Examining human perception of weight during loaded standing and walking

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While the psychophysics of weight perception may help assess the effort needed in manual material handling tasks, the perception of weight is subjective and not necessarily accurate. The purpose of this study was to examine weight perception during standing and walking. Participants (n=10) performed a series of weight comparison trials against a reference load while holding loads (standing) or carrying loads (walking). Polynomial logistic regression models were built to examine the effects of walking, box weight ratio, and reference weight level on the probability of detecting a weight difference. The results showed that weight ratio and reference weight level had statistically significant effects on the detection probability while walking did not have a significant effect. Findings from this study can help inform the design of subjective evaluation of job demands involving motion, and it can be further extended to the gradual increase in load of strengthening tasks in therapeutic exercises.

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INTRODUCTION

Manual material handling (MMH) of loads and carrying of loads is common in the workplace and even in everyday life (Ramadan, Khalaf, Ragab, & Abdelgawad, 2018). While objective measures, such as trunk load and muscle electromyography (EMG), have been analyzed to evaluate the risks of MMH, some studies utilized subjective methods such as rated perceived exertions and perceived weight of load to evaluate workload and fatigue (Ahmad & Kim, 2018). However, humans' perception of weight is not always accurate, which can influence people's decisions on lifting heavy objects and lead to potential risks (Amazeen, 2014).

There are two general types of errors when estimating the weight of an object. The first one arises when an object is perceived to be heavier or lighter than an object of the same weight, which is termed "weight illusion"(Buckingham, 2014). The most commonly studied factor associated with weight illusion is object size: smaller objects are perceived to be heavier than larger objects of the same weight (Flanagan & Beltzner, 2000; Plaisier & Smeets, 2012). This size-dependent weight illusion phenomenon can be generalized for studying other related factors, such as material weight illusion (Buckingham, Ranger, & Goodale, 2011; Flanagan & Beltzner, 2000) and temperature weight illusion (Kuhtz-Buschbeck & Hagenkamp, 2020). Material weight illusion is induced by the surface material of the objects, objects that demonstrate heavy material appearances, such as metal, will feel lighter than objects having light material appearances even though they are actually the same (Buckingham, Cant, & Goodale, 2009). Temperature weight illusion happens when the temperature of object affect people's perception of the object's weight. Specifically, people perceive the same item to be heavier at temperatures lower than the room temperature (Buckingham, 2014).

Another type of perceptual error occurs when two objects of different weights are perceived to be the same weight due to a threshold, or just noticeable difference (JND), for discriminating two weights (Brodie & Ross, 1984; Jones, 1986). In this case, the appearances of the objects are identical while the weights are different. Weber proposed that the JND was proportional to the original weight, (e.g., JND is 0.1g for weight of 10 g, then JND is 0.5 g for weight of 50 g) while Fechner assumed the JND was fixed across all weights and a logarithmic relationship was proposed (Ekman, 1959). Both assumptions were later questioned and new models were proposed (Masin, Zudini, & Antonelli, 2009). The JNDs can be a valuable tool as it can be applied to physical rehabilitation and fitness training where a therapist can gradually increase the intensity (e.g., load) for strengthening exercises without being noticed by the patients (Allin, Matsuoka, & Klatzky, 2002).

While many studies have been conducted to investigate weight illusions and JND for hand haptic perceptions, most of them restrained the participants to a fixed position, either by instructing the participants to lift weighted boxes in situ (Amazeen, 2014) or tied the forearm of participants to a dynamometer (Allin et al., 2002). To the best of our knowledge through literature review, there has been little literature in studying weight perceptions during dynamic daily movements, which may have greater practical meaning.

Walking while holding weighted objects is a common daily task that can be seen in activities like moving boxes and carrying shopping bags (Ramadan et al., 2018). Some studies found that daily walking with hand held loads could pose increasing load on the low back and cause spinal disorders (Fowler, Rodacki, & Rodacki, 2006; Park et al., 2014). Other studies investigated the influence of carrying shopping bag on walking and proposed techniques including a bag holder or two-hands carrying (Ramadan et al., 2018). While these studies analyzed trunk loadings and subjective discomfort ratings, few of them evaluated the influence of walking on perception of weighted objects. As weight perception is a subjective measure that is influenced by many factors (size, material, temperature, etc.), it was hypothesized that being in motion can affect the perception of object weight.

