Footwear Science

ISSN: 1942-4280 (Print) 1942-4299 (Online) Journal homepage: https://www.tandfonline.com/loi/tfws20

The perception of ride is multidimensional for running footwear

Cristine Agresta, Jillian Peacock, Alicia Carmichael, Karen E Nielsen, Jessica Zendler & Richard Gonzalez

To cite this article: Cristine Agresta, Jillian Peacock, Alicia Carmichael, Karen E Nielsen, Jessica Zendler & Richard Gonzalez (2020) The perception of ride is multidimensional for running footwear, Footwear Science, 12:1, 15-24, DOI: 10.1080/19424280.2019.1706645

To link to this article: https://doi.org/10.1080/19424280.2019.1706645

Published online: 07 Jan 2020.

FOOTWEAR SCIENCE
2020, VOL. 12, NO. 1, 15–24
https://doi.org/10.1080/19424280.2019.1706645

The perception of ride is multidimensional for running footwear

Cristine Agresta[a,b], Jillian Peacock[a], Alicia Carmichael[d], Karen E. Nielsen[c], Jessica Zendler[a] and Richard Gonzalez[d]

[a]School of Kinesiology, University of Michigan, Ann Arbor, MI, USA; [b]Department of Rehabilitation Medicine, University of Washington, Seattle, WA, USA; [c]Department of Statistics, University of Michigan, Ann Arbor, MI, USA; [d]Department of Psychology, University of Michigan, Ann Arbor, MI, USA

ABSTRACT
Footwear assessment is thought to be influenced by shoe comfort and the feeling of the ground-shoe interface during contact, sometimes called the ride of the shoe. Runners are often asked to rate the ride quality of smoothness as an indicator of comfort. However, previous work has shown that smoothness does not directly map to preference or comfort. This suggests that footwear assessment may be influenced by multiple perceptual qualities of ride. The goal of this study was to explore how various ride qualities influence footwear assessment. We evaluated the sensitivity of ride quality ratings to time and intended use (e.g. tempo run, recovery run). Thirty-seven runners participated in this study. They ran for 12 min at a self-selected speed while being queried every 30 s about the ride qualities of the shoe. Ride qualities were firmness, awareness, yield, energy return, ground feel, weight, sound level, and speed. Runners evaluated four unique running shoes in addition to their native shoe. Multidimensional scaling was used to reduce dimensionality and to visualise and interpret ride qualities. The results indicated that ratings of yield and energy-return were associated with the primary two emergent dimensions. However, footwear purpose influenced ride quality ratings. Runners placed increased weight on the speed quality when selecting shoes for speed work or tempo runs and placed increased weight on the yield and energy return qualities for selecting shoe for long runs or recovery runs. Findings suggest footwear assessment is shaped by multiple perceptual qualities and intentions. The ride quality mean ratings remained relatively stable during each run. Future studies aiming to identify biomechanical indicators of footwear assessment should query subjective ratings of yield and energy-return.

ARTICLE HISTORY
Received 16 June 2019
Accepted 16 December 2019

KEYWORDS
Ride; multidimensional scaling; footwear preference; energy-return; yield

Introduction

Selection of running footwear has long been considered critical to optimising the overall running experience. However, it is unclear how to best match a runner to a pair of shoes. Shoe reviews, runners, and industry experts often describe the feeling of a shoe when running in it as an important factor in selecting running footwear. Previous research has aimed to distil this feeling into quantifiable parameters that can be used to understand footwear preference and selection. Comfort of the shoe (Hintzy, Cavagna, & Horvais, 2015; Kong and Bagdon, 2010; Meyer, Mohr, Falbriard, Nigg, & Nigg, 2018; Wegener, Burns, & Penkala, 2008) and the perception of cushioning (Dinato et al., 2015; Sterzing, Schweiger, Ding, Cheung, & Brauner, 2013) have been studied extensively with mixed results. Most athletes can consistently perceive gross differences in cushioning levels but are less sensitive to small changes in cushioning. Moreover, comfort ratings are poorly correlated with cushioning and are highly runner-dependent (Dinato, et al., 2015; Lam, Mohr, Nigg, & Nigg, 2018; Nunns, Dixon, Clarke, & Carre, 2016; Slade, Greenya, Kliethermes, & Senchina, 2014; Sterzing, et al., 2013). These findings suggest that traditional footwear characteristics queried by researchers may not align with factors that individuals use to assess footwear.

Recently, assessing the ride of a shoe has gained interest over assessing either comfort or cushioning (Lam, et al., 2018). Ride has been defined as "the feeling of the shoe during heel-toe walking or running as the foot transitions from heel to forefoot

CONTACT Cristine Agresta cagresta@uw.edu Department of Rehabilitation Medicine, University of Washington, Seattle, WA, USA

Table 1. Description of shoe properties that runners wore during running trials in addition to the aggregated data from participants' native shoes.

