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ORIGINAL ARTICLE

Sensory Perception of Varied Shoe Masses in Running

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Background: Studies on the sensory perception of mass mostly focus on the hands rather than the feet. The aim of our study is to measure how accurately runners can perceive additional shoe mass in comparison to a control shoe (CS) while running, and moreover, whether there is a learning effect in the perception of mass. Indoor running shoes were categorized as a CS

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(283g) and shoes with four additional masses shoe 2 (+50g), shoe 3 (+150), shoe 4 (+250) and shoe 5 (+315).

Methods: Twenty-two participants attended a to the experiment divided into two sessions. In session one, participants ran on a treadmill for two minutes with the CS and then put on one set of weighted shoes and ran for another two minutes at a preferred velocity. A binary question was used after the pair test. This process was repeated for all the shoes to compare them with the CS.

Results: Based on our statistical analysis (mixed effect logistic regression), the independent variable, mass did have a significant effect on perceived mass, F (4,193) = 10.66, P < 0.0001, while repeating the task did not show a significant learning effect (F (1, 193) = 1.06, P = 0.30).

Conclusions: An increase of +150g is the just noticeable difference among other weighted shoes and Weber's fraction is equal to 0.53 (150g : 283g). Learning effect did not improve by repeating the task in two sessions in the same day. This study facilitates our understanding about sense of force and enhances multibody simulation in running.

When selecting a running shoe, different features including comfort [1, 2], cushioning [3], brand [4] and color [5] influence the decisions of shoe consumers. Some studies have determined that shoe mass also ranks as one of the main criteria in choosing running shoes among different levels of runners [6,7]. This might be due to the common perception that a lighter shoe will increase

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running efficiency, although recent research has produced mixed results in this respect [8-14]. The perception of mass was first determined by Weber (1834) [15], who differentiated between static mass perception through touch, and active mass perception, which incorporates tactile and muscular components. In addition, he determined that the smallest difference in mass that can be detected is proportional to the mass of the object (Weber fraction= smallest difference: object mass). How the hand perceives changes in mass (based on touch and muscular components) has since been extensively studied. Modern experiments show that the Weber fraction ratio for hand touch alone is higher than when the object is lifted with the hand [16,17]. In contrast, relatively little is known about how the foot perceives mass. Some early studies of lower limb mass perception were performed with masses cantilevered away from the limb [18,19]. Recent findings show that when participants wore running shoes and were asked to evaluate their relative masses with movements while *walking and jumping*, the subjects were poor at perceiving mass across a range of common running shoe masses (~220-360 g)[20,21]. Saxton et al. (2020) [22] investigated the perceived mass of weighted running shoes while *running*. Their findings show that wearing time and control shoes may influence mass perception by the lower limb. In another study by Greenya et al. (2014) [23], the learning effect was measured in freely chosen actions such as walking, jumping and standing over sixty seconds. Participants were asked to repeat the task for the second time, but their perception of shoe mass did not appear to improve with practice. Because of the diversity of independent variables and their effects on

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somatosensory shoe mass perception, more studies are needed to improve our understanding of mass perception through the feet. Therefore, the aim of this study is to assess how accurately subjects perceive additional shoe mass *during running*. Secondly, the potential learning effect of shoe mass discrimination *during running* is investigated.

Methods

Participants

Twenty-two male participants - 24.45 years old (±3.20) and 77. 87kg (±8.6) - were recruited from the Munich University Sports Center in Germany. Six months before time of testing, participants were required to be injury free. Prior to the experiment, they had to give written informed consent. This form refers to the confidentiality of the objectives, study risks, and includes data privacy. Moreover, this form assures subjects are free at any time to stop participating in this research without providing any reasons and without incurring penalty. This research was conducted according to the ethical standards of the 1964 Helsinki Declaration [24].

Tools of Study- Shoes

Four sizes of Running shoes ranging from 42 to 45 were selected. (*model*: Victory Performance, *company name*: Deichmann GmbH, Germany). Each shoe size was categorized as one Control shoe (without additional mass) and shoes with four additional masses such as: +50g (Shoe I=1.8

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× CS), +150g (Shoe II=1.55 ×CS), +250g (Shoe III=1.92 ×CS) and +315g (Shoe IV=2.16 ×CS). The average weights of shoes in different sizes is 283g (±21g) and the weight deviation for each shoe size is (±3g).