The purpose of this study is to investigate the influence of standing and walking on weight perception. In addition to the traditional stationary weight perception task, a task of walking while carrying a box was introduced. In specific, this study focused on the second type of perceptual errors, so the appearances of all boxes were controlled to be the same. The JND for weight perception between standing position and walking condition was compared. Weber-Fechner law for weight perception was evaluated.

METHODS

Participants

A total of ten participants (8 males, 2 females) between ages 24 - 38 years (mean = 27.7, SD = 3.9) were recruited for the study with informed consent approved by North Carolina State University's Institutional Review Board. All participants reported no physical injuries or surgeries within last three months.

Apparatus

A total of 24 identical cardboard boxes were employed to deliver the weight stimuli to the participants. All boxes were of the same size (length = 15 inches, width = 10 inches, height = 12 inches) with three weight groups: 4 lb, 8 lb, and 12 lb. An earlier pilot experimental session revealed that 20 lb load would result in participant fatigue, and therefore the three weights groups were selected to prevent fatigue. Each group had one reference box and seven experimental boxes. The weight ratio (calculated by dividing each box's weight by the reference box weight) was set between 0.85 to 1.15 in 0.05 increments. The range of weight ratio was also informed by the lab's earlier pilot session. Specifically, for the 4 lb weight group, seven boxes were used to create an array of weights that ranged from 3.4 lb to 4.6 lb in 0.2 lb increments. For the 8 lb group, seven boxes were used to create an array of weights that ranged from 6.8 lb to 9.2 lb in 0.4 lb increments. For the 12 lb group, seven boxes were used to create an array of weights that ranged from 10.2 lb to 13.8 lb in 0.6 lb increments. The boxes were placed on a table and had no identifying markers except for the three reference boxes (4lb, 8 lb, and 12 lb).

Procedures

Upon arrival at lab, participants were instructed with the proper manual material handling techniques, including: maintain a good grip and keep the boxes close to body (Amazeen, 2014). Next, participants were given practice trials to walk and carry a box until they became confident about the experimental task. Afterwards, participants were familiarized with rated perceived exertion (RPE) survey in Borg-10 scale (Borg, 1998).

Firstly, the participants were instructed to stand in front of the table and lift the boxes to their waist height and place them back onto the table. Each trial consisted of two lifts, the participant first lifted the reference box and gave a RPE score for the reference lift. The participant then randomly lifted the other box in the same weight group and put it back down. Next, the participant was asked whether these two boxes were of the same weight. A response of "yes" indicated that they perceived the weight difference and a response of "no" indicated that they did not perceive the weight difference, and finally the participant verbally gave a RPE score for the second lift. Each run consisted of 21 comparisons (3 weight groups × 7 comparisons per group) and 42 lifts. Short breaks were provided to ensure the participants were not fatigued and the breaks could be extended if requested. The participants then completed the NASA-Task Load Index (NASA, 1986) and had a longer rest (3 minutes), which could be extended upon the participant's request.

Secondly, the participant was instructed to carry a box from the table and walk along a guided path (to ensure walking the same distance for all participants). Participant was guided to walk to the end of the path and turned back, walked back toward the table, and put the box back onto the table. Afterwards, the participant was verbally asked to perform the same weight discrimination task and gave RPE scores, respectively. The boxes were reset to totally random position and participants were verbally reminded that the positions of all boxes were reset before the walking-carrying task. Longer breaks were provided between two consecutive comparison tasks. In the end, the participants completed the NASA-TLX and had a rest. The total experiment tool about 1.5 hours.

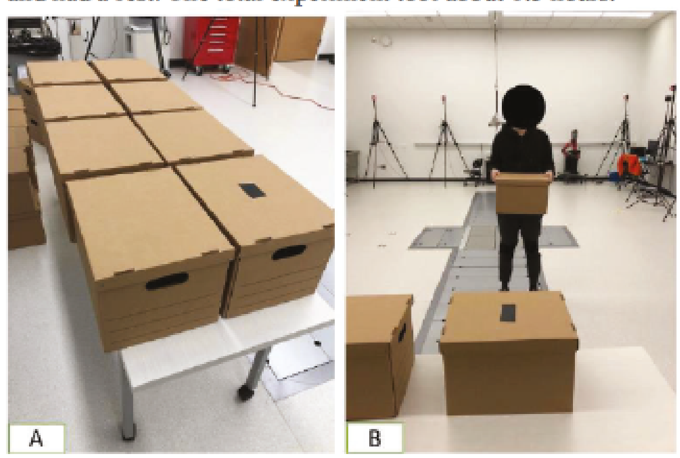

Figure 1. Experiment setup. (A) Eight boxes in one weight group, the reference box was marked with a black tape. (B) A participant carried the box back to the table.

