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Overall Preference of Running Shoes can be Predicted by Suitable Perception Factors Using a Multiple Regression Model

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Precis/Short Abstract: This study investigated the influence of footwear perception factors on overall preference of running shoes using a regression model. One hundred casual runners assessed four shoe models for fit, cushioning, arch support, and stability. Results showed that each perception factor had a true potential to improve overall user preference. (49 words)

Running head: Regression of Perception Factors

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Abstract

Objective: This study examined 1) the strength of four individual footwear perception factors to influence the overall preference of running shoes, and 2) whether these perception factors satisfied the non-multicollinear assumption in a regression model.

Background: Running footwear must fulfil multiple functional criteria to satisfy its potential users. Footwear perception factors such as fit and cushioning are commonly used to guide shoe design and development, but it is unclear whether running footwear users are able to differentiate one factor from another.

Methods: One hundred casual runners assessed four running shoes on a 15-cm visual analogue scale for four footwear perception factors (fit, cushioning, arch support, and stability), as well as for overall preference during a treadmill running protocol.

Results: Diagnostic tests showed an absence of multicollinearity between factors, where values for tolerance ranged from .36 to .72, corresponding to variance inflation factors of 2.8 to 1.4. The multiple regression model of these four footwear perception variables accounted for 77.7% to 81.6% of variance in overall preference, with each factor explaining a unique part of the total variance.

Conclusion: Casual runners were able to rate each footwear perception factor separately, thus assigning each factor a true potential to improve overall preference for the users. The results also support the use of a multiple regression model of footwear perception factors to predict overall running shoe preference.

Application: Regression modelling is a useful tool for running shoe manufacturers to more precisely evaluate how individual factors contribute to the subjective assessment of running footwear.

Word Count: 250 (abstract)

Key Words: Multivariate analysis; usability testing and evaluation; product design; tools; gait, posture

Introduction

Since the running boom started in the USA in the 1970s, the athletic footwear industry now serves a sizeable global market worth billions of dollars. Each season, consumers are introduced to new designs by shoe manufacturers, some of which are guided by technological improvements. Essentially, running footwear needs to fulfil multiple functional criteria such as comfort, fit, cushioning, traction and durability. Collectively, these criteria contribute to a user's overall preference for a particular running shoe. In designing running footwear, a shoe model is generally subjected to three main types of tests, namely mechanical, biomechanical and subjective perception testing. However, more than three decades of running footwear research have not been conclusive on how these test results individually contribute to the user's overall preference, or how they may be used to guide footwear design (Hennig 2011, Hoerzer, Trudeau, Edwards, and Nigg 2015).

Indeed, predicting running shoe preference is a complex matter. Objective procedures such as mechanical and biomechanical measurements combined with computer simulation approaches were not sufficient to accurately predict running shoe preference (Hennig 2011, Sterzing, Lam, and Cheung 2012). Thus, subjective ratings of footwear perception factors, based on altered mechanical properties of the shoe, are used as an alternative method to assess running shoes. However, these subjective ratings do not always match the alteration in mechanical properties. For example, some studies investigating perception of footwear comfort have found good correlations to mechanical factors such as heel cushioning (Lam, Sterzing, and Cheung 2011), midsole hardness (Milani, Hennig, and Lafortune 1997, Sterzing, Schweiger, Ding, Cheung, and Brauner 2013) and insole hardness (Mündermann, Nigg, Stefanyshyn, and Humble 2002). Conversely, it was reported that subjective perception of comfort did not match well with the mechanical property of shock dissipation (Goonetilleke, 1999). Furthermore, other research have shown an inability of runners to perceive specific biomechanical characteristics of running shoes. For example, runners showed similar frontal plane ankle stability perception despite testing shoes that were designed to induce different degrees of rearfoot motion (Brauner, Sterzing, Gras, and Milani 2009, Sterzing, Custoza, Ding, and Cheung 2015a, Sterzing, Thomsen, Ding, and Cheung 2015b). Running shoe preference is further complicated by extrinsic factors such as aesthetics (Williams and Nester, 2006, Au and Goonetilleke, 2007), brand and price (Clinghan, Arnold, Drew, Cochrane, and Abboud, 2008, Hennig and Schulz, 2011).

