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FUNCTIONAL CHARACTERISTICS OF RUNNING SHOES FOR DIFFERENT USER GROUPS

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ABSTRACT
The main objective of this research was to characterise the different runner groups and to determine the key functional design characteristics of running shoes for each distinct group. A comprehensive qualitative survey methodology has been developed and implemented worldwide for this purpose. Consequently, a large volume of data was collected from respondents in relation to running habits, performance and shoe characteristics. Classification of distinct runner groups has been determined based on discrete performance parameters and validated using statistical discriminant analysis. For each user group classification, the relevant functional running shoe characteristics were assessed and ranked, and design innovation opportunities mapped. The results of this research will be used by a running shoe manufacturer to inform the design of new generation sports shoes customised for specific market segments and user preferences.

Keywords: running shoes, characterisation, performance, innovation

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1 INTRODUCTION

In a highly competitive running shoe global market estimated at over $20 billion (McDougall, 2009), manufacturers are under increasing pressure to produce innovative new products, including personalized designs that add value for the customer through improved feel and performance. Customisation of running shoes with respect to specific user group requirements can contribute to increasing the customer satisfaction. In order to achieve this, the specific requirements of distinct groups of runners must be first identified and understood. A systematic, performance based method for group characterisation of contemporary runners would greatly assist designers and engineers in the research and development process for design of new generation running shoes. Hence, this research has been undertaken to investigate in greater detail the attributes and requirements of different running groups, including preferences for particular running shoe characteristics, and the mapping of design innovation opportunities. This information could be harnessed effectively by running shoe manufacturers to drive their designs towards specific market segments and user requirements.

Previous studies that have been conducted in relation to running shoe design and performance have tended to focus primarily on biomechanics, and more specifically upon the onset and prevention of injury (for example, see Novacheck (1998), Nigg et al. (2003 and 2006) and Morio et al. (2009)). Several works have also been published that address the effect of running shoe cushioning characteristics on resulting ground and foot impact forces (for example, Clarke et al. (1983), Rooser et al. (1998), Shorten (2002) and Dixon (2008). Comparatively few studies have addressed customisation of functional characteristics to specific runner requirements. For example, Toon et al. (2008) investigated the personalisation of the mechanical properties of footwear soles using selective laser sintering. Limited preliminary results of the present research have also been published (Clifton et al. (2011a)). However, no studies to date have attempted to segment the current running shoe marketplace and determine the key functional characteristics for each user group to aid in the design process. Similar characterisation approaches have been applied previously in other areas of sports technology (Subic et al. (2008, 2009), Clifton et al. (2009), Burton et al. (2010), Clifton et al. (2011b)), allowing the consideration of individual performance characteristics and parameter interrelationships at a basic design level. Using this approach, modifications to the base design or platform can be implemented to satisfy different user group requirements without having to fully redesign the product.

2 FUNCTIONAL CHARACTERISTICS OF RUNNING SHOES

The parametric design approach of deconstructing any object into linked component variables is entrenched in modern architecture and product development, and is being increasingly utilised for customisation and to maximise novelty in any design. Whilst this method provides a greater level of control over the design, effective application requires the designer to have a strong understanding of the methodology and the individual parameters that make up the final product.

In order to undertake the parametric customisation of a user-specific running shoe, it is necessary to firstly identify the key functional characteristics that form the performance basis of modern running shoes in general. A review of available literature was hence undertaken to identify the parameters most important to performance, and furthermore which drive customer satisfaction levels. It was also ensured that the parameter selection process identified attributes that could be objectively measured and quantified for any running shoe model that was commercially available. As a result, applicable running shoe standards were the foundation of the selection process and plain language was used to define the parameters, in order to minimise confusion of participants in subsequent user surveys. The functional characteristics that were selected for the study are presented below, along with applicable standard test methods of measurement in brackets.