	Habitual	Adios	Alphabounce	Supernova	Ultraboost
Heel height (mm)	27.5 ± 4.0	27.0	33.9	35.0	33.3
Forefoot height (mm)	18.6 ± 2.1	17.9	22.6	28.1	22.9
Heel-to-toe drop (mm)	9.0 ± 3.4	9.1	11.3	6.9	10.4
Weight US 9 (g)	266 ± 34	216	323	323	303
Energy return (%)		75.9	72.3	75.7	77.2

All experimental shoes were unmodified off-the-shelf models made by adidas. Values for the experimental shoes are described relative to a Men's size 9 shoe and were provided by the sponsor. Energy return percentage values were obtained using a load-driven test to 2000 N. Values reported are mean ± *SD*.

during the stance phase of gait" (Lam, et al., 2018). Ride has been described as either being "smooth or not smooth" with a general acceptance that smoother equals better. Thus, researchers have equated the singular quality of smoothness to the overall ride rating of a shoe and sought to find a biomechanical variable that can quantify this perception of smoothness.

The primary purpose of this study was to explore the extent to which each ride quality related to overall footwear assessment. Secondary aims were to evaluate the relation between ride qualities and the runner's intended use for the shoe (e.g. long run) and to explore whether ride ratings change during the course of a running session because runners purchasing a shoe typically only take a few minutes to evaluate it.

Methods

Subjects

Forty healthy distance runners (20 males) were recruited for this study through posted flyers and emails at local running clubs and running specialty stores. Inclusion criteria were minimum running distance of 19 kilometres per week, age 18–55 years old; no lower extremity injuries in the previous 6 months; no current orthotics usage; and no previous experience in running footwear, sales, or coaching. Each participant provided written informed consent before involvement in the study. Data were collected following a protocol approved by the Institutional Review Board at the University of Michigan. Three participants (3 female) were excluded from data analyses: two participants due to equipment malfunction of the hand-held device and one due to inability to complete the running protocol.

Shoe conditions

Five different running shoes, including the runner's native shoes, were tested. Characteristics of each shoe are listed in Table 1. Shoes from the same manufacturer were chosen with different characteristics, such as weight and heel-to-toe drop, so that differences in ride perception were likely to be experienced. Off-the-shelf models were chosen so that qualified subjects could be enrolled regardless of shoe size even though it reduced the consistency of the footwear conditions. Women's shoes were offered in half-sizes from US size 6 to US size 11 and men's shoes were offered in half-sizes from US size 8 to US size 13. Subjects were offered multiple sizes of each experimental shoe and self-selected their shoe size.

Ride qualities

The ride qualities used in the study were elicited through surveys and semi-structured interviews of an independent group of 20 running experts. The running experts included owners of specialty running stores, running coaches, running shoe reviewers, and experienced runners with varying levels of running speeds and distances. This group was chosen specifically because it was likely they have previously contemplated and could articulate descriptors for the specific feeling of shoes while running. This was a necessary first step to determining the most salient attributes associated with shoe ride and to identify anchor terms for each ride quality scale. The interviews were transcribed and subjected to both coding by human raters and text mining software. Three trained coders organised and compared the catalogues of words the runners used and categorised them along eight themes, or ride qualities: (1) energy return, (2) ground feel, (3) firmness, (4) yield, (5) awareness,

Table 2. Ride qualities queried during and after each running trial. Qualities were rated on a 5-point scale with descriptors at each end of the scale to anchor the perception spectrum.

Ride qualities							
Energy return	Responsive	1	2	3	4	5	Unresponsive
Ground feel	Smooth	1	2	3	4	5	Bumpy
Firmness	Soft	1	2	3	4	5	Firm
Yield	Rigid	1	2	3	4	5	Flexible
Awareness	Noticeable	1	2	3	4	5	Unobtrusive
Sound level	Quiet	1	2	3	4	5	Loud
Speed	Slow	1	2	3	4	5	Fast
Weight	Light	1	2	3	4	5	Heavy

(6) sound level, (7) speed, and (8) weight. The eight resultant qualities were assessed on a five-point scale and anchored with specific descriptors (Table 2).

Testing procedure

A digital survey was taken prior to the laboratory session to collect participant demographics and running characteristics and to establish their familiarity with the concept of "ride." Specifically, runners were asked whether they had heard of the term ride and to define ride in their own words before our operational definition was given to them. For this study, we defined ride as "the feeling of the ground, shoe, and foot as the foot transitions through cycles of contact with the ground." This definition was chosen, in part, over previous definitions (Lam, et al., 2018) in order to generalise to all runners regardless of foot strike pattern. A study investigator stated this definition to the participant prior to initial in-lab survey collection and following the self-described definition. For reference, the definition was posted on either side of the monitor in front of the treadmill during the running trials. Treadmill speed was selected by the runner to represent a comfortable training pace. All subsequent running trials were conducted at the same treadmill speed with 0% incline. Runners completed five running trials – one six-minute run in their native shoe and four twelve-minute runs in novel shoes. Following the native shoe trial, the order of the four novel shoes was randomised. Four ride qualities were asked during each trial. Three of these ride qualities – energy return, awareness, and firmness – were prioritised as a result of findings from lay expert interviews and randomly queried during each running trial. The fourth quality queried was either speed, yield, ground feel, weight, or sound level and rotated randomly during each trial. The position of the anchor was randomized across queries and recoded to standard structure (see Table 2) in processing and prior to data analysis. Queries occurred every 22 s and were presented on a monitor in front of the treadmill (Figure 1; monitor measured 31.4-in by 54.2-in). A schematic of the queries is illustrated in Figure 2.

