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The effects of fatiguing exercise and load carriage on the perception and initiation of movement

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Abstract:

Perceptual-motor coordination relies on the accurate coupling of the perceptual and movement systems. However, individuals must also be able to recalibrate to perturbations to perceptual and movement capabilities. We examined the effects of fatigue and load carriage on perceptual-motor coordination for a maximal leaping task. 23 participants completed an incremental fatigue protocol (light to fatiguing intensity stages) on two separate occasions (loaded/unloaded). At baseline and the end of every stage of the protocol, participants made perceptual judgments for the affordance of leaping. The accuracy of responses and reaction times were calculated. Mean differences in accuracy and reaction time across exercise intensity and load carriage conditions. No interaction of exercise intensity and load carriage was detected, or main effect of load carriage. A main, quadratic effect of exercise intensity was detected on reaction, with times decreasing through the moderate stage and increasing through post-fatigue. No effect of exercise/fatigue was detected on perceptual accuracy. The results indicate that exercise at high intensities through fatigue have a significant effect on perceptual-motor calibration. Contrastingly, in response to an action-scaled task, individuals can adequately recalibrate to increased load carriage.

Keywords: affordance, perceptual-motor coordination, perception-action, reaction time

1.0 Introduction:

Affordances can be defined as opportunities for action or movement provided by an environment [1]. Additionally, the reciprocal relationship between the perceptual (e.g., visual, haptic, sensorimotor) and movement systems (e.g., muscular, skeletal, neural) is referred to as *perceptual-motor coordination* or *skill* [2,3]. The processes of perceptual-motor control are often measured in terms of the ability to recognize affordances, or more specifically, the limits of affordances; termed *action boundaries*.[3] For example, the action boundary for an individual attempting to step onto a stair would be the maximal surface height that afforded the specific action of stepping (i.e., pushing oneself up onto a surface with their foot) [4]. At heights beyond this boundary, individuals would be required to adjust their movement behavior, such as pushing up onto the surface with their hands. When individuals are highly accurate in their perceptions of their action boundaries, we say they are *calibrated* [2].

However, the accuracy of affordance perception, under static or ideal conditions, may not be as important as the ability to recognize and recalibrate to changes in one's affordances. Previous research has demonstrated that, with limited task habituation, most people show high baseline perceptual accuracy for their action boundaries [5,6]. Further, in most movement environments, affordances are not static. Action boundaries are constantly changing, based on internal (e.g., changes in physical capabilities, alertness, anxiety etc.) and external (e.g., changes in task constraints, sensory stimuli, etc.) perturbations. Building off of the previous example, Mark et al. [4] demonstrated that individuals are able to estimate the action boundary for stepping with high accuracy. However, when their leg length was altered by wearing blocks under their feet, they systematically under-estimated their action boundary, until they became recalibrated to their new anthropometrics [4]. Studies have shown that calibration and recalibration occur through the process of *exploration*. Exploration can come from general interactions with the movement environment, feedback on performed movements, or feedback on the physical state of the individual. Importantly, the study by Mark did not allow for significant exploration after altering subject's action boundaries, likely leading to altered action boundary perception [4].

The ability to recalibrate to changing affordances has important behavioral risk implications, especially for athletes and individuals in active occupations, such as police, firefighters, or deployed military personnel. For one, the consequences of poor perceptual-motor coordination are more severe comparative to an average, young, and healthy population. These individuals operate in dangerous environments, where improper movement selection can result in serious injury, and for police/firefighters/military, even death. In addition, the normal operating environments for these populations are much more dynamic and demanding. External and internal perturbations to movement or perceptual capabilities occur frequently and on a different scale, compared to those for average individuals.

For instance, an office worker perceiving step-ability for a surface might be required to recalibrate to a change in weight when carrying a box. A firefighter, in a similar scenario, would be carrying multiple sources of extra weight (e.g., helmet, breathing apparatus, etc.) At the same time, their visual perception will be altered due to smoke and their facemask. Their muscular capacity may be reduced from the physical strain of their occupation. The properties of the surface (e.g., weight capacity, slope) may not be stable, due to fire damage. For an athlete, the movement task itself is likely much more dynamic and challenging, such as perceiving if a gap between defenders affords pass ability. They must be able to recalibrate to: a) changes in the gap, based on future movements of the defender, b) changes in their physical capabilities due to fatigue, c) changes in the actual task constraints, where the optimal movement may be to pass through the gap one moment and something else entirely the next. In both these scenarios, the individuals also must make their perceptions accurately as well as **quickly**, while the perceptual stimuli they are attuning to are still relevant. In contrast, the office worker would likely have ample time and capacity to explore the stair surface and then make their movement selection.