Variables and Analysis

The independent variables in this experiment included task type (standing and walking), weight ratio (from 0.85 to 1.15), and box weight groups (4 lb, 8 lb, and 12 lb). The dependent variables were the probability of detecting a difference (between the reference box and the box being lifted), just noticeable differences (JND), RPE scores and NASA-TLX scores.

For this study, the probability of detecting the difference was calculated by taking the number of yes responses divided by total number of responses. The JND was calculated at 50% level as it is a common level used in psychophysics (Booth & Freeman, 1993), which means the weight ratio difference at which people had a 50% chance of detecting the weight differences. The RPE score was normalized against the RPE score captured when lifting the reference weights, which provided the normalized RPE (nRPE) score.

A 2nd order polynomial logistic regression model was built to relate the probability of detection and weight ratio (Chen et al., 2017). A linear regression model was built to study the effects of weight ratio on nRPE. A two-sample t-test was used to evaluate participants' workload by comparing the scores obtained using the NASA-TLX. Significance level was set at $\alpha = 0.05$ for all analyses.

RESULTS

Probability of detection

A 2nd order polynomial logistic regression revealed a statistically significant effect of weight ratio on the probability of perceiving a difference, where the quadratic coefficient $b_2 = 121.89$ $(\chi^2(1) = 67.28, p < .001)$ and $b_1 = -0.83$ $(\chi^2(1) = 0.38, p = .54)$. The weight group also showed a significant effect on the probability of difference detection $(\chi^2(1) = 6.23, p = .013)$. The task type did not induce a statistically significant effect on the probability of detection $(\chi^2(1) = 2.23, p = .14)$. As can be seen in the Figure 2 and Figure 3, the curve matches well because there were only a few points due to the small increment gap (0.05). With a weight ratio < 1, the standard effect size between walking and standing is 0.77; with a weight ratio > 1, the standard effect size is 0.05.

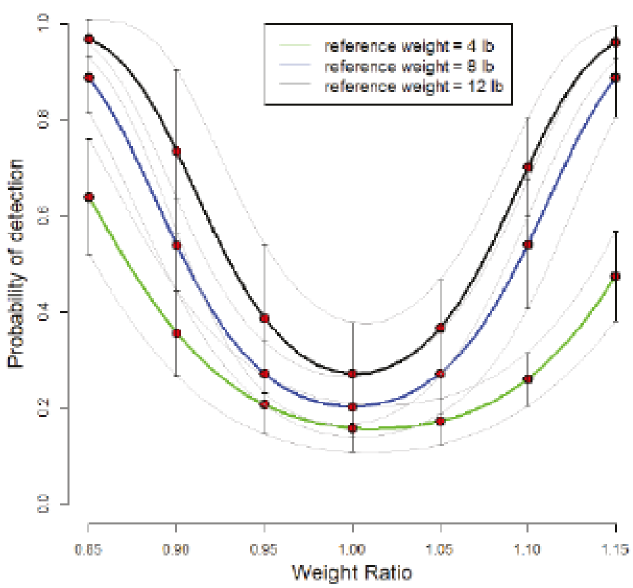

Figure 2. Plotted polynomial logistic regression models depicting the relationship between probability of detection and weight ratio at three different weight levels. The error bars are also ±1S.E at the experimental weight ratios. The gray lines represent the ±1S.E. of the respective logistics regression model.

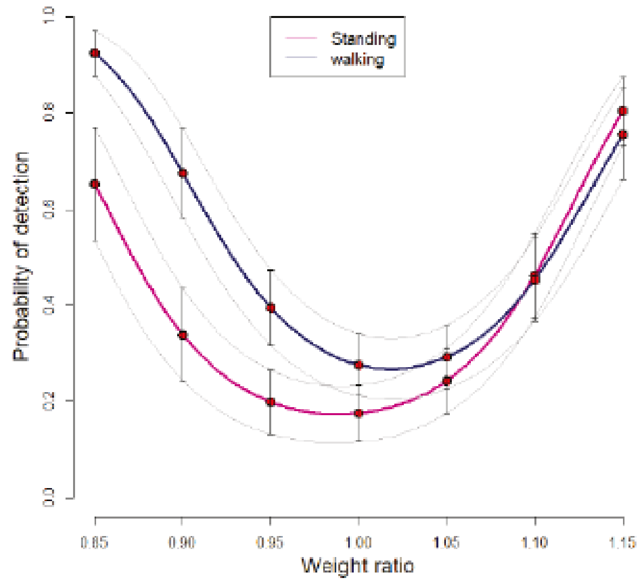

Figure 3. The plotted polynomial logistic regression models depict the relationship between probability of detection and weight ratio at two different task conditions. The error bars are also ±1S.E at the experimental weight ratios. The gray lines represent the ±1S.E. of the respective logistics regression model.