As it seems unlikely that a single subjective perception factor can predict overall running shoe preference, an alternative is to consider a combination of multiple factors. This option was employed by Mills, Blanch and Vicenzino (2010), who determined through regression that a four-factor model of heel cushioning, heel support, forefoot cushioning and arch cushioning can explain 69% of overall comfort for running shoes. A major limitation of their study was the small sample size of only 10 participants, which is generally regarded as insufficient for a regression analysis. More crucially, it was not clear if the selected footwear perception factors were multicollinear (i.e. similarly correlated) or not.

In a valid regression model of footwear perception factors, each of the individual predictors must explain a unique part of the total variance in overall preference. In technical terms, this requires that the individual factors are not multicollinear. Previously, Hennig (2011) suggested that footwear perception factors may be multicollinear. From a series of studies spanning 18 years, it was concluded that if a user has an overall liking of a shoe, the user tends to rate each of the individual footwear perception factors similarly favourable as well. From a data perspective, it meant that the correlations between overall shoe liking and footwear perception factors such as fit, pronation control and shock attenuation were very high ($r \geq .90$). If footwear perception factors are indeed multicolinear, any regression model based on those factors would not be useful since we cannot identify how important each subjective perception factor is to the overall preference of a user. Thus, when conducting a regression analysis on footwear perception factors, it is necessary to initially check that the basic requirement is satisfied, i.e., that the factors are not similarly correlated (multicollinear) to overall preference.

The purpose of the present study was to examine the strength of individual footwear perception factors to influence the overall preference of running shoes. For the methodology to be valid, we must identify if 1) selected subjective footwear perception factors satisfied the non-multicollinear assumption in a regression model, and 2) the extent to which a four-factor multiple regression model of fit, cushioning, arch support and stability can predict overall running shoe preference across four test shoes. If the findings from our research support that these selected footwear perception factors are not multicollinear, and that the model satisfactorily predicts overall shoe preference, a potential application would be to strategically guide running shoe design and development. This would allow better efficiency in prototyping resources and human participant testing time, contributing to the design and development of shoe models that are highly preferred by consumers.

Methods

Participants

The present study is based on data collected from a bi-national study on shoe perception of Beijing and Singapore runners (Kong, Lim, Ding, and Sterzing 2015). The participants were 50 Beijing and 50 Singapore Chinese male casual runners recruited by convenience sampling. The overall characteristics of participants were as follows [Mean (SD)]: Age 23.5 (2.6) y; Height 1.73 (0.05) m; Body mass 67.3 (7.8) kg. To be included in the study, participants had to have foot sizes within US 8.0 to US 9.5, adopt a rearfoot striking pattern and run at least twice a week for a minimum total distance of 10 km per week in the past 3 months prior to data collection. Exclusion criteria were pain in any part of the body at the time of the study, or back and lower extremity injuries within the past six months. Further details of the participants can be found in Kong et al. (2015).

Instrumentation

Four models of experimental running shoes (Li Ning (China) Sports Goods Co. Ltd) were used in this study (Table 1). A series of tests were performed on the shoe models, with shoe uppers cut off, to determine their mechanical properties. Rearfoot impact scores of peak acceleration (g) and rearfoot energy return (%) were measured with an impact tester (Exeter Research, Brentwood, NH, USA), using the manufacturer's guidelines. The impact centre was set to be 12% of shoe length measured from the heel. Drop height was standardised to 50 mm and the flat headed drop mass was standardised to 8.5 kg. Average values of the last 5 impacts from a total of 30 repetitive impacts are displayed for each shoe model. Forefoot stiffness (Nm/deg) was measured with a flexion tester (Exeter Research, Brentwood, NH, USA). The flexion axis at the forefoot was set to be 70% of shoe length measured from the heel. The flexion range was 45 degrees and forefoot stiffness was calculated for a flexion range of 15 to 35 degrees. Average values of the last 5 flexion movements from a total of 55 repetitive flexion movements are displayed for each shoe model.

