musculoskeletal component with increasing cycles, then the structure will fail (fig 4).[6] This will either result in, or increase the risk of, a disabling injury. Regular rest intervals should be incorporated into any running regimen to allow positive remodelling and strengthening of micro-composition of the musculoskeletal structure; this, in turn will reduce the likelihood of sustaining a chronic overuse running injury.[6] No evidence currently exists to suggest whether an infrequently high and sudden impact force is more likely to cause an injury than several sustained lesser impact forces. It has, however, been confirmed that runners who exhibit relatively high and rapid impact forces are at an increased risk of sustaining a chronic overuse injury.[6]

Different models of shoes performed better in terms of cushioning capacity under different areas of the foot. The brands investigated performed differently in relation to cost. Therefore, before any definitive conclusions concerning the relationship between cushioning and cost can be made, more models and more brands should be investigated. It would appear from the shoes studied that performance, in terms of cushioning, is not related to cost. In fact, plantar pressure was lower overall in low- and medium-cost shoes than in high-cost shoes. Even though this difference is small, it may be significant over time with repetitive impact loading. This may suggest that less expensive running shoes not only provide as much protection from impact force as expensive running shoes, but that in actual fact they may also provide more. However, it should be acknowledged that this study concentrated on only

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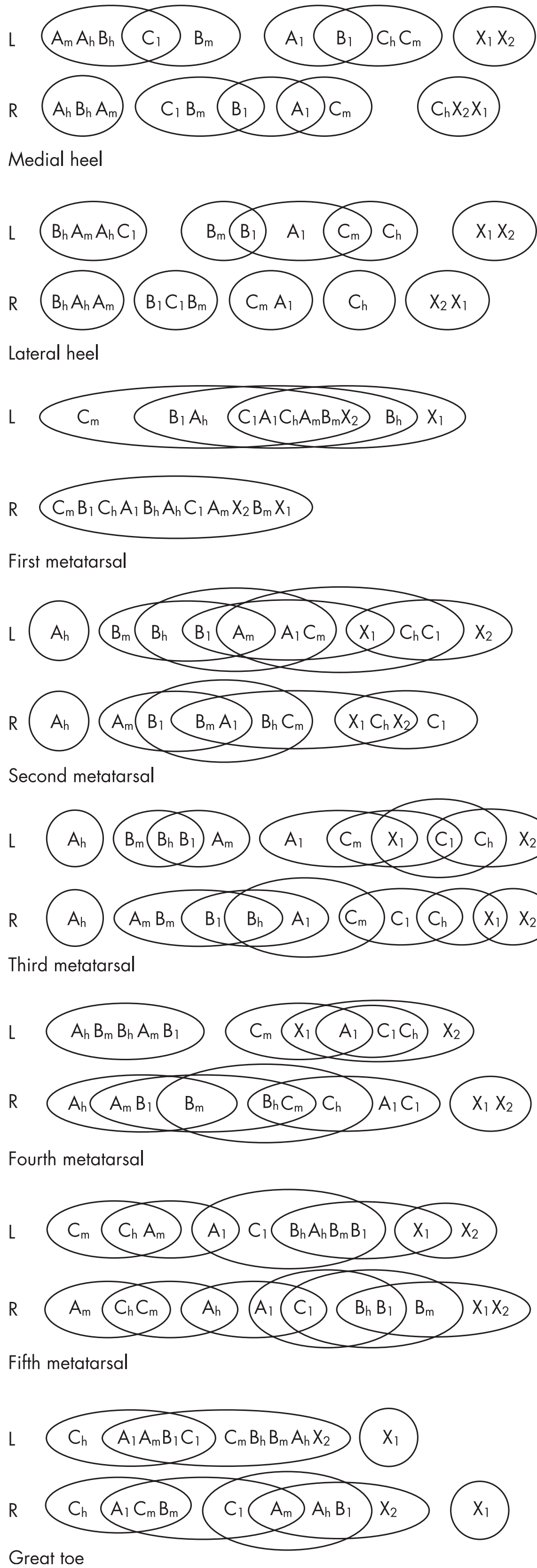

Figure 3 Venn diagrams representing differences in plantar pressure recorded under each area of the foot (refer to table 1 for shoe codes).

two aspects of running shoe design: cushioning and comfort. Before any definitive conclusions can be made between brands, the durability of the mid-soles and in-soles should also be tested. It should also be acknowledged that pressure measurements were recorded whilst walking rather than running, and that joint forces were not considered.

Consistent plantar pressure distribution patterns in walking and running phases suggested that running shoes performed comparably while walking and running on a treadmill. Caution should be exercised when interpreting these results as only a small number of subjects participated. Running shoe performance on a treadmill was found to differ from that in an overground situation.[20] However, this finding is questionable because the kinematics of running were compared between a set of control shoes and the subjects' own personal shoes, which would be more familiar to the subjects. Also, the foot-strike region was not accounted for.[21] Further research at our Institute is currently being conducted in this area of shoe performance testing, and walking/running versus brands/cost.

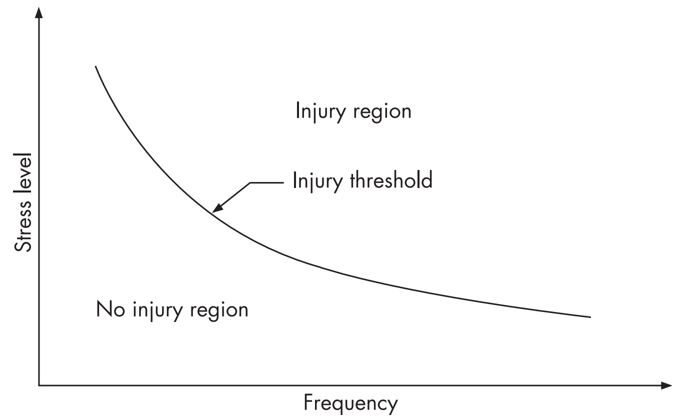

Figure 4 Injury threshold curve.

What is already known on this topic

- Advertising of advanced safety features and protective devices of more expensive running shoes is deceptive.
- Athletic footwear reduces impact force peaks and shock wave intensity by up to 36%.
- Running shoes with a more elastic mid-sole offer better cushioning.
- A 123% greater injury frequency was observed amongst runners who trained in expensive running shoes compared with those running in less expensive models or brands.

What this study adds

- In the three brands tested, expensive running shoes did not provide better cushioning than the cheaper shoes within the same brand.
- Plantar pressure was lower overall in low- and medium-cost running shoes than in high-cost shoes.
- Comfort was not related to either the distribution of plantar pressure or the cost of running shoes.
- More models and more brands are currently being tested.

The broad between-subject variability of comfort scores suggests that comfort is highly subjective. Comfort ratings for both control shoe trials were similar. This may suggest that subjects can be consistent in assessing comfort. It has been suggested that lower plantar pressure distribution under the medial forefoot and the great toe influences the perception of comfort. However, no relationship between comfort and plantar pressure could be observed under these or any other areas of the foot in this study. The agreement between actual and estimated cost of shoe was found to be 0.081. The most common value selected was the intermediate price. This would suggest most of the subjects chose the "common ground" value. The low value of agreement calculated would suggest that the subjects were poor at estimating the cost of shoes based on comfort.

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Competing interests: No shoe manufacturer involvement was established. All authors declare that they have no competing interests.

Informed consent was obtained for publication of figure 1.

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