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Original Research

Somatosensory Perception of Running Shoe Mass may be influenced by Extended Wearing Time or Inclusion of a Personal Reference Shoe, Depending on Testing Method

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ABSTRACT

International Journal of Exercise Science 13(6): 342-357, 2020. Consumers may purchase running shoes on the basis of their masses, yet little is known about shoe mass perceptual abilities. In this multi-part experiment, four groups of twenty-five young adult males (total n = 100) were challenged to gauge the relative masses of five unfamiliar running shoes. The four groups differed by the length of time they were given to wear the shoes (up to 1 minute versus 5 minutes) and whether or not they were able to use their own personal running shoes as a reference. After wearing each individual pair of shoes, participants provided perceived comfort and heaviness rankings using visual analogue scales (VAS). After wearing all five pairs of unfamiliar shoes, participants gave a verbal ranking of relative shoe mass. Participants also hefted the shoes with their hands and positioned them in order of relative mass. Extended wearing time improved overall verbal ranking accuracy, but did not improve mass perception accuracy as determined by comparing VAS heaviness rankings to actual shoe masses. Conversely, use of a personal reference shoe improved mass perception accuracy as determined by comparing VAS heaviness rankings to actual shoe masses, but did not improve overall verbal ranking accuracy. Hand perceptual scores were similar across the four groups, likely due to a ceiling effect. VAS comfort scores were unrelated to shoe masses. The results suggest that wearing time and reference shoes may influence mass perception by the lower limb in a context-specific manner.

KEY WORDS: Athletic shoe; handling time; mass perception; wearing time

INTRODUCTION

There are many different factors that influence a consumer's decision to buy a certain running shoe, including comfort, fit, design, brand, color, or style (5,7,10,16,46). One factor important to many runners is shoe mass. This is due to the public's perception that a lighter shoe will increase running efficiency, although recent research has given mixed results (4,9,13,17–19,24). When shopping for a pair of running shoes, consumers use many different methods to test the shoes, including comparing the weights in their hands, trying them on, and ambulating in them for a short period. The actual mass of the shoes is not labeled on most boxes, so without prior research or directly weighing the shoes in-store, consumers have to rely on their somatosensory perception of shoe masses instead.

How the foot and/or lower limb may perceive running shoe mass, and whether or not it can discriminate between masses of common running shoe models, is poorly understood. Early research concerning lower limb mass perception used attached weights or studied amputee populations (14,21,22). More recent research in which participants wore running shoes and were asked to evaluate their relative masses demonstrated that the foot is poor at perceiving mass across a range of common running shoe masses (~220-360 g) (45), that practice may not improve mass perception accuracy (20), that there is no difference in mass perception accuracy between males and females (23), and that the hands are far more accurate at perceiving shoe mass and can perceive small differences in mass (20,23,45), even when given shoes outside the normal mass ranges that participants would normally encounter (23). One study using basketball shoes also showed poor foot perception of shoe mass across common basketball shoe masses (~350-640 g) (34). Interestingly, in that investigation, participants performed better in lower-mass shoes versus higher-mass shoes when they were aware of the masses, but exhibited no differences in performance when unaware of the masses. Mechanoreceptors in the foot have a much higher threshold of activation than mechanoreceptors in the hand largely due to skin thickness (6,15,25), which may partially explain perceptual disparities between the foot and hand. More studies have been performed concerning consumers' perception of shoe comfort (12,26,30–32,36,37,39), and it has been suggested that comfort perception may be related to perceptions of other footwear characteristics (37) such as mass perception (45). Given the importance of a consumer's perception of footwear in making purchasing decisions (10,42,43) and the impact those decisions can make on both subsequent athletic performance and safety (7,34,41,44), it is important to better understand how the foot/lower limb perceives athletic footwear mass.

The goal of the present investigation was to determine if two factors—extended wearing time and inclusion of a personal reference shoe—would influence shoe mass perception accuracy. A previous study (45) served as a baseline for comparison. In that study, twenty-five participants were given up to sixty seconds to wear and then evaluate the relative masses of five unfamiliar running shoes without using their own personal shoes as a reference.

METHODS

In this current study, three additional experiments using a method similar to a previous study (45) were performed: one kept the time allotment the same and included a reference shoe, one extended the testing time but did not include a reference shoe, and one extended the testing time and included a reference shoe. Results from the three new experiments were then compared back to the baseline experiment (45) mentioned in the introduction. It was hypothesized that both factors (extended wearing time and use of personal reference shoes) would improve shoe mass perception accuracy, whether they were employed together or separately.