To reduce appearance bias as much as possible, which was a confounding factor previously highlighted by Williams and Nester (2006) and Au and Goonetilleke (2007), shoes were standardised to be all black in colour. Participants were asked to rate four variables of footwear perception, namely 'Fit', 'Cushioning', 'Arch support' and 'Stability', as well as their 'Overall preference' for each test shoe. The four footwear perception variables were selected based on the literature to reflect key functional features of a running shoe as desired by runners and recommended by researchers. Fit serves as an indicator of how well the geometric shape of a running shoe accommodates the runner's static and/or dynamic foot shape. Cushioning serves as a measure of how well the frequent and repetitive foot strike impacts during running are attenuated. While fit and cushioning are related to running shoe comfort, they were given priority over comfort as they would allow specific adjustment of shoe properties when expressed insufficient by runners. Schubert, Oriwol, and Sterzing (2011) recommended the use of fit and cushioning variables based on a recent large scale running shoe questionnaire identifying runners' most important shoe requirements. Sterzing and colleagues (2015b) discussed the importance of cushioning and stability. Both factors, when functioning insufficiently, provoke physiologically inefficient muscular co-contraction during running, which should be avoided by adequate running shoe constructions. Arch support was included as it had been repeatedly highlighted in the ongoing barefoot versus shod running debate (e.g. Lieberman 2012, Murphy, Curry, and Matzkin, 2013). While barefoot running represents a no support condition, a running shoe provides certain degrees of support to stabilise the longitudinal arch of the foot during stance phase load bearing. Subjective ratings were based on 15-cm visual analogue scales (VAS) and recorded to the nearest 0.1 cm, where 0 was 'Dislike extremely' and 15 was 'Like extremely'. The VAS is widely used in athletic footwear studies (e.g. Clinghan et al. 2008, Lam et al. 2011, Sterzing et al. 2013) and has been shown to be reliable (e.g. Mündermann et al. 2002, Mills et al. 2010), particularly in comparison to Likert scales (Mills et al. 2010). Scales of 10- and 15- cm were reported in the literature to have the smallest measurement error (Seymour, Simpson, Charlton, and Phillips, 1985), and the choice of 15-cm scales was to allow better differentiation between the data (Price, Bush, Long, and Harkins, 1994).

Table 1. Selected mechanical characteristics of the four Li Ning test shoes.

	Running shoe model			
	Hyper arc (A)	Basic cushion (B)	Superlight (C)	Unit bow (D)
Characteristics				
Length (mm)	2750	2750	2750	2750
Mass (kg)	0.327	0.295	0.230	0.292
Rearfoot Thickness (mm)	32.0	31.0	29.0	32.0
Rearfoot Midsole Width (mm)	8.7	8.9	8.5	8.4
Forefoot Stiffness (Nm/deg)	0.19	0.16	0.19	0.23
Rearfoot Impact Score (g)	11.6	9.8	11.1	11.2
Rearfoot Energy Return (%)	44.4	46.0	45.7	46.6

Note. This data set was similarly presented in a previous study by Kong et al. (2015).

Procedures

This research complied with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board at Nanyang Technological University. Informed consent was obtained from each participant. Running took place on a treadmill (TechnoGym Excite+ RUN NOW 700). The prescribed warm-up was one minute of treadmill running in each shoe model, resulting in a total of four minutes. This warm-up protocol also served to familiarise the participants with the four different shoe models used in this study, as well as determining their individually preferred running speed which was then used throughout the experiment. Participants were then randomly assigned each of the four pairs of test shoes. During the experiment, participants ran at their individually preferred speed for five one-minute trials in each shoe model, assessing one perception factor on the VAS after each trial.

Each participant ran at his individually preferred speed for all trials, which totalled 20 trials. The mean preferred speed across all participants was 7.6 (1.3) km/h [or 2.11 (0.36) m/s], and ranged from 5.5 to 12.0 km/h. Assessments of the four footwear perception factors (fit, cushioning, arch support and stability) were randomly ordered, and was always followed lastly by assessment of overall shoe preference. Between shoes, participants removed their footwear to jog on the spot (on the ground) while only wearing their socks for 10 seconds to desensitise the tactile sensations of the previous test shoes.