- *Permeability*: The ability of the running shoe to allow the passage of air and moisture to and from the foot (ASTM F1900 – 98).
- *Impact Absorption:* The ability of the running shoe to absorb shocks and forces that are transmitted to the lower leg (ASTM F1976 – 06 or ASTM F1614 - 99).
- *Energy Return:* The ability of the shoe to return energy absorbed during the foot strike.
- *Stability:* How stable the shoes feel whilst running on uneven surfaces (ASTM F1833-97).
- *Flexibility:* The flexibility of the running shoe from heel to toe (ASTM F911-85).
- *Torsional Flexibility:* The amount the shoe twists during running.

- *Traction:* The ability of the shoe to grip your normal running surface (ASTM F2333 – 04).
- *Outsole Durability:* The ability of the shoe outsole to resist wearing out over time.
- *Cushioning Consistency:* The ability of the shoe to provide a consistent level of cushioning during a typical run.
- *Shoe Weight:* How heavy the shoe feels whilst running.
- *Price*[1]*:* The amount paid for running shoes.

3 USER CENTRED SURVEYS

The employment of user surveys within product research and development is well established and can greatly enhance the commercial success of the finished product in any market sector. The survey process that was implemented in this study was multi-faceted, aiming to first identify and characterise the relevant user groups of modern running shoes. A second follow-up survey was circulated to elicit the relative importance of each functional running shoe characteristic over the determined user groups, and furthermore allow the subjective rating of current running shoe models using these parameters.

3.1 User profiling survey

An initial user profiling survey was conducted online utilising a commercially hosted survey website. The survey was conducted online rather than using paper-based surveys or other face-to-face methods, as this allowed the research team to maximise the sample size and global geographic spread of participants. The questions in the user profiling survey addressed the following subject matter:

- Personal attributes (gender, age, weight, height, shoe size)
- Geographic attributes (country of residence, state/region, area classification)
- Running habits (reasons for running, number of sessions per week, distance per session, time per session, running environments, running surfaces, weather conditions, temperature, time of day, group or solo runner, other fitness activities)
- Buying preferences (brand, model, reasons for purchase, knowledge of personal running gait and effect on purchase, purchase frequency, typical shoe cost, preferred retailer)

Prior to public circulation of the user profiling survey, multiple pilot trials were conducted to identify problems and implement any necessary revisions. This has been pinpointed as a crucial stage in the overall survey process (Oppenheim, 2000). Invitations to participate in the survey were circulated via email to running clubs, interest groups, forums, magazines, fitness clubs, professional associations and race organisers worldwide.

3.2 Shoe characteristics survey

The second survey addressed perceptions regarding the functional characteristics of modern running shoes, including requirements for the creation of ideal products. This information facilitated the benchmarking of existing running shoes against user expectations and determination of the current models with the greatest customer satisfaction levels.

Participants were asked to assess their requirements of running shoes, as well as rate the performance of specific brands and models. As per the first survey, the entire process was conducted online to maximise the geographic scope and sample size. Furthermore, the questions were again constructed using a multiple choice format where possible, to simplify the analysis of the results. However, due to the complex nature of the second survey's content, a number of supporting images were also utilised to assist participants in the interpretation of the various running shoe functional characteristics. A generic un-branded running shoe was modelled, which enabled the research team to anonymously demonstrate the different features and attributes of a running shoe without referring to a specific product that might favour a particular manufacturer or otherwise influence the neutrality of the study. Figure 1 below shows the image that was used to illustrate the concept of running shoe "Permeability".

The question format utilised in the second survey was based upon an approach described in Subic et al. (2008). For each of the functional characteristics, participants were first questioned, using a scale from 1 (unimportant) to 10 (essential), regarding the personal importance of each attribute to running shoes. This allowed all of the parameters to be given a relative weighting. Secondly, respondents were asked

[1] Whilst the final *"Price"* parameter is not strictly a functional characteristic, it is regarded as being a crucial aspect of many running shoe users' purchasing decision, and furthermore must be considered in relation to cost of raw shoe materials and manufacturing processes.

to specify, again on a scale from 1-10, the level of each functional characteristic in their ideal running shoe. For this question, the endpoints of the 1-10 scale were dependent on the feature under consideration. For example, when assessing permeability, a response of 1 indicated air/water tight running shoes whilst conversely, an answer of 10 referred to shoes that are fully porous. This question facilitated user group benchmarking of the various performance aspects of modern running shoes. The final question for each parameter assessed the level of the attribute present in the user's current running shoes, using the same 1-10 scale as the previous ideal level question. A response table was implemented for this question to permit easy performance comparison between multiple shoe models (maximum of three) owned by the user. The specific models currently owned were identified at the beginning of the survey, and classified as their primary, secondary and tertiary pairs. Respondents were also requested to enter the age of each pair, to provide context to the subsequent performance ratings.