To increase the shoe mass, the lead tape was attached to the fore and rear parts of the shoes. However, the center of mass for each shoe must be kept constant during this procedure. The experiment was conducted as a blind test by partially concealing the 20 shoes with black tape (see Figure 1).

Study Procedure

Initially, participants warmed up with the control shoe on the treadmill for the first 10 minutes of the experiment. Subjects also defined their desired velocity for the experiment under blind test conditions aided by the experimenter. Next, participants ran on the treadmill for two minutes with CS, and then they continued for another two minutes with a random pair of weighted shoes. After that, they were allowed to take a rest for one minute. For comparison, all possible pair tests with the CS were repeated according to this process. After completing all possible pair tests with CS, subjects were given up to-one hour until they felt ready to start the second session following the same procedure as in the first session. In session two, participants ran with the preferred velocity selected in the first session. After completing the first session,

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subjects were given up to-one hour until they felt ready to start the second session following the same procedure as in the first session.

Methods of Data Collection and Analysis

After each pair tests with CS, participants responded to a comparative question, 'is the second shoe perceived to be heavier?'. The answer is binary, where *yes* means 'the second shoe was perceived to be heavier' and *No* means 'the second shoe *was not* perceived to be heavier'. For further statistical analysis, correct responses were converted to '1' while incorrect responses to the '0'. A mixed effect logistic regression with and without interaction effect were used in SAS 9.4 (Statistical Analysis System). Several steps were taken to prevent participants from perceiving indirect information about the shoes. Participants were asked not to touch or handle the shoes at any stage during the test of mass perception through the feet. The experimenters put the shoes on subjects' feet, laced them and removed them after the test. Participants were not allowed to walk or jump in the shoes. They began running on the treadmill immediately after lacing. These procedures prevented the participants gaining any perceptual information about shoe mass that could confound the perceptions from simply wearing the shoes. In addition, to minimize possible tactile cue differences, participants were provided with similar socks, (45% Polypropylene, 35% cotton, 20% Polyamide).

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Results

The effect of two independent variables, Mass and Session, on perceived mass (dependent variable) among 22 subjects was investigated with *Mixed effect logistic regression with and without interaction*. In the Mixed effect logistic regression without interaction, Mass had a significant effect on perceived mass, $F(4,193) = 10.66$, $P < 0.0001$, while Session did not $F(1, 193) = 1.06$, $P=0.30$. Moreover, the model with the interaction effect showed that Session and interaction effect (Mass × Session) were not significant ($P > 0.005$).

In addition, a post hoc test, namely Dunnett-Hsu, was used to compare all weighted shoes with the CS. According to Table 1, the test comparisons between the CS and other weighted shoes show a significant difference (in Alpha Level of 0.05), except for shoe I in comparison with the CS. The results show that the odds ratios when comparing the CS and weighted shoes are higher than one (Figure 2) except for the CS versus Shoe I. Accordingly, there are significant differences between the CS and weighted shoes but not shoe I (See Table 1 and Figure 2).

The accuracy in session one for shoe I, shoe II, shoe III, and shoe IV in comparison with CS are 31%,72%, 86% and 100% respectively while in the second session are 31%, 68%, 86% and 95%. Repeating the task did not affect perception of shoe mass significantly. The total drop in accuracy from the first session to the second session across all five pair tests shows that there is

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no learning effect. The accuracy of shoe mass perception dropped 2% from session one (72%) to the session two (70%). In addition, the insignificant p-value = 0.30 determined that there is no effect of Session on perceived shoe mass (Figure 3).