Data Analyses

Data from all 100 participants (50 Beijing and 50 Singapore Chinese males) were combined after initial collinearity diagnostics revealed that whether the two groups were analysed separately or together, the results did not indicate the presence of multicollinearity (cut-off criterion to be discussed below). Furthermore, collinearity diagnostics compare one set of data of a predictor variable (e.g. fit) against each of the other three sets of data from the other predictor variables (cushioning, arch support and stability). Since these procedures do not compare an average or weighted value, thus, population pooling does not affect collinearity values given that each participant contributes one data point for the four predictor variables.

Simultaneous multiple regression analyses were conducted separately for each of the four test shoes to avoid double-counting each participant. The four footwear perception variables of fit, cushioning, arch support and stability were entered as a single predictor block for overall shoe preference. The proposed regression model may be written as:

$$y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + e$$

where y = overall preference, $x_{1\text{-}4}$ = fit, cushioning, arch support and stability, $a_{1\text{-}4}$ = coefficients of regression and e = intercept.

The linear regression model was selected to reflect the incremental improvements in shoe design/manufacturing processes. For example, if we increase cushioning material of the shoe by 2 mm, what is the effect on subjective user rating of cushioning? Standardised residuals were plotted against unstandardised predicted values for visual inspection, and the assumptions of linearity, independent errors, and homoscedasticity were met.

Diagnostics were carried out to determine the tolerance values and the variance inflation factors (VIF), which are formal detection tests of multicollinearity (O'Brien, 2007). The absence of collinearity is a necessary requirement to conduct valid regression analysis. Tolerance is derived as 1 minus the coefficient of determination of a regression of a single predictor variable (e.g., fit) on all the other remaining predictor variables (cushioning, arch support, and stability). Tolerance values are usually accompanied by VIF values, which are defined as the inverse of tolerance. Multicollinearity is indicated by small values for tolerance and large values of VIF. The commonly used criteria values for tolerance and VIF respectively are .10 and 10 (Cohen, Cohen, West, and Aiken, 2003), which may be insufficient to sieve out multicollinearity (Keith, 2006). Furthermore, a review by O'Brien (2007) found numerous suggestions of tolerance and VIF in the literature. We chose to follow the recommendations of tolerance value above .17 and VIF below 6 by Keith (2006), who illustrated with numerical examples as to why these stricter values were necessary. In Keith (2006), one example of two correlated predictor variables showed VIF to be 5.3. Based on that number, Keith (2006) used the upper-bound of 6 as a suggested cut-off value for VIF.

For the multiple regression model, the coefficient of determination (R^2), standardised (β) and unstandardised regression coefficients (*b*) were reported. The R^2 value may range from 0 to 1.0, with a larger value meaning that the regression model explains more of the total variance. The standardised coefficient β allows comparisons between the variance explained by each predictor variable across the four shoe models, while the unstandardised coefficient *b* allows assessing the importance of each factor within the model for a particular test shoe. For example, a β of 0.3 for the variable of fit for a certain shoe model indicates that for every 1 cm increase in VAS rating for fit, the overall preference rating would increase by 0.3 cm. All statistical analyses were performed in SPSS version 21.0 (SPSS Inc., Chicago, IL, U.S.), with significance level set at .05 a priori.

Results

Descriptive statistics of VAS measurements for the four test shoes are displayed for all five variables in Table 2. The mean VAS scores ranged between 7.0 and 10.3 cm on the 15-cm scales. Overall, Shoe C was the least preferred, while Shoe D was the most preferred.

Table 2. Visual analogue scale (VAS) measurements (cm) presented as Mean (SD) for four shoe models (liking magnitude: 0 - dislike extremely, 15 - like extremely).

Variable	Shoe A	Shoe B	Shoe C	Shoe D
Fit	9.0 (3.0)	9.0 (3.1)	8.2 (3.3)	10.3 (2.7)
Cushioning	8.7 (3.0)	10.3 (2.7)	7.0 (3.6)	9.6 (3.1)
Arch support	8.9 (2.9)	8.9 (3.3)	7.1 (3.4)	9.5 (2.9)
Stability	9.2 (3.0)	9.6 (2.7)	8.4 (3.2)	10.0 (2.6)
Overall preference	9.2 (3.0)	10.1 (3.0)	7.9 (3.6)	10.4 (2.9)

Note. This data set was based on a previous study by Kong et al. (2015).