Figure 1. Permeability supporting image

4 SURVEY RESULTS ANALYSIS

4.1 User profiling

The first survey attracted a total of 736 respondents, of which 585 provided a complete set of responses (79.5% completion rate). Whilst the majority of the completed responses originated from within Australia (64%), there were pools of respondents from the USA (24%), Europe (6%) and Asia (2%). The age distribution of the participants was a skewed normal distribution, with the peak centred in the 30-39 age bracket. Regarding basic physical characteristics, the average weight/height (mean ± standard deviation) of the sample collected was 76 ± 11 kg/180 ± 7 cm for males, and 62 ± 11 kg/167 ± 7 cm for females. Furthermore, the majority of the respondent sample was classed as possessing a normal BMI (79%), with only 3% classed as underweight, 15% overweight and 3% obese. The key performance parameters selected to characterise the group classifications were as follows:

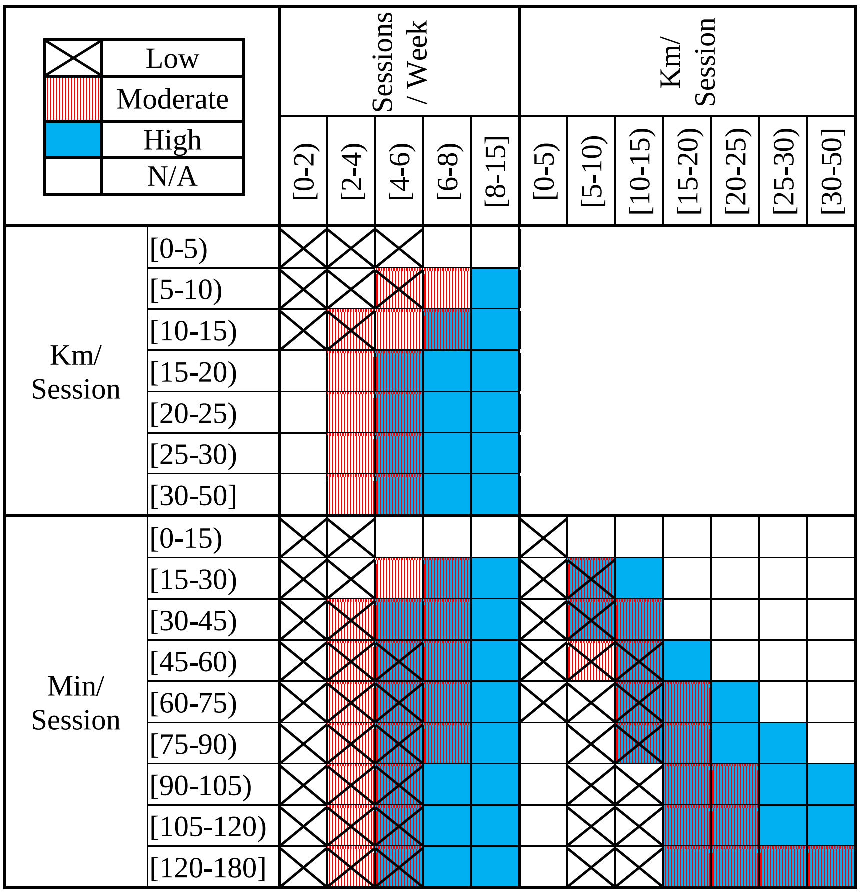
- The average number of running sessions per week (Sessions/Week)
- The average distance run per session (Km/Session)
- The average session time (Min/Session)