Two of the most regular perturbations for athletes and individuals in active occupations are fatigue and load carriage (i.e., additional body-borne weights). For the purposes of this study, the definition of fatigue follows that described by Abbiss [7]; feelings or sensations of tiredness, resulting in decrements in muscular performance and physical function. For sports medicine professionals working with athletes, fatigue is often cited as creating an injury-prone environment, given its negative effects on neuromuscular and psychomotor control and muscular function [8-10]. Further, both fatigue and load carriage have been frequently cited as occupational barriers for police, firefighters and active military [11-13]. They have also shown significant effects on movement capabilities, such as neuromuscular control, muscular capacity and operational mobility [12,14], and perceptual capabilities, such as cognitive performance and alertness [15]. Therefore, to mitigate the risks of their work, athletes and individuals in active occupations would be required to frequently recalibrate to these alterations to movement and perceptual capabilities.

Several studies have begun to examine the effects of fatigue and load carriage on perceptual-motor coordination. However, within this work there are significant gaps in knowledge. First, only one study has addressed the effects of fatigue [16]. Even in consideration of this study, there are significant methodological concerns that put the validity of the demonstrated effects in question. Second, several studies addressing the effects of load carriage have utilized low magnitudes of load (≤10% of body weight), relative to those reportedly carried by police, firefighters and military [17,18]. If load carriage does affect perceptual-motor coordination, the magnitude of this effect is likely proportional to the carried load. Still, the final two gaps are, perhaps, of greater significance. No previous work has addressed the interactive effects of fatigue and load carriage on perceptual-motor coordination. This is an important gap, given that these perturbations are rarely experienced independently for active occupations. Finally, previous work has failed to incorporate a measure of how quickly movement perceptions are initiated, along with the accuracy of perceptions. Again, given the dynamic environments of active occupations, the speed of perception-action processes is likely as important as accuracy.

Therefore, the purpose of this study was to examine the interactive effects of fatigue and load carriage on both the accuracy and initiation of perceptual responses to an affordance-based task. We hypothesized that fatigue and load carriage would negatively affect both accuracy (decreased) and initiation times (increased) for affordance perception. A secondary purpose was to investigate the effects of incremental exercise intensities, building to fatigue, to study the process of potential perturbations to movement/perceptual capabilities, and resulting perceptual responses. As it was exploratory, and without previous literature for guidance, no a-priori hypotheses were made regarding this aim.

2.0 Materials and Methods:

The current study utilized a within-group design with randomized and counterbalanced session order. Participants completed two testing sessions: one with load carriage (loaded), and the other without (unloaded). Approval for all testing procedures was obtained from the University IRB prior to any testing and written informed consent was obtained from all participants.

23 participants were recruited (Men/Women = 11/12, Age (yrs) = 25.26 ± 3.26, Body Mass (kg) = 72.80 ± 15.66, Height (cm) = 170.26 ± 11.15) who were: 1) ages 18-35, 2) highly

active, defined as participating in physical activity at least 4 days a week for 45 minutes a day, including aerobic activity performed at a high intensity, 3) without history of neurological\vestibular disorders or conditions that would contraindicate exercise. The median score on the Tegner Activity Level Scale for the sample was a 6 (IQR = 5-7), which corresponds to an activity level of being recreationally active in sports like tennis badminton, handball, racquetball, down-hill skiing, or jogging at least five times a week. Inclusion was not based on experience with load carriage. Given the high magnitude of load and the novelty of the perceptual task (jumping with load), it is was not expected that load carriage experience would convey an advantage/disadvantage while performing the task. An a-priori sample size estimation was performed (PASS 15.0.3 software NCSS, LLC, Kaysville, UT) for repeated-measures analysis of variance (ANOVA), and based on the work of McMorris et al.[10]. It was determined that 23 participants would be necessary to achieve 81% power with the following criteria: a) 2 within-subject factors and participants measured 5 times, b) effect size of 0.6, c) $\alpha=0.05$.