Collinearity diagnostics are displayed for the four predictor variables in Table 3. Tolerance values ranged from .36 to .72, corresponding to VIF of 2.8 to 1.4; these were above the cut-off values of .17 and below 6 for tolerance and VIF respectively. Thereby, the range of cut-off values indicates the four predictor factors are not multicollinear, and that each of them explains unique parts of the variance in overall preference.

Table 3. Collinearity diagnostics of tolerance and variance inflation factor (VIF) for footwear perception variables contributing to overall preference for each shoe model.

	Shoe A		Shoe B		Shoe C		Shoe D	
Variable	Tolerance	VIF	Tolerance	VIF	Tolerance	VIF	Tolerance	VIF
Fit	.72	1.4	.50	2.0	.53	1.9	.43	2.3
Cushioning	.48	2.1	.52	1.9	.54	1.9	.41	2.5
Arch support	.51	2.0	.51	2.0	.44	2.3	.42	2.4
Stability	.68	1.5	.48	2.1	.53	1.9	.36	2.8

Note: The cut-off values were set at tolerance > .17 and VIF < 6 respectively (Keith 2006).

Correlation and regression coefficients are shown in Table 4. All correlation coefficients (r) were significant at $p < .001$, exhibiting moderate magnitudes ranging from .435 to .734. For all four test shoes, the regression coefficients (β, *b*) of the footwear perception variables were significantly related to overall preference with the exception of arch support for Shoe A ($p = .181$). On the whole, the proposed regression model accounted for 77.7% to 81.6% of the variance in overall preference for each of the test shoes. Specifically, the test statistics were Shoe A $F(4, 95) = 82.7$, $p < .001$, $R^2 = .777$; Shoe B $F(4, 95) = 92.7$, $p < .001$, $R^2 = .796$; Shoe C $F(4, 95) = 105.6$, $p < .001$, $R^2 = .816$; Shoe D $F(4, 95) = 90.5$, $p < .001$, $R^2 = .792$. At the individual level of each predictor variable, cushioning was either the most important or second most important predictor of the variance in overall preference. This was indicated by larger regression coefficients (β, *b*) compared to those of the other three predictor variables for each shoe model. For example, based on the standardised regression coefficient b for Shoe D, the model predicts that a 1.0-cm increase in VAS for cushioning would lead to a 0.40 cm increase for overall preference. In comparison, the values for the other three factors for shoe D are 0.21 cm (fit), 0.27 cm (arch support) and 0.20 cm (stability). In contrast, for Shoe C, a 1.0-cm increase in VAS for fit would result in a

0.37 cm increase for overall preference, while other factors would cause smaller positive effects: cushioning (0.30 cm) arch support (0.19 cm), stability (0.28 cm).

Table 4. Correlation and regression coefficients for footwear perception variables and overall preference for each test shoe.

		Correlation coefficients (r)[a]				Regression coefficients					
Model	Variable	Arch support	Cushioning	Fit	Overall preference	β	*b*	*t*	*p*	R^2	e[b]
Shoe A	Fit				.69	.36	.35	6.23	.000	.777	-0.66
	Cushioning			.48	.74	.34	.34	4.92	.000		
	Arch support		.67	.44	.64	.09	.09	1.35	.181		
	Stability	.49	.50	.41	.69	.32	.32	5.51	.000		
Shoe B	Fit				.78	.35	.34	5.25	.000	.787	-1.60
	Cushioning			.60	.74	.27	.29	4.07	.000		
	Arch support		.58	.59	.73	.25	.23	3.80	.000		
	Stability	.63	.60	.62	.72	.19	.21	2.73	.008		
Shoe C	Fit				.78	.35	.37	5.70	.000	.816	-0.85
	Cushioning			.58	.76	.30	.30	5.06	.000		
	Arch support		.62	.63	.75	.19	.19	2.82	.006		
	Stability	.64	.55	.55	.73	.25	.28	4.11	.000		
Shoe D	Fit				.75	.20	.21	2.76	.007	.792	0.42
	Cushioning			.71	.82	.43	.40	5.80	.000		
	Arch support		.63	.61	.74	.22	.27	3.02	.003		
	Stability	.73	.68	.66	.76	.18	.20	2.30	.024		

Note. [a]All correlation coefficients (r) were significant at $p < .001$. [b]The intercept of the equation (e) was not significant for any of the regression equations, where $p > .05$. Standardised (β) and unstandardised regression coefficients (*b*), coefficient of determination (R^2) and intercept of the equation (e*)* were reported.