Participants
The Drake University Institutional Review Board approved the research (IRB ID 2010-11042). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (38). This investigation included original data collection (from a sample of 75 participants) and a larger final analysis which utilized that data plus previously reported data from a subpopulation of 25 more participants (45); thus the final analysis included 100 participants. For the original data collection, a convenience sample of 75 adult males who could safely exercise in a men's size 12 running shoe and had no biomechanical abnormalities participated across three separate experiments in this study. All provided written informed consent prior to data collection. Anthropometric characteristics of the study populations are provided in Table 1. Each group in Table 1 represents a separate experiment, as will be seen in subsequent figures. The X-axis denotes the use of a reference shoe or not and the Y-axis denotes the length of time allowed for testing. Data presented in all figures will be spatially organized in the same order as this table.

Table 1. Anthropometric data of the study populations and overall layout of the study.

	No Reference Shoe	Reference Shoe
Up to 1 min for Testing	Group 1N Age: 21.4 ± 3.53 Height: 180.2 ± 3.20 Weight: 71.3 ± 8.11 Body Fat %: 12.9 ± 3.11	Group 1R Age: 19.5 ± 1.58 Height: 180.1 ± 5.85 Weight: 81.0 ± 9.43 Body Fat %: 12.3 ± 4.21
Fixed 5 min for Testing	Group 5N Age: 19.2 ± 0.75 Height: 178.4 ± 7.33 Weight: 77.3 ± 8.24 Body Fat %: 11.9 ± 3.76	Group 5R Age: 21.0 ± 4.89 Height: 180.7 ± 6.80 Weight: 74.5 ± 10.41 Body Fat %: 11.9 ± 3.74

Note: Values reported are averages ± standard deviations using the following units: age in years, height in centimeters, weight in kilograms, and body fat in percentage as determined by foot-to-hand bioelectrical impedance analysis (BIA).

Based on one-way ANOVA, there were no statistical differences in any anthropometric characteristic across the four subpopulations. Each of the separate experiments thus had an n = 25, which was chosen to achieve a perfectly counterbalanced Latin square design within each experiment. A power analysis of results obtained in prior variations of this protocol (20,23,45) indicated that 25 participants per cell are sufficient to detect group-wise differences as large as those reported between these variations with a power of 0.8.

Protocol
Table 1 also serves as an illustration of the overall experimental concept. The two variables were the use of a personal reference shoe (versus no reference shoe), and the length of time spent testing each shoe (up to 1 minute versus 5 minutes). The baseline study, where participants were allowed up to one minute to wear the shoes without the use of a personal reference shoe (45), is designated as Group 1N. The three new experiments are represented by the three other cells: Group 1R included participants that were allowed up to sixty seconds to wear the shoes with inclusion of a personal reference shoe, Group 5N included participants that were given five

minutes to wear the shoes without inclusion of a personal reference shoe, and Group 5R included participants that were given five minutes to wear the shoes with inclusion of a personal reference shoe. Thus, testing in Groups 1N and 1R was up to one minute whereas testing in Groups 5N and 5R was a fixed five minutes, and Groups 1R and 5R included a reference shoe whereas Groups 1N and 5N did not.

Due to the retrospective nature of the new experiments relative to Group 1N, the study design is not a true 2×2 factorial design because combinatorial equivalence was not achieved given how the testing time was handled. In Group 1N originally (and subsequently Group 1R), participants had up to one minute to test each shoe. Participants could test the shoes in any way they wished (running on a treadmill, standing in place, jumping, etc.) and they could spend all sixty seconds or stop earlier. This is because, in the Group 1N study, the goal was to emulate conditions consumers might experience in a retail setting and there was no intent to explore different testing variables. In Groups 5N and 5R, participants were required to wear the shoes for the full five minutes and to run on a treadmill the entire time.

The unfamiliar shoe models used in all four groups were men's size 12 shoes from the Nike Lunar series (Nike Inc., Beaverton, OR), though participants were blind to the shoe type. Shoes were unmodified for testing. The masses of the unfamiliar shoe models were (in g): Shoe A = 220, Shoe B = 273, Shoe C = 294, Shoe D = 331 and Shoe E = 362. In Groups 1N and 5N, the unfamiliar shoes were the only shoes tested, so participants wore a total of five shoes. In Groups 1R and 5R, the participants' self-selected running shoes were used as a reference shoe, so those participants wore a total of six shoes and the personal reference shoes were always the first shoes worn.