2.1 Procedures:

During the first visit, demographic and anthropometric measures were taken. The remaining test procedures were identical between sessions with the exception of the participant being loaded or unloaded during the warm-up and performance of the perceptual task for maximal leaping affordability. For the loaded session, participants were outfitted with a weighted vest worn around the shoulders and chest. The vest was adjusted to 30% of bodyweight (BW), representing an average load for occupational athletes [19]. The weighted vest was only worn during the warm-up and while performing the perceptual task.

2.1.1 Incremental Fatigue Protocol:

The incremental fatigue protocol was performed on a treadmill and was developed based on the protocol described in two previous studies [20,21]. Slight alterations were made so that each sub-maximal stage included a set intensity and the final stage was performed to a fatigued state (volitional fatigue).

Resting measurements for heart rate, ratings of perceived exertion using the Borg scale (6-20), and ratings of fatigue using the Profiles of Mood-state questionnaire for Fatigue (0-20)[22,23] were first collected. Next, familiarization trials for the perceptual task were performed. Participants were then given a 10-minute warm-up at 5.6 km/h and 0% incline, either loaded or unloaded. For the loaded session, this allowed participants to become calibrated to the weighted vest prior to baseline measurements of the perceptual task. This was the only portion of the session for which the participant was loaded while on the treadmill. Following the warm-up, the fatigue protocol consisted of 4 stages, progressing from a light intensity through volitional fatigue. An outline of each stage and the measures taken is provided in Figure 1.

Heart rate reserve was determined by subtracting the participant's resting heart rate from their age-predicted maximum heart rate (220-age). For the first three stages, only treadmill speed was adjusted to obtain the necessary heart rate zone. For the fatiguing stage, participants started at the final speed used for the high intensity stage and treadmill incline was increased 1% every minute until volitional fatigue. Treadmill speeds were recorded during the 1st testing session and matched for the 2nd to ensure identical workloads. Heart rate and ratings of perceived exertion were monitored continuously and recorded every 5 minutes. The perceptual task was performed again at the end of every stage. The Profiles of Mood-state fatigue questionnaire was administered once more, directly after volitional fatigue was reached.

2.1.2 Perceptual Task:

The perceptual task for maximal leaping affordance was developed based on leaping tasks described in a previous study [5], with adjustments to allow for the measurement of reaction time. Participants were first outfitted with Senaptec Strobe Training Eyewear (SENAPTEC LLC, Beaverton, OR), which were customized and integrated with force plate software (Vicon Nexus 2.6.1, Oxford, UK) to allow for the blocking of vision to be auto-controlled and synchronized with ground reaction force data. The set-up for the task (Supplemental Figure 1) consisted of an approximately 1.2x4.6 meter runway, extending from two force plates (Kistler, Winterthur, Switzerland). A colorless rubber mat was used to cover the runway and a white rubber line (approximately 0.08 x 1.2 m) was used as the jump marker.

The task procedures were explained and warm-up jumps were given (minimum of 3). Participants then completed the jumps for maximal distance. Participants started with either foot on two force plates in a parallel stance and feet shoulder-width apart. They were instructed to jump as far as possible while still successfully landing on both feet. Three jumps were performed, with 1-minute rest in between, and the furthest of the 3 was recorded. This distance represented the participant's action boundary for the affordance of maximal leaping (Range of Distances at Baseline (m): Unloaded = 1.15-2.43, Loaded = 0.96-2.01) Only two maximal jumps were used to reassess the action boundary at the end of every exercise stage.

For action boundary perception trials, participants began facing away from the force plates and with their vision blocked (eyewear lenses completely dark). A marker was placed at a percentage of their action boundary: 95, 100, or 110%. These distances were selected based on pilot testing, finding that distances below 95% or above 110% were too easily discernible as jumpable/not jumpable. After the marker was placed, participants were moved to the starting position on the force plates and instructed to 'get ready'. At a period of 1-2 seconds later, the participant's vision was cleared and they assessed the jump distance presented by the marker. If they deemed the distance to be jumpable, they responded by performing the action (Supplemental Figure 1). If they deemed it to not be jumpable, they stepped off the force plates to the side. Participants were instructed to assess the jump distance as quickly and as accurately as possible. No verbal feedback on the accuracy of responses was given.

After each trial, participants were given a short rest while the marker was reset. Order of jump distances was block-randomized (block = 3 jumps) so that each distance appeared the same number of times but in a random order. Jump order was matched between sessions. Prior work at our lab found excellent reliability (ICC = 0.930) with 12 familiarization jumps at the beginning of a session, and 6 testing jumps for data collection at each measurement timepoint. Trials were collected as quickly as possible after each exercise stage, with a mean time to complete all jumping trials from the end of exercise of 4.7 ± 0.4 min.