Discussion

The purposes of the present study were to identify if 1) selected subjective running footwear perception factors satisfy the non-multicollinear assumption in a regression model, and 2) the extent to which a four-factor multiple regression model of fit, cushioning, arch support and stability can predict overall running shoe preference across four test shoes. It was shown that the non-multicollinear assumption was satisfied. Furthermore, the proposed model was able to explain a large percentage of the variation in overall preference of the four different shoe models.

The absence of multicollinearity in the footwear perception factors is a mandatory pre-requisite for a regression model, for example, each of the factors must explain a unique part of the total variance in overall preference. Our results demonstrated that casual runners were able to rate the four selected factors separately when assessing the different test shoes. This finding contrasts the suggestion by Henning (2011) that participants generally rated all perception factors similarly well if they liked a particular shoe. One explanation is the two key methodological differences used in this study compared to the series of studies examined by Henning (2011). It is likely that in the previous work, participants experienced high cognitive demands as they had to attend to multiple perception tasks simultaneously in order to provide their ratings after a single run of approximately 10 km. Furthermore, they were all asked to rate their overall preference of the shoe model first, before proceeding to rate each specific footwear perception factor. In our study, each perception variable was assessed in separate trials, allowing participants to focus solely on one variable at a time, thereby avoiding any overload of attentional demand. In addition, participants were asked to rate overall preference at the end after having assessed the four perception variables. Thus, our study design prevents the overall preference rating from influencing individual perception factors. It is likely that the order by which participants assess the footwear perception factors versus the overall preference variable has decisive influence on the results. Further research is needed to confirm this hypothesis.

The present four-factor model of fit, cushioning, arch support and stability explained between 77.7% to 81.6% of variance in overall shoe preference for the four test shoes. Compared to Mills and colleagues (2010) who used a four-factor model that was heavily weighted towards cushioning factors (heel cushioning, heel support, forefoot cushioning and arch cushioning) which explained 69% of overall comfort, the proposed model in the present study is an improvement towards identifying the underlying factors that constitute overall running shoe preference. This difference in explaining a larger percentage of variation in overall preference is likely due to the inclusion of fit, arch support and stability perception variables. These are important footwear perception factors as suggested by previous research (Miller, Nigg, Liu, Stefanyshyn, and Nurse 2000, Lam et al. 2011, Schubert et al. 2011, Weerasinghe, Goonetilleke, and Signes 2012). It remains important for future studies to confirm the validity of the proposed model or even optimise it, as the applied methods are relatively new to the area of footwear and general product preference research.

Compared to a single factor, the four-factor regression model was able to explain a larger percentage of the variation in overall preference. The correlation coefficients of the four factors ranged from .64 to .82, which explained between 41.0% to 67.2% of the variance in overall preference if just one factor was considered. In comparison, combining the four factors accounted for 77.7% to 81.6% of the variation in overall preference. Thus, the findings support the use of a combination of subjective perception variables to predict overall running shoe preference. Nevertheless, it has to be stated that the different predictor variables display different importance regarding their contribution to overall product preference. For the running shoes in our study, cushioning appears the most influential predictor variable, which is highly plausible considering the repetitive ground impacts sustained during running.

The proposed model may be used as a critical tool for researchers and running shoe manufacturers as a first step to identify overall shoe preference and its main contributing features. Subsequent research could then be directed at identifying the key mechanical characteristics of the shoe model(s) that were favoured in order to guide improvement of running shoe design and development. For example, are we able to link a 2 mm increase in cushioning material of the shoe to the effect on subjective user rating of cushioning and overall shoe preference? In future, the methods demonstrated in the present study may also be prospectively applied to predict running shoe preference from a larger group of runners.