Several proactive steps were undertaken to prevent participants from perceiving indirect information about the unfamiliar shoes. When testing mass perception by the feet, participants never handled the shoes—the experimenters placed the shoes on their feet, and then participants were allowed only to tighten the laces. Likewise, experimenters always removed the shoes from their feet after wearing. This avoided the participants receiving any perceptual information about shoe mass from their hands that could confound the perceptions from wearing the shoes. To minimize possible tactile cue differences based on participants wearing different socks, participants were provided with brand new lower-cut athletic socks to wear whenever they were wearing the unfamiliar running shoes. All participants within a group wore identical pairs of the new socks. However, across the four groups, socks differed in terms of manufacturer and composition based on local availability at the time each group was being tested. For Group 1N, socks were 80% cotton and 20% synthetic fibers. For Groups 1R, 5N, and 5R, socks were 0-6% cotton and 94-100% synthetic fibers. Visual cues also had the potential to influence participants' perceptions (1). For Groups 1N and 1R, participants wore a pair of laboratory goggles taped so they could see in every direction except downwards during the entire testing period. Groups 5N and 5R did not wear the goggles due to perspiration during running and the potential for goggles fogging up, so those participants were directed to avoid looking at the shoes and were observed for compliance.

For the foot portion, the first pair of shoes (the participants' personal reference shoes in Groups 1R and 5R, or the first of five pairs of unfamiliar running shoes in Groups 1N and 5N) was placed on the participants' feet by the experimenter and the participant was handed the laces and allowed to blindly tighten and tie the shoes. Participants then had either up to sixty seconds (Groups 1N and 1R) or a fixed five minutes (Groups 5N and 5R) to wear the shoes in the manner previously described. For the Group 5N and 5R participants, a Sole TT8 treadmill was used for running. The treadmill speed was initially set to 8 mph at the start of each trial, but participants could subsequently modulate the speed and run at whatever pace they chose, although they were not allowed to see the treadmill speed at any time. Group 1N and 1R participants who opted to run used the same treadmills.

The hand portion was performed only in Groups 1N and 1R (due to concerns about attentional fatigue given the longer length of time it took to complete their respective foot portion in Groups 5N and 5R). Participants in Groups 1N and 1R stood in their socks only before a lowered sash that hid the right shoe of all five pairs together. They placed their hands under the sash where they could blindly heft and compare the masses of the shoes; participants worked with all the shoes at once and had as much time as they wished to heft and then position the shoes. They were asked to physically position the shoes left to right from lightest to heaviest.

Different measures were used across the foot and hand portions, and across various groups.

Three different types of foot mass perception scores were collected during the foot portion, each of which is described in more detail below: visual analogue scale (VAS) scores relating to the perceived heaviness and comfort of single pairs of running shoes immediately after wearing each pair; relative perceived mass scores related to the entire collection of shoes after wearing all of them; and, for Groups 1R and 5R only, an additional acute mass perception score from asking participants if a given pair of unfamiliar shoes was lighter or heavier than their own personal running shoes immediately after wearing each unfamiliar running shoe pair. Thus, the VAS and acute mass perception scores were collected after testing each individual pair of shoes, whilst the relative perceived mass scores were collected after wearing all shoes used in the experiment.

The VAS were administered after testing each individual pair of shoes as participants sat on the plinth (Groups 1N and 1R) or straddled the treadmill belt (Groups 5N and 5R). Separate VAS scales were used for perceived heaviness and perceived comfort, though each was 10-cm long (28,32). Participants drew a vertical line in relation to a continuum from least amount possible to most amount possible (as one example, the heaviness continuum had an anchor phrase of "least heavy imaginable" on the left and an anchor phrase of "most heavy imaginable" on the right).

In Groups 1R and 5R only, at the same time the VAS were administered, participants were also asked verbally if the unfamiliar shoes were heavier or lighter than their personal shoes using a binary response of "heavier" or "lighter".

The relative perceived mass scores were collected after participants had worn all the shoes in the study. Participants were verbally asked to rank the shoes from lightest to heaviest; a representative participant response would sound like, "The third pair of shoes was the lightest, followed by the fifth pair, then the second…". Group 1R and 5R participants included their personal reference shoes in the rankings. For the purposes of analysis, the shoe they designated the lightest was given a value of "1", the next lightest a value of "2", and so forth.

For the hand mass perception (Groups 1N and 1R only), there was only one measurement. After participants had physically positioned the shoes, the sash was raised and the order of shoes observed. As with the overall verbal rankings, the lightest shoe was given a score of "1", the next lightest shoe a score of "2", and so forth.

Rating of perceive exertion (RPE) scores using the standard Borg scale were collected at minute four of each five-minute run in Groups 5N and 5R. A large-print scale was shown to the participants, who then verbally reported their numerical response. Running speed was also recorded at this time.

Statistical Analysis

Statistical treatment varied by data type and group. Given the nature of the experimental design, groups were always treated as discrete entities (i.e., even if statistical analyses showed no differences in a perceptual outcome between two or more groups, those groups were never pooled for subsequent analyses). Data regarding the participants' personal reference shoes used in Groups 1R and 5R were omitted from analysis because each participant's personal shoes had different masses and constructions; any attempt to compare verbal mass rankings, VAS heaviness scores, or so forth across participants' personal shoes or in relation to the test shoes would be meaningless due to that variation.