2.2 Data Reduction:

The accuracy of responses (ACC) on the perceptual task was calculated as a percentage of total trials where an accurate assessment was made (i.e., where either jumping was afforded and the participant jumped or jumping was not afforded and the participant did not jump). Participants were almost 100% successful on trials where they decided to jump and the marker was within reach (Mean Success Rate = 97.48 ± 2.69% of total trials). Therefore, this variable was not considered in the analyses. The initiation of perceptual responses was quantified using reaction times (RTs). For each trial, the RT was calculated as the time interval (ms) between participants receiving visual information (clearing of eyewear) and a decrease in vertical ground reaction forces > 10% BW. Finally, rate of force development was calculated at baseline and each stage of the fatigue protocol, using the vertical ground reaction forces from maximum jump trials. The start of the concentric phase was defined as the first minimum value in the force curve, indicating the eccentric to concentric transition. The end of the concentric phase was defined as the point of maximum forces, indicating the feet beginning to leave the force plate. Rate of force development was calculated as the average rate of change in vertical forces, or the average slope, across this interval. For each set of 2 maximal jumps, the peak value was used. These procedures were shown to have good reliability in pilot testing (ICC = 0.671).

2.3 Data Analysis:

IBM SPSS Statistics 23 (IBM, Armonk, New York) was used for all statistical analyses (α = 0.05). Descriptive statistics were calculated for all variables and normality was checked with Shapiro-Wilk tests. Mauchly's test of sphericity was used to check for homogeneity of variance/covariance, and Greenhouse Geiser corrections were applied in the case of violations. Maximal heart rates close to 100% of age-predicted max were considered indicative of fatigue. Further, increases in ratings of perceived exertion on the Borg Scale and Profiles of Mood-state fatigue scores, as well as decreases in maximum jump distance and rate of force development, were considered indicative of fatigue. As tests for mean differences indicated no significant differences, all these variables were averaged across testing sessions. Paired t-tests were used to test for mean differences in maximum jump distance and rate of force development between peak (occurring after the moderate-high intensity stages) and post-fatigue measurements.

To assess the main and interactive effects of increasing exercise intensity through fatigue and load carriage on RT, a 2 (loaded vs unloaded) x 5 (exercise stage: baseline through fatigue) repeated measures ANOVA was used. The interaction term (load x exercise stage) was considered as well as main effects of load and exercise intensity. Pairwise comparisons were performed using a Bonferroni correction. Both the linear and quadratic terms were considered.

For ACC, the range of scores was found to be limited, with most participants making one or fewer errors within testing blocks. Therefore, to analyze the interactive effect of exercise intensity and load carriage, delta scores were calculated for differences in ACC between loaded and unloaded sessions (delta score = mean ACC in unloaded condition - mean ACC loaded). Friedman's test was used to test for mean differences across exercise stages (delta score x exercise stage). Participants were then dichotomized into "poor" and "good" performers, using a median cut-off of 83.33%. Cochran's Q tests were used to test for the main effect of exercise intensity, and McNemar's test was used to test for the main effect of load carriage, on ACC.

3.0 Results:

Mean heart rate and perceived exertion increased steadily across exercise stages, as expected. The mean observed maximum heart rate, expressed as a percentage of each participants age-predicted max, was 98.62 ± 3.81%. Large changes were observed in mean ratings of perceived exertion (Mean change = 13 ± 1, or 94% of total scale) and fatigue scores (Mean change = 16 ± 2, or 80% of total scale). Finally, results of paired t-tests revealed significant differences between peak- to post-measurements for both maximum jump distance (Mean Change (cm) = -7.96 ± 7.17, $p < 0.01$, $d = 0.26$) and rate of force development (Mean change (N/s) = -802.10 ± 716.24, $p < 0.01$, $d = 0.51$). Finally, peak levels or changes in variables are consistent or larger than those previously reported on similar fatiguing protocols.[20,21,24]

3.1 Reaction Time:

A repeated measures ANOVA (Figure 2) showed no significant interaction of exercise intensity and load carriage on RT (F (2.7,59.8) = 0.390, $p = 0.82$), even when the quadratic term was considered ($F = 0.011$, $p = 0.92$). However, a main effect of exercise intensity was found to be significant, with the quadratic term showing a better fit (F (1,22) = 18.587, $p < 0.01$, η_p^2 =

0.458). Pairwise comparisons revealed a significant decrease in mean RT between baseline and moderate intensity stages (Mean Difference (ms) = -38.25 ± 11.90, p = 0.04, d = 1.43), and a significant increase in mean RT between the moderate intensity and fatigue stages (Mean Difference (ms) = 38.82 ± 11.33, p = 0.02, d = 1.34).