There are several limitations of our study. The first limitation relates to the selection of the perception factors. In our study, we selected four footwear perception factors that reflect the key features of a running shoe based on the literature. Although our proposed model based on these factors can predict running shoe preference to approximately 80%, future studies could investigate if having more or less factors would improve the regression model. Nevertheless, the challenge lies in creating a model with high accuracy of prediction yet does not overly burden the running shoe user with too many items to respond to, allowing participants to maintain their high level of attentional demand all throughout testing (Lam et al. 2013). Another consideration is that we did not differentiate between possible subgroups within the casual runners, for example, different foot types. Previously, Mündermann, Stefanyshyn, and Nigg (2001) found that participants preferred different arch support types depending on their foot arch height. Specifically, participants with a lower foot arch preferred that viscous and hard shoe insert, compared to the elastic and soft option. Future studies may further investigate the influence of physical characteristics on subjective footwear preference. Lastly, in our study, we were limited to testing four existing shoe models from the same footwear manufacturer. As each manufacturer have their own proprietary elements (e.g. shoe last, midsole material or design), our findings from the four shoe models in this study may not be fully applicable to shoe models from other manufacturers. For example, certain shoe brands have a wider forefoot construction that would be more appealing to specific consumers, which in turn could influence subjective perception of fit, cushioning, arch support and stability. Furthermore, testing of existing shoe models does not allow for systematic alteration of their mechanical properties, which would have been better in identifying the causal relationships between subjective perception and shoe characteristics (Sterzing, 2011). It is acknowledged that a final justification of the generalisability of our model would warrant a prospective validation by inclusion of a new, independent group of runners. However, this aspect was beyond the scope of our current research. Future studies can expand the current work to other brands of shoe manufacturers, validate and optimise the proposed regression model to predict runners' preference.

Conclusions

In conclusion, the present study provides support for a multiple regression model of four footwear perception factors, namely fit, cushioning, arch support and stability, to predict overall running shoe preference. The four footwear perception factors did not exhibit a problem of multicollinearity, thus the regression model is valid. Thereby, a useful tool is introduced to allow more precise evaluation of how individual factors contribute to the subjective assessment of running footwear. Future research should aim at prospectively validating and optimising the proposed model for the evaluation and prediction of running shoe preference.

Key points

- Multiple regression model of footwear perception factors is useful in predicting overall running shoe preference.

- Collinearity diagnostics revealed that casual runners were able to rate individual footwear perception factors separately.
- The prerequisite of the absence of multicollinearity for a valid multiple regression model was met.
- Thus, each of the four perception factors of fit, cushioning, arch support and stability has a true potential to improve overall running shoe preference for the users.

References

Au, E. Y., and Goonetilleke, R. S. 2007. "A qualitative study on the comfort and fit of ladies' dress shoes." *Applied Ergonomics* 38(6), 687-696.

Brauner, T., Sterzing, T., Gras, N., and Milani, T. L. 2009. "Small changes in the varus alignment of running shoes allow gradual pronation control." *Footwear Science* 1(2), 103-110

Clinghan, R., Arnold, G. P., Drew, T. S., Cochrane, L. A., and Abboud, R. J. 2008. "Do you get value for money when you buy an expensive pair of running shoes?" *British Journal of Sports Medicine* 42(3), 189-193.

Cohen, J., Cohen, P., West, S. G., and Aiken, L. S. 2003. "Applied multiple regression/correlation analysis for the behavioral science." Mahwah, NJ: Lawrence Erlbaum.

Goonetilleke, R. S. 1999. "Footwear cushioning: Relating objective and subjective measurements." *Human Factors* 41(2), 241-256.

Hennig, E. M. 2011. "Eighteen years of running shoe testing in Germeny - a series of biomechanical studies." *Footwear Science* 3(2), 71-81.

Hennig, E. M., and Schulz, J. 2011. "Subjective evaluation of biomechanical shoe properties during blinded and non-blinded running". *Footwear Science* 5(Suppl1), S75.

Hoerzer, S., Trudeau M. B., Edwards, B., and Nigg, B. 2015 “How reliable are subjective footwear comfort assessments?.” *Footwear Science* 7, S106-S107.

Keith, T. Z. 2006. Multiple regression and beyond. Pearson Education.

Kong, P. W., Lim, C. Y., Ding, R., and Sterzing, T. 2015. “Subjective evaluation of running footwear depends on country and assessment method: A bi-national study.” *Ergonomics, 58*(9), 1589-1604. doi:10.1080/00140139.2015.1018957

Lam, W. K., Sterzing, T., and Cheung, J. T. 2011. “Reliability of a basketball specific testing protocol for footwear fit and comfort perception.” *Footwear Science* 3(3), 151-158.