In essence, these parameters break down the total distance and time run per week by each respondent into discrete variables. Unlike the majority of questions in the survey, these specific performance questions were posed in an open text-box format, allowing ranges to be entered. In the event that a range was entered in any of the responses, an average value was taken. All of the data was categorised to simplify the analysis, using the following data ranges for each variable:

- Sessions/Week: [0-2), [2-4), [4-6), [6-8), [8-15]
- Km/Session: [0-5), [5-10), [10-15), [15-20), [20-25), [25-30), [30-50]
- Min/Session: [0-15), [15-30), [30-45), [45-60), [60-75), [75-90), [90-105), [105-120), [120-180]

The resulting categorised performance data was firstly intuitively examined to determine if any natural clustering was present. From basic plots of the variables, three clusters were apparent, which were labelled as Low, Moderate and High runner classifications. Table 1 shows the combined results of the intuitive runner classification, which compares the three variables simultaneously and maps the group membership and boundaries. It is noted that there are some combinations of the three variables that can refer to more than one classification, in which case the upper group is the correct classification. However, for the majority of performance variable combinations, there is only one unique classification when mapped over the three parameters. The unshaded regions of the table refer to variable combinations for which no data was present.

Table 1. Intuitive identification of ability-based running groups



To validate the intuitive runner classifications, the data was analysed using a variety of statistical tools in SPSS, a discriminant analysis, cluster analysis and advanced neural networks (multi-layer perceptron and radial basis function). These types of validation processes are recommended in the literature (e.g. Johnson and Wichern, 1998) when a classification method has been developed on the basis of intuitive cut-offs between groups.

The results of the discriminant analysis and neural networks indicated that the intuitive runner classification process was very successful, and the two-step cluster analysis to a lesser extent. Firstly, the discriminant analysis cluster map illustrated that the overall density of the data within each classification group was high, and the separation between the groups was pronounced. 519 out of 577 or 89.9% of the original intuitive classifications were correct ($\kappa = 0.847$, $p < 0.001$), which is considered outstanding (Landis and Koch, 1977). Secondly, both of the neural network processes employed also produced highly significant results. The multi-layer perceptron model indicated that 96.0% of the 577 intuitive classifications were correct ($\kappa = 0.939$, $p < 0.0005$), whilst the radial basis function established that 84.9% of the classifications were correct ($\kappa = 0.775$, $p < 0.0005$). Both of these results are also considered outstanding. Finally, the two-step cluster analysis, although producing significant agreement with the intuitive classification ($\kappa = 0.416$, $p < 0.001$), the agreement is only considered moderate (Landis and Koch, 1977), and less logical structure was apparent within the variables.

Hence, based on the results of the various statistical routines, the intuitive group classification table shown in Table 1 can be confidently utilised by running shoe manufacturers to tailor designs towards specific user groups with known usage ranges.

4.1 Running shoe characteristics

The second survey attracted a total of 333 respondents, of which 275 provided a complete set of responses (82.6% completion rate). Of the 275 respondents, 163 were male (59.3%) and 112 were female (40.7%). To breakdown the respondents by runner classification, 74 were members of the Low group (26.9%), 112 were classed as Moderate (40.7%), whilst 89 were considered High ability runners (32.4%). Furthermore, the proportion of females decreased as the classification changed from Low to High, from 60.8% to 35.7%, and finally to 30.3%.

In terms of running shoe parameters, Table 2 displays the importance and ideal level of each functional characteristic for the complete dataset across both sexes. All means are colour coded by group on a spectrum from red to black (if required), on the basis of statistically significant differences between values ($p < 0.05$). Parameters are classified using a different colour if significantly different to the parameter with the largest mean in any sub-group.

Several commonalities between male and female preferences are apparent. For example, the weight of the shoe was considered the most important attribute for both sexes, however was not statistically unique for women (in a group with 5 other parameters). Furthermore, it was desired to possess the statistically lowest scaled level of any of the parameters for both men and women. The torsional flexibility was rated the least important parameter for both men and women (however only statistically unique for women), whilst the outsole durability was desired by both sexes to be the parameter with the highest relative magnitude (again, only statistically unique for men).