An explanation or detailed description of the specific ride qualities were not given to the runner beforehand. This was done intentionally as to not bias the runner in their immediate experience of shoe ride. Further, runners were asked to rate the ride of the shoe using anchor terms (for example: yield was anchored from flexible to rigid, Figure 1). These are terms used to describe running footwear and would have been familiar to the runner. If runners asked how they should interpret each ride quality, a study team investigator said that each descriptor can be interpreted as 'whatever that means to you.'

Runners had seven seconds to select an answer using a hand-held device (Pyka, Current Designs, Inc., Philadelphia, PA, USA) (inset Figure 1). Runners were asked to report on the feeling of the ride of the footwear at that moment. Investigators ensured that participants understood that ride perception was allowed to change. Participants verbally acknowledged that the trials were not a 'memory test' of perception. In addition to in-trial ratings, post-run ratings for each ride quality were assessed immediately after each running trial via digital survey. Runners were asked to rate the ride qualities of the ideal footwear for four intended running purposes. The four run purposes included (1) long run, defined as 6 miles or longer; (2) easy or recovery run; (3) speed work, and (4) tempo run.

A schematic of the full experimental protocol is illustrated in Figure 3.

Data analysis

Nonmetric individual difference multidimensional scaling (INDSCAL) was used to analyse the ride ratings for each shoe and the ride ratings of the ideal footwear for each run purpose. INDSCAL was used to examine within-shoe patterns for the eight ride qualities. For each shoe we computed an 8×8 distance matrix on the post-run ratings of the eight

Figure 1. Illustration of data collection set-up. Runner is answering query about the ride quality, yield, on the monitor via hand-held device (device shown in picture inset).

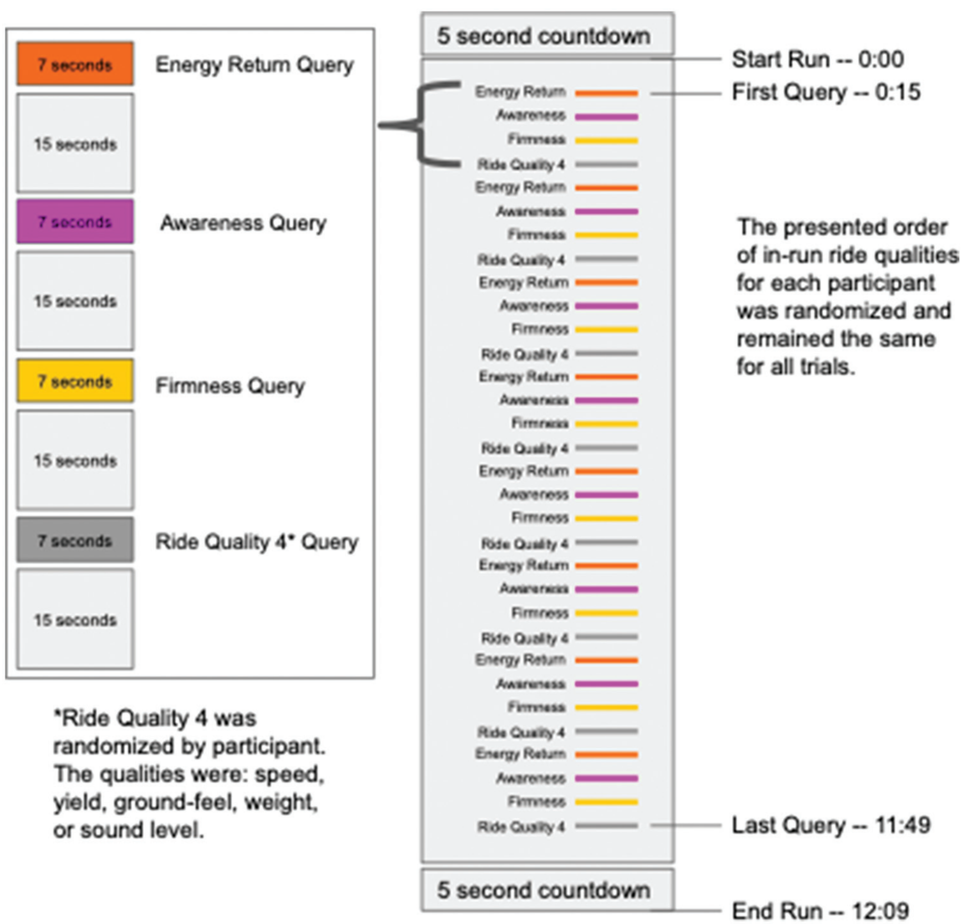

Figure 2. Schematic of ride quality queries.