Just Noticeable Difference (JND)

A 2nd order polynomial logistic regression model revealed that 50% JND for the three weight groups: for the 4 lb weight group the weight ratios were 0.873 and 1.154, for the 8 lb weight group the weight ratios were 0.905 and 1.094, and the for the 12 lb group the weight ratios were 0.931 and 1.073. Accordingly, 50% JND by weight was at 3.49 lb and 4.62 lb for 4 lb group; 50% JND was at 7.24 lb and 8.75 lb for 8 lb group; 50% JND was at 11.17 lb and 12.88 lb for 12 lb group.

The model also revealed that the 50% JND for standing condition was at weight ratio = 0.872 and weight ratio = 1.106, and the 50% JND for walking condition was at weight ratio = 0.929 and weight ratio = 1.109. The means of JNDs in each condition was summarize in the Table 1 and Table 2 below.

Table 1. JND for the three weight groups.

	50% JND in weight ratio	50% JND in weight
4 lb.	0.14	0.56
8 lb.	0.095	0.76
12 lb.	0.071	0.85

Table 2. JND for standing and walking condition.

	50% JND in weight ratio
Standing	0.117
Walking	0.09

nRPE

The linear regression model revealed that weight ratio is a significant indicator of nRPE $(F(1{,}418) = 357.8, p < .001)$.

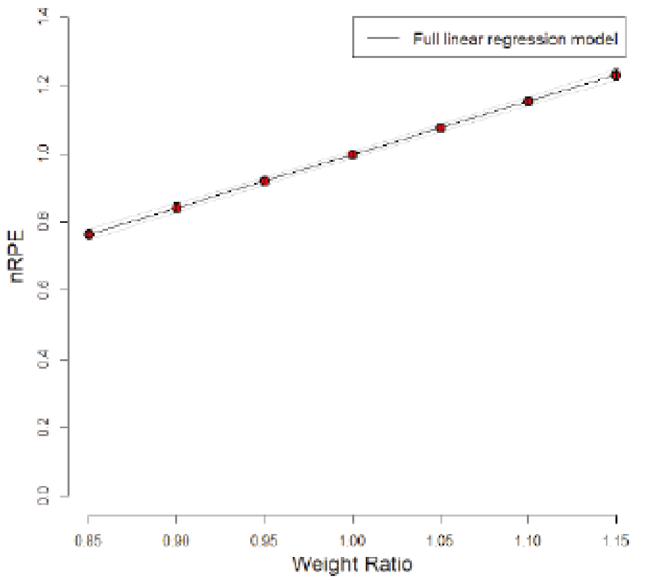

Figure 4. Linear regression model on nRPE across different weight ratios. The error bars are also ±1S.E at the experimental weight ratios. the gray lines represent the ±1S.E. of the respective logistics regression model.

NASA-TLX

A two-sample t-test indicated that physical demand $(t(18) = 3.67, p = .001)$ and efforts $(t(18) = 3.34, p = .002)$ were significantly higher during walking condition. Only these two significant domains were plotted in Figure 5.