Significant differences were also present between the male and female complete dataset results, with females rating impact absorption, energy return, stability, traction and cushioning consistency as significantly more important than males ($p < 0.05$).

Within each group, there was far greater discrimination amongst the male results, both in terms of importance and user ideal values, particularly for the latter where 7 statistically distinct groups were present. This contrasts to that of the female results, with only 4 and 5 distinct groups for importance and ideal level, respectively. There was also little in common in terms of group membership between both sexes.

Table 2. Complete dataset results

Parameters	Men		Women	
	Importance	User Ideal	Importance	User Ideal
Permeability	6.4 ± 2.4	7.0 ± 1.9	6.9 ± 2.0	6.7 ± 2.0
Impact absorption	7.4 ± 2.7	7.2 ± 2.7	8.4 ± 2.1	8.1 ± 2.4
Energy return	6.2 ± 2.6	6.7 ± 2.7	6.9 ± 2.4	7.5 ± 2.3
Stability	6.9 ± 2.8	6.7 ± 2.7	7.9 ± 2.2	7.8 ± 2.4
Flexibility	7.4 ± 1.9	7.4 ± 1.8	7.7 ± 1.9	7.7 ± 1.6
Torsional flexibility	5.8 ± 2.4	6.0 ± 2.2	5.7 ± 2.3	5.9 ± 2.0
Traction	7.7 ± 1.9	7.9 ± 1.8	8.4 ± 1.6	8.4 ± 1.5
Outsole durability	7.7 ± 1.9	8.4 ± 1.6	8.1 ± 1.9	8.5 ± 1.6
Cushioning consistency	7.4 ± 2.6	7.8 ± 2.4	8.4 ± 1.7	8.4 ± 1.8
Shoe weight	8.2 ± 1.8	3.8 ± 2.9	8.4 ± 1.9	3.5 ± 2.6
Price	6.7 ± 2.6	5.0 ± 2.5	6.5 ± 2.5	5.6 ± 2.2

Similar analyses can be conducted based on the three determined runner classifications. However, to summarise the running shoe preferences, Tables 3 and 4 compares the characteristic importance ranks across the three user groups for both sexes using the same group colour code.

Assessing the differences in group membership across the various runner classifications for both men and women, the highest mean group members are identical for both male and female low runners. Furthermore, there is only one different parameter between low and medium groups for both males and females, and one parameter difference between female low and high runners. Interestingly, the male high group had far greater discrimination between parameters (4 groups compared to 3), and a unique parameter with statistically the highest mean (shoe weight).

Table 3. Male importance rank comparison

Rank	Low	Moderate	High
1	Impact absorption	Shoe weight	Shoe weight
2	Stability	Traction	Outsole durability
3	Cushioning consistency	Cushioning consistency	Traction
4	Outsole durability	Flexibility	Flexibility
5	Shoe weight	Impact absorption	Cushioning consistency
6	Traction	Outsole durability	Impact absorption
7	Flexibility	Stability	Price
8	Price	Price	Permeability
9	Permeability	Permeability	Energy return
10	Energy return	Energy return	Stability
11	Torsional flexibility	Torsional flexibility	Torsional flexibility

Table 4. Female importance rank comparison

Rank	Low	Moderate	High
1	Cushioning consistency	Cushioning consistency	Shoe weight
2	Traction	Traction	Impact absorption
3	Impact absorption	Impact absorption	Traction
4	Outsole durability	Stability	Cushioning consistency
5	Shoe weight	Shoe weight	Outsole durability
6	Stability	Outsole durability	Stability
7	Flexibility	Flexibility	Flexibility
8	Permeability	Permeability	Energy return
9	Energy return	Energy return	Permeability
10	Price	Price	Price
11	Torsional flexibility	Torsional flexibility	Torsional flexibility

Considering male runners in isolation, most notably, impact absorption, torsional flexibility and stability statistically decrease in importance as the ability of the runner increases (particularly for the latter). Also, it appears that as the ability of the runner increases, the male preferences become more discrete, as evidenced by the number of groups in each classification (2, 3 and 4 for low, medium and high runners, respectively). At the high level, male runners would appear to place the greatest emphasis on shoe weight, followed by the performance of the outsole (traction and outsole durability) plus shoe flex (flexibility). On the other end of the scale, torsional flexibility was in the lowest group for males across all three classifications, but again there was further parameter discrimination as the ability increased. Similarly, energy return was also given very low importance.