For the overall verbal rankings from both the foot portion and the hand portion, participants' numerical scores of shoe mass were compared to the actual order of shoe mass to generate squared residuals (R2) for each individual participant, which were then used in subsequent analyses as overall accuracy scores. One-way ANOVAs with Fisher's LSD post hoc tests were used to compare foot portion or hand portion accuracy between the four levels of the independent variable (1N, 5N, 1R, 5R). To compare differences in foot portion or hand portion accuracy scores for different shoes within each group, or VAS marks from the foot portion for different shoes within each group, repeated measures nested ANOVAs with Sidak post hoc tests were used. To check for correlations between any of these measures within each group, Pearson's rank-order correlations were used. Significance was defined as $p < 0.05$.

RESULTS

Masses of Participants' Personal Running Shoes: All participants brought their personal running shoes to the lab for weighing regardless of whether they used them in the perceptual tests (Groups 1R and 5R) or not (Groups 1N and 5N). Some of these shoes were marketed strictly as running shoes, whereas others were marketed as cross-trainers. Masses of personal reference shoes varied greatly among the participants but were not statistically different in any pairwise comparisons between groups (expressed as means ± standard deviation): 1N = 331.7 ± 52.3 g, 1R = 324.7 ± 75.8 g, 5N = 298.7 ± 39.1 g, 5R = 305.1 ± 50.8 g). Of the Group 1R and Group 5R participants, twenty (40%) wore the same brand of shoes as used in this study for running, but of those twenty, only two wore Nike Lunar running shoes and the models they wore were different from the unfamiliar shoes used in the study.

Foot Portion: Verbal Rankings: All participants verbally (numerically) ranked the shoes in order of relative mass after wearing all pairs. Verbal rank accuracy scores varied by group (expressed as means ± standard deviation): 1N = 35.0% ± 28.3%; 1R = 37.3% ± 26.0%; 5N = 60.0% ± 24.0%; 5R = 52.9% ± 30.0%). ANOVA revealed a main effect by group (p = 0.032), with post hoc tests indicating that Group 1N accuracy scores were significantly lower than both Groups 5N and 5R (p = 0.001 and 0.021, respectively), and also that Group 1R scores were significantly lower than Groups 5N and 5R (p = 0.004 and 0.045, respectively); however, there were no significant differences between Groups 1N and 1R, or between Groups 5N and 5R.

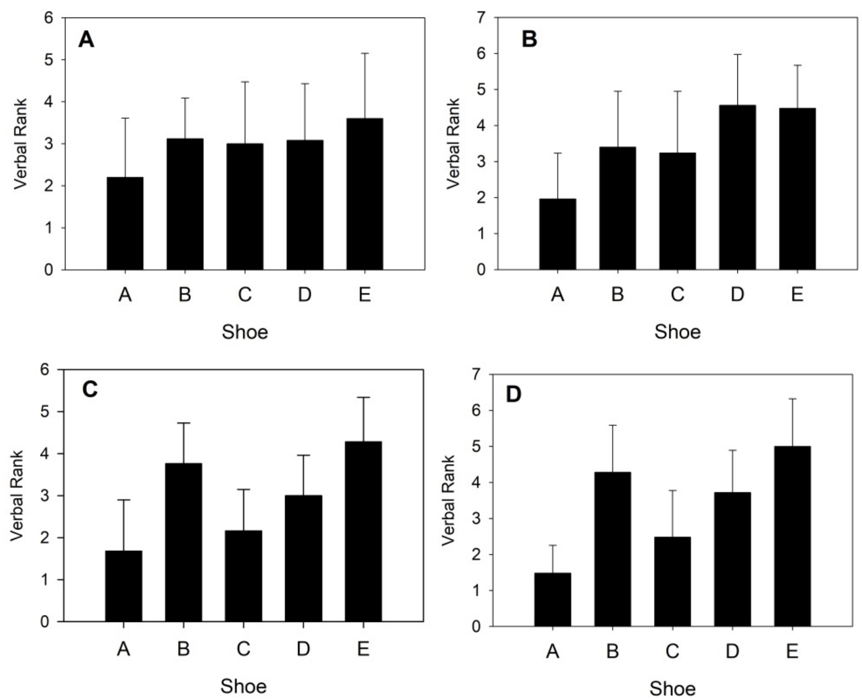

Figure 1. Verbal rankings of shoe mass from the foot portion of all four groups, expressed as mean rank ± standard deviation. Shoes are ordered lightest to heaviest from left to right in each graph. Panels represent the different groups: A = Group 1N, B = Group 1R, C = Group 5N, and D = Group 5R.