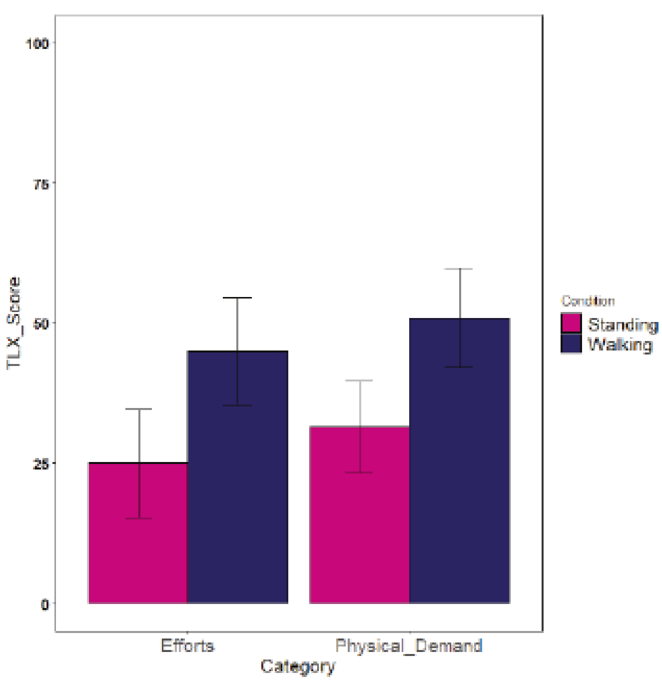

Figure 5. The means and ±1 S.E of the NASA-TLX scores for walking and standing condition for two domains: efforts and physical demand.

DISCUSSION AND CONCLUSIONS

This study evaluated human weight perceptions during different conditions: standing and walking. Earlier studies have examined the perception of weight in stationary postures, yet various practical jobs require moving and carrying of loads. In specific, effects of weight ratio, weight level and walking were studied on the probability of detecting weight differences. The results demonstrated that the weight ratio and weight level had significant influences on the probability of detection, the normalized rated perceived exertion was significantly related to the weight ratio, and the participants' physical demand and efforts were significantly higher during the walking condition.

Weight ratio had a statistically significant effect on the probability of detection, which was plausible as the weight ratio deviates more from the unity weight ratio = 1, the difference between reference box weight and task box weight increased, and it was easier for participants to perceive the discrepancy (Chen et al., 2017). Given that participants showed lower detection probability at weight ratio near to the unity weight ratio, it was possible that the therapist could increase the loads of rehabilitation task slightly while without being noticed by the patients (Allin et al., 2002).

The weight group indicated a statistically significant effect on participants' probability of weight differences detection ($p = .013$), with 12 lb weight group showed highest detection probability and 4 lb weight group showed lowest detection probability. Weber's law stated that JND is proportional to the initial stimuli and relative discrimination sensitivity is constant across different stimuli intensity (Ekman, 1959), such that JND is 1 g for 100 g object and 2 g for 200 g object. According to Weber's law, at the same weight ratio, participants should have the same probability of detecting a difference across three weight levels, which did not hold for this study, as participants had higher detection probability at higher weight levels. The JND by weight was approximately between 0.6 lb and 0.8 lb across the three weight levels, and thus this finding was more aligned with Fechner's assumptions that all JNDs were equal ("Weber-Fechner Law," 2005).

Walking did not induce a significant higher detection probability compared to standing and lifting ($p = .14$). However, it can be seen from the Figure 3 and the effect size calculation that walking and carrying showed higher detection probability when weight ratio < 1, which could be due to the fact that walking and carrying a box is a physically demanding task (can be seen from the NASA-TLX results in Figure 5), thus it was easier for participants to detect the alleviated differences when the second boxes were lighter compared to the reference box. In addition, there existed other confounding variables between walking and standing that might have an effect on weight perception. A potential confounding variable was time per trial: the walking trial was longer than the standing trial since the participants carried the load and walked. Yet, controlling the lifting time to be equal across all trials may result in unnatural performances that could potentially influence participants' weight perception (e.g., participants stood and started to judge and overthink). In consideration, we encouraged the participants to finish the tasks in their preferred pace that would not result in fatigue. Another confounding variable is the order of the two conditions. The order in this study was always standing task first and walking task later. To eliminate the potential order effects, prolonged rest time (three minutes) was provided between these two conditions.

To accommodate perception discrepancies for different participants, we utilized the term of nRPE, which showed relative exertions compared to the exertions associated with lifting the reference box. The results showed that nRPE was linearly related with weight ratio, in addition, using nRPE centered the RPE scores and lower original RPE variances. The NASA-TLX revealed that participants experienced significant higher physical demand and exerted more efforts during walking and carrying task, and more attention need to be paid to walking and carrying tasks.

One limitation of this study is the number of participants was relatively small ($n = 10$) due to recruitment challenges. The study can be further expanded with other postures and weight ranges to validate the JND in weight perception. Another limitation was the weight ratio gap between boxes, to avoid participants getting fatigue during the experiment, we adopted the design of weight ratio incremental = 0.05, more closely compacted weight incremental shall be used to accurately depict the detection probability – weight ratio curve. Finally, the recruiting participants in this study were relatively young adults, this study can be further carried out on other age groups.

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