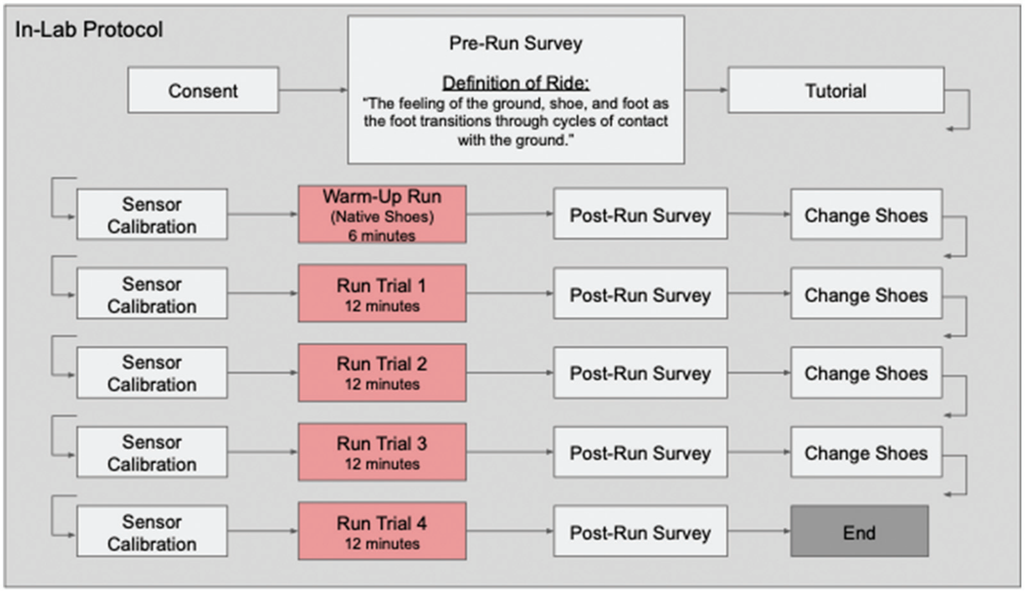

Figure 3. Schematic of study experimental protocol.

ride qualities and then used individual differences multidimensional scaling to examine these five distance matrices. INDSCAL differs from other dimension reduction procedures such as principal component analysis (PCA) in that multiple proximity matrices are analysed simultaneously (e.g. five 8×8 proximity matrices) to model a common dimensional reduction, which are analogous to eigenvectors in PCA, and provides weights on those dimensions to measure relevance of each dimension across the unit of analysis (e.g. shoes). The INDSCAL model estimates points in a t dimensional space and computes weighted distances between computed points i and j for unit l (in our application i and j refer to ride qualities) using the weighted Euclidean distance.

$$d_{lij} = \left(\sum_{k=1}^{t} w_{lk} (x_{ik} - x_{jk})^2 \right)^{1/2} \tag{1}$$

The computed distances are compared to the observed distance matrices using an optimisation approach to estimate the configuration matrix x and the weight matrix w that minimise the loss function (a normalised least squares metric called stress) between the observed and computed distance matrices. The configuration matrix x provides a common spatial representation that can be interpreted geometrically and the weight matrix w provides additional interpretation of how spatial dimensions are stretched or constricted by each individual unit l (see Borg and Groenen, 2005, for details). If all the weights are 1, then this model reduces to a standard Euclidean model but the estimated weights permit interpretation of the degree to which that particular dimension contributes to the distance computation (i.e. whether the weight is less or greater than 1).

The R package 'smacof' was used to perform the individual difference multidimensional scaling (de Leeuw & Mair, 2009). We used the nonmetric form of INDSCAL given that the ride ratings were ordinal five-point ratings; thus, our findings are unique up to monotonic transformation of the rating scale and is more general than PCA where results are unique up to a linear transformation. We conducted a nonmetric INDSCAL on the eight ride ratings across the five shoes to assess how the estimated dimensions are differentially weighted in the evaluations of the five shoes (i.e. for this analysis the units l are the five shoes). Similarly, we conducted a second nonmetric INDSCAL on the eight ideal ride qualities for the four running purposes to assess how the estimated dimensions are differentially weighted across running purposes (i.e. for this analysis the units l are the four running purposes). Stress was used as a measure of goodness of fit (the objective function to minimise) and we estimated nonparametric bootstrapped confidence intervals (500 bootstrap samples) around the estimated stress value (Weinberg, Carroll, &

Table 3. Mean and *SD* ride qualities across experimental shoes.