Figure 1 shows the participants' relative verbal ranks during the foot portion in relation to the actual relative masses of the shoes across all four participant groups, with shoes ordered lightest to heaviest from left to right in each graph. ANOVA revealed significant differences in verbal rankings for different shoes within each of the four groups (all $p \leq 0.03$), with post hoc tests indicating some significant pairwise comparisons in all groups except for Group 1N. For Group 1R, participants correctly perceived a significant difference in the mass of Shoe A versus Shoes C, D, and E (Table 2). For Group 5N, participants correctly perceived a significant difference in the mass of Shoe A versus Shoes C-E, Shoe B versus both Shoes C and E, and Shoe D versus

Shoe E (Table 2). For Group 5R, participants correctly perceived a significant difference in the mass of Shoe A versus all other shoes, Shoe B versus both Shoes C and E, and Shoe D versus Shoe E (Table 2).

Table 2. Pairwise comparisons for verbal rankings in the foot portion.

		Shoe A	Shoe B	Shoe C	Shoe D	Shoe E
Group 1R	Shoe A	—				
	Shoe B	NS	—			
	Shoe C	0.041*	NS	—		
	Shoe D	<0.001*	NS	NS	—	
	Shoe E	<0.001*	NS	NS	NS	—
Group 5N	Shoe A	—				
	Shoe B	NS	—			
	Shoe C	<0.001*	<0.001*	—		
	Shoe D	0.013*	<0.001*	NS	—	
	Shoe E	<0.001*	NS	NS	<0.001*	—
Group 5R	Shoe A	—				
	Shoe B	0.036*	—			
	Shoe C	<0.001*	0.003*	—		
	Shoe D	<0.001*	NS	NS	—	
	Shoe E	<0.001*	<0.001*	NS	0.006*	—

Note: Numbers represent p-values. Asterisks (*) indicate a significant difference and NS denotes non-significant differences. Group 1N is not included in the table because it had no significant pairwise comparisons.

Participants in Groups 1R and 5R also provided an additional, acute verbal score by indicating whether a given pair of unfamiliar shoes was heavier or lighter than their own shoes immediately after wearing each pair of unfamiliar shoes. Heavier/lighter accuracy scores, expressed as means ± standard deviation, were 70.0% ± 25.4% for Group 1R and 74.4% ± 22% for Group 5R. A student's t-test indicated no significant differences in accuracy of heavier/lighter scores between the two groups.

Foot Portion: VAS Ratings: All participants completed VAS for heaviness and comfort immediately after wearing each pair of unfamiliar running shoes (Figure 2).

Regarding heaviness, ANOVA revealed a main effect of shoe within all four groups (all $p \leq 0.01$). Sidak post hoc tests uncovered significant pairwise comparisons that differed by group. For Group 1N, participants correctly perceived a significant difference in the mass of Shoe A versus Shoe E ($p = 0.011$). For Group 1R, participants correctly perceived a significant difference in the mass of Shoe A versus Shoes C-E and in Shoe D versus Shoes B and C (Table 3). For Group 5N, participants correctly perceived a significant difference in the mass of Shoe B versus E ($p = 0.035$). Within Group 5R, participants correctly perceived a significant difference in the mass of Shoe A versus Shoes C-E, Shoe B versus Shoes C and E, and Shoe D versus Shoe E (Table 3).