Discussion

In our study, the sensory threshold of perceived mass is distinguished by the additional weight of +150g (p- value < 0.05). An 'odds ratio' higher than 1 only occurred when the additional shoe mass was greater and equal to +150g. In our study – based on Weber's law – the just noticeable difference (JND) is 150g and Weber's fraction is equal to 0.53 (150:283). Several factors have to be considered when relating the JND and Weber fraction measurements to results presented in the literature. Slade et al. (2014) [20] determined that an increase of 140g is the sensory threshold (JND) and the Weber fraction is 0.64 (the initial shoe mass is 220g). The difference in the JND may be due to the methodological difference in the original shoe masses of both studies, which is ~ 63g. This difference may have affected the subjective threshold, where the Weber fraction decreases when the mass increases up to 200g [26]. Findings of Hausler et al. (2016)[21] determined that JND of 100g is required for the foot to consistently (and accurately) perceive differences among weighted running shoes. Besides the methodological difference of origin of shoe mass, a 'sex-specific difference' may also have increased the foot's activation threshold. Moreover, other factors which led to our results were the use of the control shoe

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and binary questionnaire. As runners are used to their own shoes, thus using the control shoe for a pair comparison with weighted shoes can reduce all potential biases[22]. Visual analogue Scale (VAS) was a main tool in past related studies [20, 21, 22]. However, the complexity of this measure, VAS, can influence the reliability of assessments[27,28]. In other words, the number of individuals who reliably assessed the footwear could be increased by reducing the complexity of the VAS measure to simple binary Yes/No questions.

Another part of our findings determined that foot perception of shoe mass does not improve with practice. Our findings are in line with those of Greenya et al (2014) [23]. In our study, repeating the sessions does not show any effect on perceived mass. The accuracy, from 72% in session one, dropped to 70% in session two. Greenya et al. (2014) [23] determined that accuracy was 93% in the first trial compared with 92% in the second trial for the hand test. They also showed that the accuracy with the feet did not differ significantly[23].

The findings from some of the aforementioned studies [20, 21, 22, 23] also determined that hands have a higher sensitivity - with respect to the additional mass - than feet. While moving or holding mass by hand, both touch and muscle contribute to perception of mass. In our study, the weight of the shoe could probably not be perceived by the touch-sense in the skin of the feet. Thus, the shoe mass is mostly perceived with the degree of tension in the muscle when lifting weight [29]. We speculate that acceleration of the feet in the swing phase of running influences the Golgi Tendon Organ (GTO) and muscle spindle. By inserting up to +150g

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additional mass, the GTO, which is a cluster of sensory receptors, will be stretched and depolarized significantly in the swing phase and send the signals through Ib-afferent synapses to the brain cerebellum and cerebral cortex [30]. The sensitivity of tendon organ receptors to changes in muscle force suggests that the discharges arising from these receptors could provide the basis for judgments of force [31,32]. This judgment may be related not only to perceived heaviness, as reported by Brooks et al. (2013) [33], but also perceived mass.

In addition, we generated a running gait model using a multibody system simulation in the Simpack software to calculate the knee moment while running. The calculation of the knee joint moment *in swing phase* in Sagittal plane - and with a velocity of 2.6 m/s- is increased by 7.5% when additional shoe mass is 150g (in comparison to the CS). This increase of knee moment - product of moment of inertia and angular acceleration- which could majorly contribute to the threshold of mass perception in running. Future study is necessary to investigate the relationship between joint kinematics and kinetic of runners and theirs' perception of mass with control shoe and shoe 2 (+150g).

Conclusions

In our study, we developed a new methodological framework for perceiving shoe mass. An increase of +150g is the just noticeable difference among other weighted shoes and Weber's fraction is equal to 0.53 (150g:283g). Learning effect did not improve by repeating the task in

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two sessions in the same day. The accuracy of mass perception while running drop two percent from session one to session two. Future study is necessary to investigate the relationship between kinematics and kinetic variables and perception of mass while using control shoe and shoe 2 (+150g).

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Conflict of Interest: None reported.

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Table 1. Difference of weight Least Squares Means Adjustment for Multiple Comparisons

Label	Es	Sd	A.P	A.L	A.U
G1	-0.21	0.46	0.97	-1.36	0.93
G2	1.50	0.47	0.007	0.31	2.68
G3	2.51	0.56	<.0001	1.10	3.92
G4	4.45	1.07	0.0002	1.77	7.13

Es: Estimate, Sd: Standard deviation, A.P: Adjustment P-value., A.L: Adjustment Low, A.U: Adjustment upper

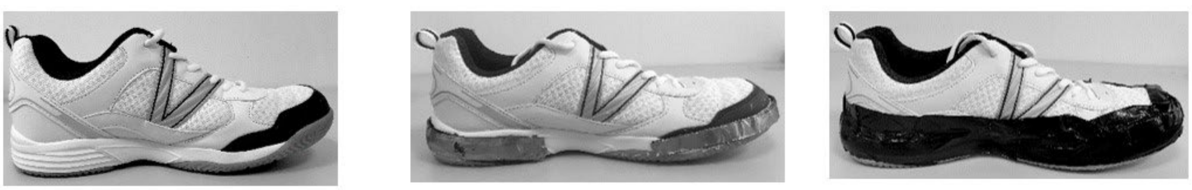

Figure 1. Procedure of weighting shoe sample in the experiment. A, Indoor running shoe (control shoe). B, Lead tape added to fore and rear parts. C, Concealed with the black tape.