	Adios		Alphabounce		Supernova		Ultraboost		Native		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	*F*
Speed	4.3	1	2.9	1	2.9	1	3.4	1.1	3.3	0.8	11.7 (4180)
Yield	3.1	1.4	2.9	1.2	2.6	1.1	4.2	1	3.5	1.2	11.9 (4144)
Ground feel	2.1	1	2.9	1.2	2.6	1.1	1.6	0.8	1.6	0.8	11.8 (4144)
Energy return	2.8	1.5	2.8	1.1	2.8	1.2	2.6	1.3	2.4	1	0.8 (4180)
Awareness	3.2	1.6	2.3	1.2	2.7	1.3	3.4	1.3	3.9	1.1	9.1 (4180)
Firmness	3.7	1.4	3	1.3	3.3	1.1	1.8	1.1	2.7	1.1	12.2 (4180)
Weight	1.4	0.8	3	1	3.3	1.1	1.9	1	2.2	1.1	20.6 (4144)
Sound level	2.2	1.2	2.6	1.1	3.2	1.1	1.9	1.1	2.5	1	7.0 (4144)

A Satterthwaite correction was applied to the denominator degrees of freedom for all eight tests.

Cohen, 1984); a screeplot was used to decide on the number of dimensions t and we examined $t = 2$ to $t = 6$.

Commonly used linear models also were employed. A general linear mixed model was performed to test differences in the post-run ride quality ratings across shoes and assess the consistency of ride quality at timepoints within the running trial. Omnibus tests of significance for shoe and running purpose were based on the Satterthwaite correction and pairwise tests used the Tukey test.

Results

Using a general linear mixed model, we found that ride qualities collected post run were significantly different across the five shoes for seven of the eight dimensions, all $p < .0001$ except for the ride quality energy return with $p = .52$ (Table 3). Tukey post-hoc tests (family-wise error rate corrected to .05) revealed several significant differences across the five shoes. For example, the Adios (the lightest shoe with the lowest heel and forefoot height) differed from the other four shoes on the ride quality of speed (all four Tukey *p*-values were less than .05 with no other significant comparisons) and the Supernova (the heaviest shoe with highest heel height and most heel-to-toe drop) differed from the Adios, Ultraboost and native shoe on the ride quality of sound level (no other significant comparisons). The key finding from these ratings is that the shoes used in this study elicited different mean profiles across seven of the ride qualities suggesting that multiple ride qualities are needed to understand the ride perceptions that runners have about shoes.

We selected a two-dimensional solution ($t = 2$ in Equation 1; Figure 4) based on the screeplot of the stress values. There were no appreciable drop off in

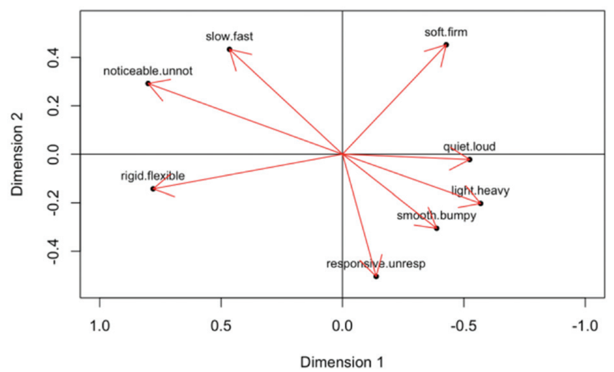

Figure 4. Plot of dimensions derived from a nonmetric individual differences multidimensional scaling analysis of ride qualities. Dimensions are defined to be orthogonal to each other. Ride qualities that appear more vertical or horizontal more closely identified with the vertical and horizontal dimensions, respectively. We interpret these two dimensions as yield (rigid—flexible) and energy return (responsive—unresponsive).

stress when moving to three or four dimensions. The final solution had stress = .10 (95% bootstrapped CI .083 –.126) and a residual sum of squares = 1.54. We interpret these two dimensions as yield (rigid – flexible) and energy return (responsive – unresponsive) given the orientation of the vectors representing each of the eight ride characteristics. However, it is worth noting that sound level (quiet – loud) could be used in place of yield to interpret dimension one. Further insight emerges from the weights associated for each shoe. The Supernova and the native shoe exhibited approximately equal weights for these two dimensions (Supernova weights 1 and 1.08 for D1 and D2; native shoe weights 1.03 and 1.02 for w as defined in Equation 1), while the Adios (weights .91 and 1.28) and Alphabounce (weights .90 and 1.29) primarily weighted the energy return dimension and the Ultraboost primarily weighted the yield dimension (weights 1.13 and .67). There is no known test of significance for the weights though