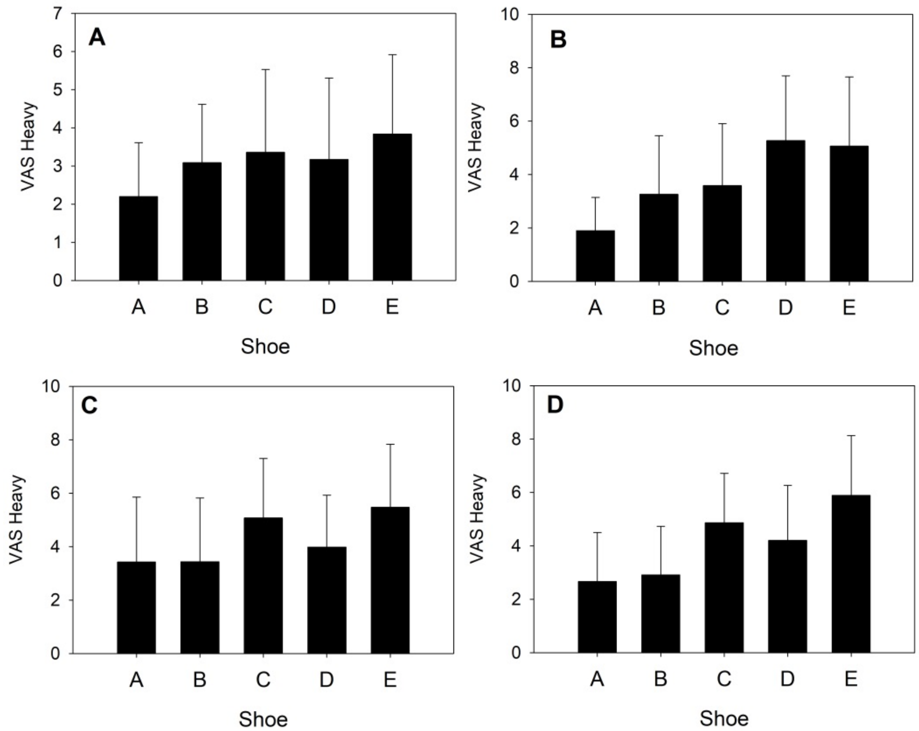

Figure 2. Visual analogue scale (VAS) marks for heaviness across the four experiments, expressed as mean distance in cm ± standard deviation. Shoes are ordered lightest to heaviest from left to right in each graph. Panels represent the different groups: A = Group 1N, B = Group 1R, C = Group 5N, and D = Group 5R.

Within each group, Pearson's rank-order correlations comparing VAS heaviness marks to actual shoe masses within each participant were calculated (expressed as r: 1N = 0.28; 1R = 0.53; 5N = 0.33; 5R = 0.57). Pearson's rank-order correlations comparing VAS heaviness marks to verbal rankings within each participant yielded more heterogeneous results across groups (1N = 0.63; 1R = 0.56; 5N = 0.62; 5R = 0.63).

Table 3. Pairwise comparisons for VAS marks in the foot portion.

	Group 1R					Group 5R				
	Shoe A	Shoe B	Shoe C	Shoe D	Shoe E	Shoe A	Shoe B	Shoe C	Shoe D	Shoe E
Shoe A	—					—				
Shoe B	NS	—				NS	—			
Shoe C	0.004*	NS	—			0.002*	0.007*	—		
Shoe D	<0.001*	0.015*	0.04*	—		0.013*	NS	NS	—	
Shoe E	<0.001*	NS	NS	NS	—	<0.001*	<0.001*	NS	<0.001*	—

Note: Numbers represent p-values. Asterisks (*) indicate a significant difference and NS denotes non-significant differences. Statistically significant pairwise comparisons for Groups 1N and 5N are provided in the main text.

Regarding comfort (Figure 3), ANOVA revealed a main effect of shoe within all four groups (all $p \leq 0.03$). Sidak post hoc tests uncovered significant pairwise comparisons that differed by group. Within Group 1N, participants perceived a significant difference in comfort between: Shoe A versus Shoes B, C, and E (all $p \leq 0.036$); and between Shoe D versus Shoes B and C (p = 0.028 and 0.001, respectively). Within Group 1R, participants perceived a significant difference in comfort between Shoe B versus Shoes A and D (both $p < 0.001$). Within Groups 5N and 5R, there were no statistically significant perceived differences.

Within each group, Pearson's rank-order correlations comparing VAS comfort marks to VAS heaviness marks within each participant revealed poor correlations (expressed as r: 1N = 0.07; 1R = -0.10; 5N = -0.07; 5R = -0.29).

Participants in Groups 1R and 5R also gave VAS ratings of comfort and heaviness for their personal running shoes. These scores were not included in the aforementioned comparisons because doing so would have rendered it impossible to compare across reference shoe and non-reference shoe groups. With regards to heaviness, participants in Groups 1R and 5R rated the heaviness of their personal shoes as 3.1 ± 1.8 (Group 1R) and 3.7 ± 2.0 (Group 5R). When compared to Figure 2, the Group 1R average heaviness rating would fall between the ratings for Shoe A and B, and the Group 5R average heaviness rating would fall between the ratings for Shoe B and D. With regards to comfort, participants in Groups 1R and 5R rated the comfort of their personal shoes as: 1R = 7.1 ± 1.7 and 5R = 6.4 ± 2.0. Both groups' average comfort ratings for their personal shoes were higher than their average comfort ratings for any of the unfamiliar shoes.