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Figure 2. Odds ratio and all pair tests with Control Shoe

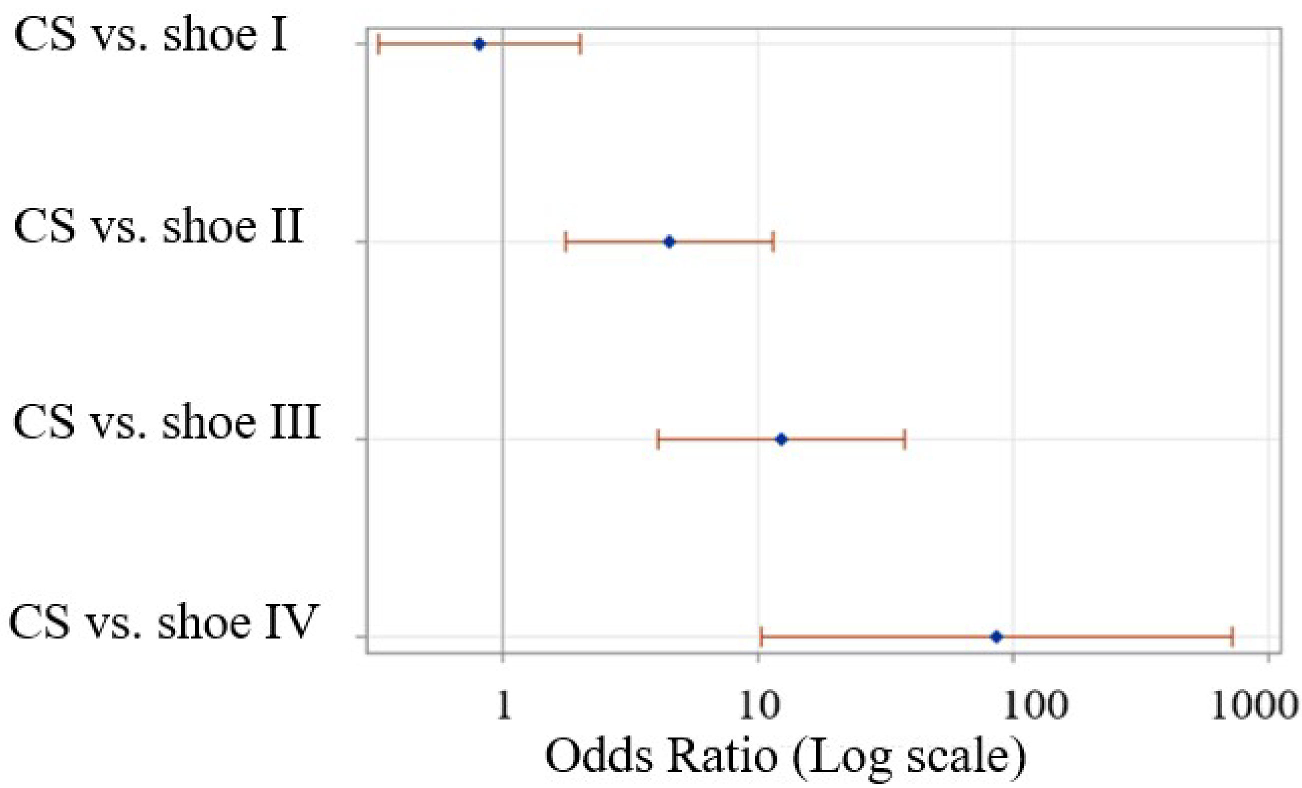

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Figure 3. Number of subjects correctly perceived additional mass in all possible pair tests with

Control Shoe (n=22)