The parameter importance rank results for females were far more consistent between user classifications, with equal numbers of parametric groups for low, medium and high runners (3). As mentioned above, group membership was also highly similar across the various abilities, where cushioning consistency, traction, impact absorption, outsole durability and weight were all in the highest mean groups. At the other end of the scale, torsional flexibility was always in the lowest mean group, with price, permeability and energy return also in the two lower groups.

Overall, the functional characteristics were far more independent of runner ability for females, compared to the corresponding male requirements. Therefore it would be expected that different running shoe designs are of far greater importance for men with differing running habits than women.

5 INNOVATION OPPORTUNITY MAPPING

Having identified user preferences across each running ability group, further analysis of the survey data was conducted to identify potential areas for future design innovation. This was achieved using a performance satisfaction measure, formulated to assess the specific subjective parameters requiring the most variation. It was defined as follows:

$$P_j = \frac{1}{n}\sum_i^n (I_{ij} - R_{ij}) \tag{1}$$

Where P_j for $j = 1,2..,11$ are the performance variations required in each subjective parameter, n is the number of survey participants in each user group, whilst I_{ij} and R_{ij} are the ideal parameter levels and running shoe ratings, respectively, of the j^{th} performance parameter for the i^{th} respondent. This improvement measure was plotted against the average parameter importance for each subjective performance parameter, to assess innovation opportunities. The resulting charts for both male and female runners across the Low, Moderate and High ability groups are shown in Figure 2 below.