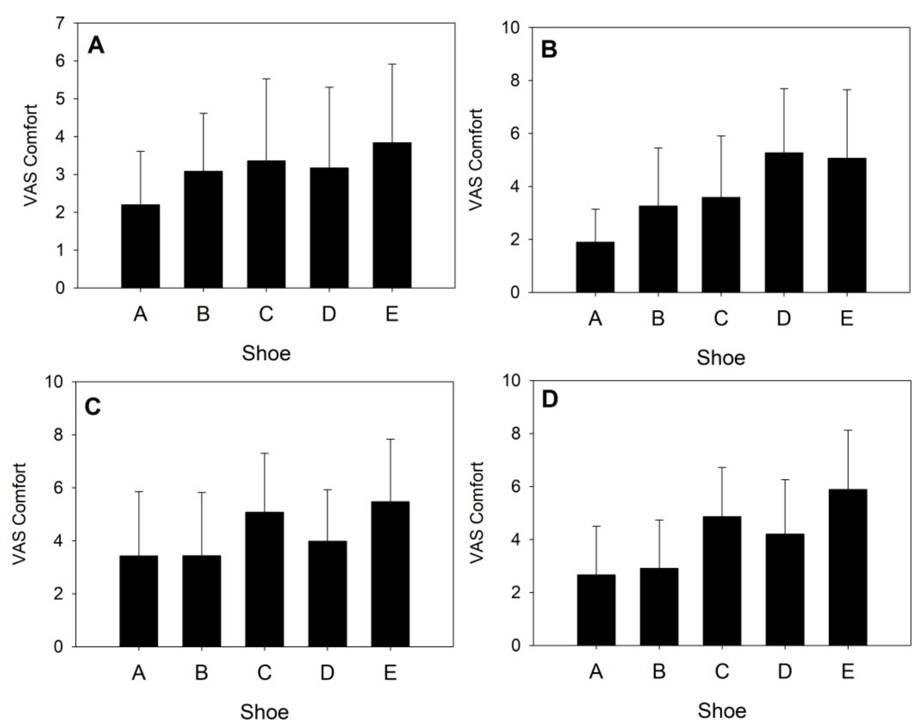

Figure 3. Visual analogue scale (VAS) marks for comfort across the four experiments, expressed as mean distance in cm ± standard deviation. Shoes are ordered lightest to heaviest from left to right in each graph. Panels represent the different groups: A = Group 1N, B = Group 1R, C = Group 5N, and D = Group 5R.

Hand Portion: Hand perception of shoe mass was tested only in Groups 1N and 1R (Figure 4). When asked to blindly physically position the shoes from lightest to heaviest, accuracy scores were similar for the two groups (expressed as means ± standard deviation: 1N = 91.9% ± 12.7%; 1R = 90.6% ± 8.6%). ANOVA found no significant difference between the two groups. The amount of time spent hefting the shoes differed significantly ($p = 0.01$) between the two groups (expressed as means ± standard deviations in seconds: 1N = 63.6 ± 26.2; 1R = 93.9 ± 50.1). A Pearson's correlation coefficient found no relationship between hand assessment accuracy and time spent ($p = 0.305$; r = 0.14).

ANOVA revealed significant differences in hand rankings for different shoes within each group (both $p \leq 0.001$). Sidak post hoc tests indicated that all pairwise comparisons were significantly different in both groups (all $p \leq 0.008$).

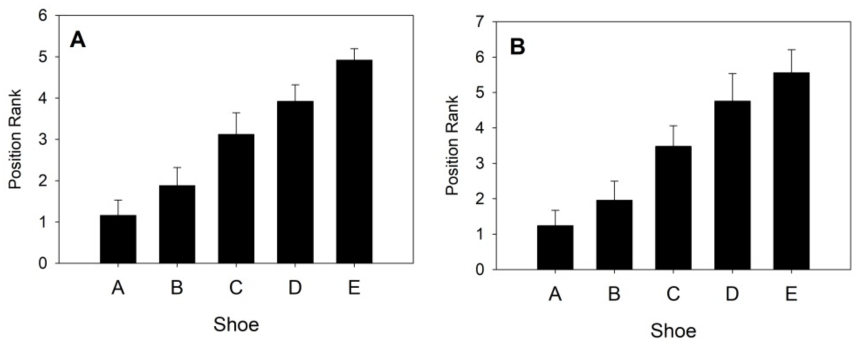

Figure 4. Ranking of shoe mass from the hand portion of the experiment, expressed as mean rank ± standard deviation. Hand testing was done only with Group 1N (panel A) and Group 1R (panel B). Shoes are ordered lightest to heaviest from left to right in each graph.

DISCUSSION

The first hypothesis was that extended wearing time (5 min vs. 1 min.; 5N and 5R vs. 1N and 1R) would improve mass perception accuracy by the foot. The data were mixed in their support of the first hypothesis. When asked to verbally rank-order the shoes after wearing all pairs, participants in Groups 5N and 5R were significantly more accurate than participants in Groups 1N and 1R (see Results text, "Foot Portion: Verbal Ratings" subsection, first paragraph). The number of significant pairwise comparisons was also greater in Groups 5N and 5R as compared to Groups 1N and 1R (Figure 1, Table 2). Those two outcomes suggest the extended wearing time improved mass perception accuracy by the foot. However, when participants in Groups 1R and 5R were asked to make dichotomous heavier/lighter comparisons between each pair of unfamiliar shoes and their personal reference shoes immediately after wearing each pair of unfamiliar shoes, there was no significant difference in overall accuracy between the two groups (see Results text, "Foot Portion: Verbal Ratings" subsection, third paragraph). With regards to the heaviness VAS data, mass perception accuracy as determined by comparing relative VAS rankings to actual relative shoe masses (Figure 2, Table 3) was no different in Groups 1N and 1R when compared to Groups 5N and 5R. These latter two outcomes suggest the extended wearing time did not improve shoe mass perception accuracy by the foot. Foot accuracy scores from the Groups 1N and 1R were similar to the 34% accuracy found in an analogous test of female participants (23).