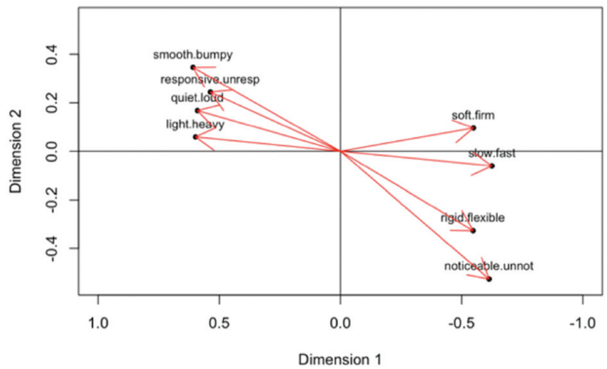

Figure 5. Plot of dimensions derived from multidimensional scaling analysis of ride qualities related to intended use (long run, recovery run, tempo or speed work). Dimensions are defined to be orthogonal to each other. Ride qualities that appear more vertical or horizontal are used to interpret the dimension. Speed (slow—fast) and sound (loud—quiet) are the ride qualities for Dimension 1, which reflect quality used to select shoe preference where intended run in tempo and/or speed work.

in some special cases they can be modelled statistically if one has a theoretical model with predictors (Clarkson & Gonzalez, 2001).

INDSCAL was also used to find patterns in eight ride quality ratings across the four intended running purposes. We selected the two-dimensional solution based on the screeplot (stress = 0.07, bootstrapped CI .037 – .111 and residual sum of squares = .57) and shown in Figure 5. The first dimension, representing the horizontal axis, is interpreted as the ride qualities of sound level and weight. The second dimension, representing the vertical axis, did not have a clear interpretation so while we retain it in the solution we do not attempt to interpret it. Dimension 1 (sound level and weight) was weighted more heavily for speed training (1.13 and 0.13 for D1 and D2, respectively) and tempo (weights 1.3 and 0.18) runs (Figure 5). Though uninterpretable, Dimension 2 was the primary dimension for long (weighs .46 and 2.18) and recovery (weights .51 and 2.12) runs (i.e. the weights on dimension 2 were greater than 2 and the weights on dimension 1 were less than 1).

The mean ride ratings collected during the running session showed consistency over time. Figure 6 shows the means at each of the nine times; none of the tests over time were statistically significant ($p > .16$) using a linear mixed model.

Discussion

The current study examined the extent to which ride qualities follow a multidimensional structure and whether perceived ride qualities changed over the course of a run or differed by running purpose. Individual difference multidimensional scaling was used to reduce dimensionality and visualise ride ratings for several shoes including runners' native shoes. To our knowledge, this is the first study that parsed footwear perception into multidimensional qualities and queried each independently. Both our methodological (multiple ride quality queries in real-time) and data-analytic approach (multidimensional scaling models) are novel in the field of footwear science and led to a deeper and more granular appreciation for what represents ride perception for each runner.

Ride perception is multidimensional

Given the ratings scales we used, runners appear to perceive footwear along two dimensions of ride perception. The first dimension is *yield*, or the feeling of flexibility of the shoe when running, while the second dimension is *energy return*, or the responsiveness of the shoe. This finding may explain why previous work attempting to connect the perceived smoothness of a ride to footwear selection was not consistent (Lam, et al., 2018). Further, the adage '*the smoother the better*' (Lam, et al., 2018) appears to hold as nearly all runners preferred a smooth ride when asked to rate ideal ride qualities. Thus, focussing on smoothness may not be helpful in predicting individual preference or making meaningful modifications to shoe design. The next step for this work is to identify biomechanical and shoe properties that influence the perception of yield and/or energy return rather than the feeling of smoothness during contact phase cycles.

Ride perception is generally consistent over short durations

Ride qualities did not significantly change over the course of a 12-min run. Practically, this suggests that, in general, a runner's experience of the ride of a shoe post run is a fairly accurate representation of their experience during the run. Ratings acquired