Lam, W. K., Sterzing, T., and Cheung, J. T. 2013. “Influence of protocol complexity on fit perception of basketball footwear.” *Footwear Science* 5(3), 155-163.

Lieberman, D. E. 2012. “What we can learn about running from barefoot running: An evolutionary medical perspective.” *Exercise and Sport Sciences Reviews* 40(2), 63-72.

Milani, T. L., Hennig, E. M., and Lafortune, M. A. 1997. “Perceptual and biomechanical variables for running in identical shoe constructions with varying midsole hardness.” *Clinical Biomechanics* 12(5), 294-300.

Miller, J. E., Nigg, B. M., Liu, W., Stefanyshyn, D. J., and Nurse, M. A. 2000. “Influence of foot, leg and shoe characteristics on subjective comfort.” *Foot & Ankle International* 21(9), 759-767.

Mills, K., Blanch, P., and Vicenzino, B. 2010. “Identifying clinically meaningful tools for measuring comfort perception of footwear.” *Medicine and Science in Sports and Exercise* 42(10), 1966-1971.

Mündermann, A., Nigg, B. M., Stefanyshyn, D. J., and Humble, R. N. 2002. “Development of a reliable method to assess footwear comfort during running.” *Gait & Posture* 16(1), 38-45.

Mundermann, A., Stefanyshyn, D. J., and Nigg, B. M. 2001. “Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors.” *Med Sci Sports Exerc* 33(11), 1939-1945.

Murphy, K., Curry, E., and Matzkin, E. 2013. “Barefoot running: Does it prevent injuries?” *Sports Medicine* 43(11), 1131-1138.

O’Brien, R. 2007. “A caution regarding rules of thumb for variance inflation factors.” *Quality & Quantity* 41(5), 673-690.

Price, D. D., Bush, F. M., Long, S., and Harkins, S. W. 1994. “A comparison of pain measurement characteristics of mechanical visual analogue and simple numerical rating scales.” *Pain* 56(2), 217-226.

Schubert, C., Oriwol, D., and Sterzing, T. 2011. “Gender and age related requirements of running shoes: A questionnaire on 4501 runners.” *Footwear Science* 3(Suppl 1), S148-150.

Seymour, R. A., Simpson, J. M., Charlton, J. E., and Phillips, M. E. 1985. “An evaluation of length and end-phrase of visual analogue scales in dental pain.” *Pain* 21(2), 177-185.

Sterzing, T. 2011. “Comprehensive evaluation and systematic development of innovative athletic footwear.” International Symposium on Footwear Technology, China Society of Sports Biomechanics, Chengdu, China.

Sterzing, T., Lam, W. K., and Cheung, J. T.M. 2012. “Athletic footwear research by industry and academic”. In *The Science of Footwear,* edited by R. S. Goonetilleke, 605-622. Florida: CRC Press.

Sterzing, T., Schweiger, V., Ding, R., Cheung, J. T.-M., and Brauner, T. 2013. “Influence of rearfoot and forefoot midsole hardness on biomechanical and perception variables during heel-toe running.” *Footwear Science* 5(2), 71-79.

Sterzing, T., Custoza, G., Ding, R., and Cheung, J. T.-M. 2015a. "Segmented midsole hardness in the midfoot to forefoot region of running shoes alters subjective perception and biomechanics during heel-toe running revealing potential to enhance footwear." *Footwear Science,* 7(2), 63-79.

Sterzing, T., Thomsen, K., Ding, R., and Cheung, J. T.-M. 2015b "Running shoe crash-pad design alters shoe touchdown angles and ankle stability parameters during heel-toe running." *Footwear Science,* 7(2), 81-93.

Weerasinghe, T. W., Goonetilleke, R. S., and Signes, G. S. 2012. "Why the optimal fitting of footwear is difficult." In *Advances in Affective and Pleasurable Design*, edited by G. J. Yong, 371-377. London: CRC press.

Williams, A. E., and Nester, C. J. 2006. "Patient perceptions of stock footwear design features." *Prosthetics and Orthotics International* 30(1), 61-71.

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