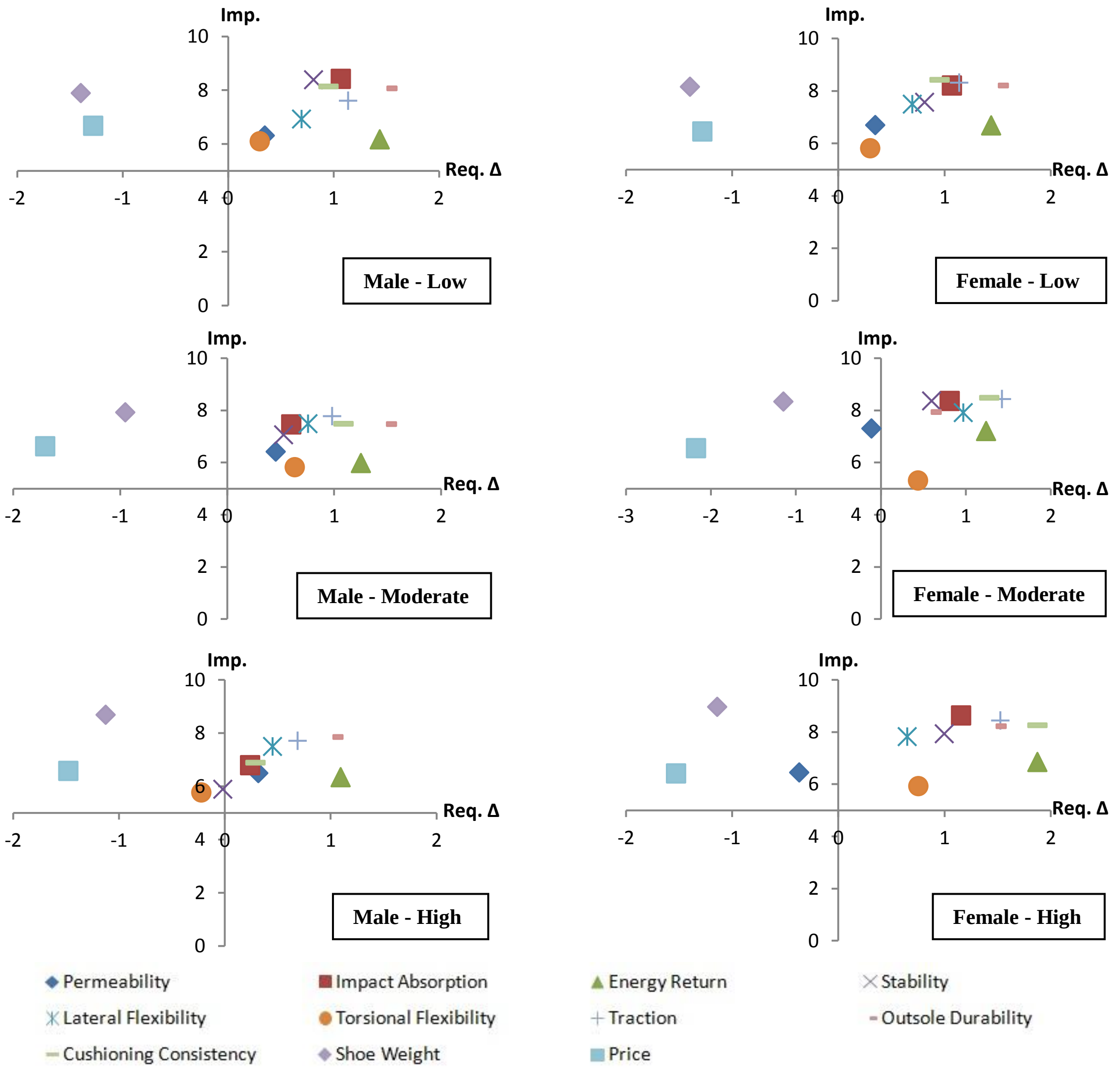


Figure 2. Innovation opportunity maps

To assess overall trends across the maps, it was noted that generally, shoe weight and price were the main attributes requiring a decrease in magnitude to improve user satisfaction, whilst all remaining parameters required an increase in magnitude (limited exceptions for permeability and torsional flexibility in three of the maps). By calculating the product of the importance and required variation values, the key performance characteristics across each ability group were identified. These are the parameters which, according to the user ratings, represented the greatest sources of user dissatisfaction. Interestingly, the results showed commonalities across the various ability groups, where for both Low male and female runners, an increase in outsole durability and decrease in price would be of greatest benefit. For the Moderate male and female runners, both groups also strongly desired a decrease in price, and the males also strongly valued an increase in outsole durability. The Moderate female runners most desired an increase in running shoe traction. Finally, the High level male and female runners had the least commonality in their user satisfaction results. The males most valued a decrease in user shoe weight and price, whilst the females preferred an increase in traction and cushioning consistency. These key findings do provide evidence supporting the shift amongst some user groups towards a more slimline, barefoot style running shoe design at lower cost.

It is noted that the maps do not assess inter-relationships between performance characteristics, or in other words, whether increasing the level of certain parameters will cause a consequent change in other characteristics. This must be taken into consideration in the subsequent design stages when modifying or customising the design of any running shoe.

6 CONCLUSION

The research presented in this paper has characterised distinct runner groups using discrete performance parameters. Based on this, the desired functional characteristics and design innovation opportunities for improved running shoe designs have been identified for each ability group.

Key performance metrics including kilometres run per session, running sessions per week and time per session were identified based on online surveys involving 585 respondents worldwide. Three runner group classifications (Low, Moderate and High) were determined intuitively through a simultaneous comparison of all three predictor variables. This classification was validated using statistical analysis, where the intuitive groupings were shown to be justifiable and significant.

Eleven functional characteristics of running shoes have been identified and described based on a review of existing literature and available industry standards. These attributes were investigated based on the data collected through a comprehensive qualitative survey process, allowing the importance and desired parameter levels to be determined for the three distinct runner groups. The formulation of innovation opportunity maps has also identified the parameters causing the most user dissatisfaction amongst each ability group.

By establishing and prioritising relevant functional characteristics of running shoes for distinct runner groups, we have established a knowledge base for the design specification of new generation sports shoes customised for specific market segments and user preferences. The presented user-based customisation process could potentially lead to new generation products with increased customer satisfaction.

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