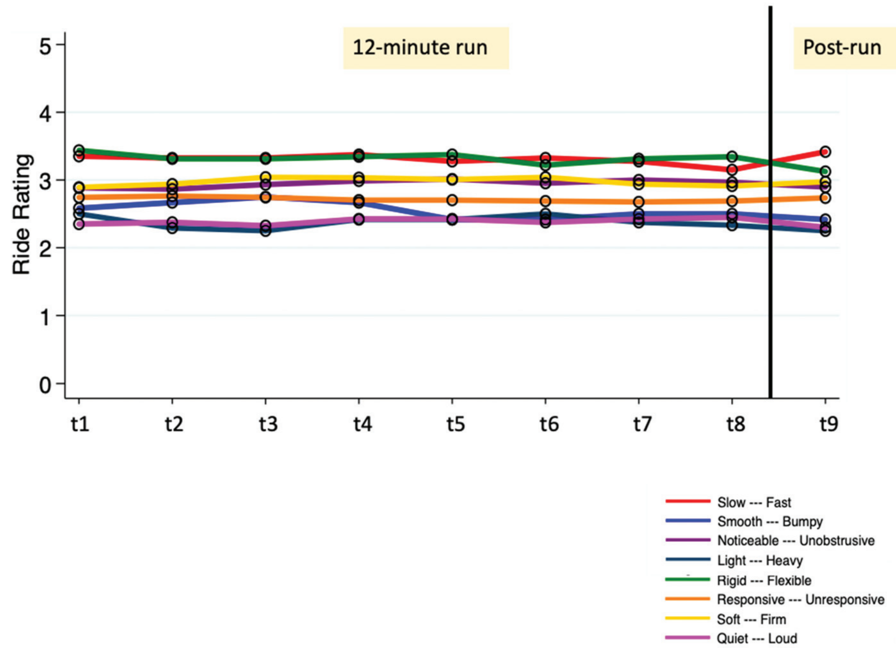

Figure 6. Average ride ratings across participants for each query point. Participants received queries for four ride qualities during the in-run portion of the protocol. Three of the four qualities were consistent across participants, which were energy return, awareness, and firmness. The fourth quality was randomly selected from the remaining five ride qualities, which were speed, yield, ground feel, weight, and sound level. Each participant rated all eight ride qualities on the post-run survey. The time points t1 through t8 indicate query responses during the run while t9 indicates query response on the post-run survey.

post-run were similar to averages reported during the run. It is important to note that running speed was held constant throughout the run and across trials. Importantly, we did not obtain ratings of perceived exertion scores or monitor heart rate. We suspect that runners were not substantially fatigued as per the selection criteria they were not running longer than typical for them. However, additional work is needed to determine the influence fatigue has on footwear perception or preference. Likewise, we did not assess mental fatigue. That is, the trials required significant mental activity in the form of responding to rating scales that is typically not present during running. This may have caused some runners to choose the same ride rating as trials progressed to decrease cognitive load. Future studies that utilise similar query rates and lengthy running trials may want to include a measure of cognitive load. For this study, interpretation of runners' fatigue on ride perception cannot be given.

Ride perception is influenced by running shoe purpose

The intended purpose of the run influenced which ride qualities were more heavily weighted when ranking footwear preference. For speed training and tempo runs, the feeling of weight and speed were associated with the primary dimension. This corresponds to the literature investigating actual shoe weight (in grams) to running performance (Hoogkamer, Kipp, Spiering, & Kram, 2016) and energetics (Franz, Wierzbinski, & Kram, 2012). Of the eight qualities developed, none were adequate in capturing the dimensional attribute used to select footwear for long distance runs or recovery (easy) runs. This finding represents a critical gap that must be filled by future research given that most typical types of runs performed by recreational runners are long and easy runs.

Perceived footwear ride may discriminate better than comfort

Ride may be a more discriminating construct than comfort to recommend different subjective experiences. Ride may be used to direct runners to shoes that elicit different feelings. For instance, the same runner may want a shoe for speed training that is fast and light but a shoe for recovery runs that is unobtrusive and quiet. However, the runner will most likely want both shoes (speed training and recovery shoe) to be comfortable. The present study suggests that yield and energy return, in particular, warrant further study for predicting footwear assessment within the context of ride purpose. This multidimensional approach could provide a better metric by which to customise shoe design or to re-examine the qualities that drive comfort in order to create user experiences.

Practical application

A contribution of this work is the use of analytic models (i.e. individual differences multidimensional scaling) not commonly employed in perceptual or biomechanical research. With multidimensional scaling, we were able to elucidate key dimensions of footwear perception. Multidimensional scaling provides a graphical representation of the similarity between variables in a reduced dimensional space (Borg and Groenen, 2005). Multidimensional scaling found that two dimensions were sufficient to approximate the association across the eight ride qualities. Nonmetric individual difference scaling produces dimensions that are orthogonal to each other, much like eigenvectors in PCA. However, PCA does not account for variability across shoe and running purpose within the same model (i.e. different PCAs would have to be conducted for each shoe and running purpose making comparisons across PCA solutions difficult). Likewise, similarity modelling can help to *visualise* the differences in qualities and how dimensions varied by shoe and running purpose in a way that examining group means linear models or ANOVAs cannot provide. This analysis complements and adds value to traditional analysis methods for the study of human behaviour, perception, ratings and movement.

Limitations

There are several limitations to this study. Firstly, we did not directly ask runners about the comfort of the shoe. Therefore, inferences regarding how comfort relates to ride qualities or previous work on footwear comfort could not be performed. Secondly, runners in this study were all recreational athletes with a wide range of experience (8.4 ± 6.4 years) and most were rearfoot strikers. It may be that elite runners or runners with greater experience have keener or particular perceptions about footwear or that a specific foot strike pattern significantly influences the experience of ride. Therefore, findings cannot be generalised to all types of runners. Thirdly, three of the four experimental shoes used similar midsole material, which could have contributed to the lower variation of energy return ratings across shoes. Additional shoes with varying materials should be tested to determine their influence on energy return perception. We note that energy return did not emerge as a significant predictor in the linear mixed model analyses that compare means across shoes (a between-shoe comparison) but did emerge as one of the key dimensions in the INDSCAL analysis, which examines association across the eight ratings within a shoe. Likewise, we did not standardise sock-type across all runners. It is possible that variations in sock thickness may have influenced ride perception. Finally, the sample size was too small to make confident inferences about the association between specific shoe properties and ride qualities or about differences across subject groups. We did find trends between shoe properties, specifically rearfoot thickness and shoe weight, and ride perception. We also conducted a posthoc analysis of the INDSCAL model separately for men and women; we did not observe gender differences for either the INDSCAL on shoes nor the INDSCAL on running purpose (congruity coefficients from the Procrustes approach to compare two spatial solutions were .956 and .962 respectively; see Borg & Groenen, 2005). However, additional work with larger sample sizes and a large portfolio of shoes must be done to extend this modelling strategy in a form that can assess heterogeneity over different runner segments and help inform shoe design directly.