The second hypothesis was that using a personal reference shoe (in Groups 1R and 5R, but not in Groups 1N and 5N) would improve mass perception accuracy by the foot. The data were mixed in their support of the second hypothesis. With regards to the heaviness VAS data, mass perception accuracy as determined by comparing relative VAS rankings to actual relative shoe masses (Figure 2, Table 3) was greater in Groups 1R and 5R when compared to Groups 1N and 5N, suggesting that using a personal reference shoe improved mass perception accuracy by the foot. However, when asked to verbally rank-order the shoes after wearing all pairs, participants in Groups 1R and 5R collectively were no more accurate than participants in Groups 1N and 5N collectively (Figure 1, Table 2). The number of significant pairwise comparisons was no greater in Groups 1R and 5R as compared to Groups 1N and 5N. Those two outcomes suggest the personal reference shoe did not improve shoe mass perception accuracy by the foot.

Hand perception of shoe mass was tested in Groups 1N and 1R only, and both groups had similar accuracy scores (Figure 4), indicating that the reference shoe did not improve hand accuracy; however, the hand accuracy scores were so high that it is difficult to distinguish a ceiling effect from any effect of the reference shoe. These hand perception scores are similar to the 95% accuracy found in an analogous test of female participants (23). The significantly longer testing time of Group 1R relative to Group 1N was likely due to the extra pair of shoes included in the comparison.

Across the four groups, the average mass of the participants' normal running shoe was ~315 g, placing it midway between the masses of Shoes C and D and thus squarely within the mass range of the unfamiliar running shoes; thus, participants were likely accustomed to the range of masses presented by the unfamiliar running shoes.

Correlations between comfort VAS marks and actual shoe masses were poor (Figure 3), suggesting the two factors were not associated. This finding is consistent with previous shoe comfort perception studies (2,3,23). Separate studies have shown the foot may be poor at perceiving other shoe characteristics one would presume are related to perceived comfort, such as mileage-related decreases in heel midsole cushioning (11), ground reaction forces or plantar pressures (12,40), or even custom shoe orthotics (29). By contrast, after reviewing studies relating running injuries to running shoe selection, Nigg and colleagues concluded that runners find different running shoes "comfortable" for different reasons (based on their unique bodily architecture (31)), and that the shoes they select lower their personal running-related injury risk and also improve their personal running economy (39); if this "comfort filter hypothesis" is true, then it would suggest feet can perceive slight differences in shoe characteristics. Supporting this hypothesis, other studies reported that participants perceived differences in comfort between orthoses of varying characteristics (33,35) or based on how the shoe influenced plantar pressure (8). Clearly more research is necessary to determine what features of the shoe can or cannot be discerned by the feet, and consequently how those features impact perceived comfort, though it is likely a combination of both shoe design characteristics and individual wearer characteristics interact in determining shoe comfort. Unsurprisingly, participants in Groups 1R and 5R rated their own personal shoes as more comfortable than any of the unfamiliar test shoes (see Results text, "Foot Portion: VAS Ratings" subsection, sixth paragraph).

There are several limitations to this study. Because the testing time was handled slightly differently between groups, this study is not a true 2×2 factorial design because combinatorial equivalence was not achieved with regards to testing time—whereas participants in Groups 5N and 5R performed a fixed five minutes of running in each shoe, participants in Groups 1N and 1R could engage in a variety of activities and had up to sixty seconds but could stop sooner if they wished. This study utilized only college-aged males capable of exercising safely in a men's size 12 shoe so that the same pair of shoes could be used across all groups; while it's unclear if these results are generalizable to other populations, a study in female participants analogous to Group 1N yielded functionally identical results (23), suggesting that these phenomena are likely similar in females (and in people of different statures). It is also unclear if the results are generalizable to other shoe types, such as heavier (e.g., basketball) or lighter (e.g., wrestling) shoes, but one study of basketball shoes indicated that athletes could not perceive differences in basketball shoes whose masses spanned ~300 g (34). In Groups 1R and 5R, the different masses of the participants' personal references shoes may have introduced some unavoidable confounding variation. Participants in this investigation wore goggles to preclude their being influenced by the shoe's appearance; however, in a real-world retail setting, consumers would be using visual cues (27).

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