Conclusion

In general, recreational runners favoured the perceptions of yield and energy return during running over the other ride qualities when selecting a shoe. When selecting footwear for a specific purpose, such as speed training or tempo runs, the perception of speed and weight heavily influenced footwear preference. Querying perceptual qualities at the end of run can provide useful and similar information as querying during the course of a brief run. Findings from this work can be used to in later studies to identify biomechanical variables that correspond to the subjective experience of ride. More work is needed to understand what qualities of footwear perception are critical when selecting shoes for distance or recovery runs.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was supported by adidas AG [AWD000151].

References

Borg, I., & Groenen, P. (2005). *Modern multidimensional scaling: Theory and applications* (2nd ed.) . New York: Springer.

Clarkson, D., & Gonzalez, R. (2001). Random effects diagonal metric multidimensional scaling models. *Psychometrika*, *66*(1), 25–43. doi:10.1007/BF02295730

de Leeuw, J., & Mair, P. (2009). Multidimensional scaling using majorization: SMACOF in R. *Journal of Statistics*, *31*(3), 1–30.

Dinato, R. C., Ribeiro, A. P., Butugan, M. K., Pereira, I. L. R., Onodera, A. N., & Sacco, I. C. N. (2015). Biomechanical variables and perception of comfort in running shoes with different cushioning technologies. *Journal of Science and Medicine in Sport*, *18*(1), 93–97. doi:10.1016/j.jsams.2013.12.003

Franz, J. R., Wierzbinski, C. M., & Kram, R. (2012). Metabolic cost of running barefoot versus shod: Is lighter better? *Medicine & Science in Sports & Exercise*, *44*(8), 1519–1525. doi:10.1249/MSS.0b013e3182514a88

Hintzy, F., Cavagna, J., & Horvais, N. (2015). Evolution of perceived footwear comfort over a prolonged running session. *The Foot*, *25*(4), 220–223. doi:10.1016/j.foot.2015.08.003

Hoogkamer, W., Kipp, S., Spiering, B. A., & Kram, R. (2016). Altered running economy directly translates to altered distance-running performance. *Medicine & Science in Sports & Exercise*, *48*(11), 2175–2180. doi:10.1249/MSS.0000000000001012

Kong, P. W., & Bagdon, M. (2010). Shoe preference based on subjective comfort for walking and running. *Journal of the American Podiatric Medical Association*, *100*(6), 456–462. doi:10.7547/1000456

Lam, C. K.-Y., Mohr, M., Nigg, S., & Nigg, B. (2018). Definition and quantification of 'ride' during running. *Footwear Science*, *10*(2), 1–6. doi:10.1080/19424280.2018.1453872

Meyer, C., Mohr, M., Falbriard, M., Nigg, S. R., & Nigg, B. M. (2018). Influence of footwear comfort on the variability of running kinematics. *Footwear Science*, *10*(1), 29–38. doi:10.1080/19424280.2017.1388296

Nunns, M. P., Dixon, S. J., Clarke, J., & Carre, M. (2016). Boot-insole effects on comfort and plantar loading at the heel and fifth metatarsal during running and turning in soccer. *Journal of Sports Sciences*, *34*(8), 730–737. doi:10.1080/02640414.2015.1069378

Slade, S. J., Greenya, J. G., Kliethermes, C. L., & Senchina, D. S. (2014). Somatosensory perception of running shoe mass. *Ergonomics*, *57*(6), 912–920. doi:10.1080/00140139.2014.904009

Sterzing, T., Schweiger, V., Ding, R., Cheung, J. T.-M., & 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. doi:10.1080/19424280.2012.757810

Wegener, C., Burns, J., & Penkala, S. (2008). Effect of neutral-cushioned running shoes on plantar pressure loading and comfort in athletes with cavus feet: A crossover randomized controlled trial. *The American Journal of Sports Medicine*, *36*(11), 2139–2146. doi:10.1177/0363546508318191

Weinberg, S., Carroll, J., & Cohen, H. J. (1984). Confidence regions for INDSCAL using the jackknife and bootstrap techniques. *Pyschometrika*, *49*(4), 475–491. doi:10.1007/BF02302586