3.2 Accuracy of Perception Responses:

Friedman's test for differences in delta scores (loaded vs unloaded) revealed no significant interaction of exercise intensity and load carriage on ACC (Friedman's Statistic (4) = 1.70, p = 0.79). Results of Cochran's Q tests revealed no main effect of exercise intensity (Cochran's Q (4) = 0.65-5.96, p = 0.20 - 0.96), and results of McNemar's test revealed no main effect of load (Chi-Square (1) = 1.00, p = 0.51) on the percentage of participants categorized as "good" performers for ACC (Figure 3). Raw ACC data are presented in Figure 4.

4.0 Discussion:

The purpose of the current study was to establish the effects of fatigue and load carriage on the perception of maximal leaping affordances. A secondary purpose was to establish the effects of increasing, sub-maximal intensities.

The observed responses in RT and ACC after fatiguing exercise are partially in line with previous research. Pijpers et al. [16] reported no differences in ACC for maximum reach height after a fatiguing bout of rock-climbing. However, several methodological differences limit the interpretability of their results, including: a) sample of only females, b) perceptual task and exercise protocol performed on the same apparatus, meaning that participants were receiving significant exploration during the exercise protocol, c) fatigue protocol not performed to volitional fatigue and objective criteria (blood lactate and change in reach distance) indicating that participants were not significantly fatigued. Further, no measure of the timing of perceptual responses was obtained by the previous authors. Therefore, even if these methodological flaws are overlooked, the current study provides a more complete picture of perceptual-motor coordination in response to fatigue.

Our results indicate that during fatiguing exercise, accuracy of action boundary perception may simply be maintained by increasing the time over which the perceptual-motor responses are initiated. This was evidenced by increases in mean RT through the high intensity to fatiguing exercise stages, coupled with no observed changes in mean ACC on the perceptual task. This is an important finding, given that a wealth of literature has demonstrated full and rapid recalibration to changing action boundaries in response to other perturbations [18,25,26]. Traditionally, calibration has been defined in terms of perceptual accuracy for action boundaries (i.e. higher accuracy means a more calibrated state).[2] However, we would argue that a more wholistic approach, in terms of including how quickly perceptual decisions are made, needs to be considered in defining the state of calibration. As discussed previously, this is especially true for athletes and individuals in active occupations. For these populations, affordances are rarely static, where opportunities for action may be present and gone in a matter of milliseconds. Therefore, the accurate and **rapid** detection of relevant information within the environment, along with the integration of how this information relates to one's movement capabilities and boundary, is imperative.

As such, it is likely that delays in the movement initiation may have just as severe of implications as inaccurate perception. These delays could effectively limit an individual's available affordances, thereby increasing the likelihood of risky movement pattern selection and subsequent occupational falls, collisions or other types of injury. For example, an athlete in a fatigued state may take a second longer to perceive their affordance for cutting between two defenders. In that time, the gap between the defenders closes. It may be that the optimal movement decision is now to stop and not attempt to reach the point beyond the defenders. However, the constraints of a competitive, sporting environment are such that the athlete is likely to attempt to still carry out the movement task. Therefore, the available affordances for the athlete are now to: a) attempt quickly change direction to cut around defenders, where risky movement patterns leading to musculoskeletal injury are more likely, or b) still try to go through the gap, where a collisions leading to injury or concussion are more likely. This is supported by the work of Eagle et al. [27] demonstrating an association between concussion risk and deficits in response time to a perceptual-motor control task, with no deficits in perceptual accuracy. However, future research is needed in confirming how these deficits in the time taken to perceive affordances translate to behavioral risk in a normal athletic or physically demanding occupational environment.

The hypotheses for the effects of sub-maximal exercise intensities were also partially confirmed, with RTs decreasing through light/moderate intensities and then increasing again through higher intensities. Furthermore, the main effect of exercise intensity showed a large effect size ($\eta_p^2 > 0.25$)[28]. While no previous literature has reported the effects of increasing exercise intensity on perceptual-motor coordination, these results do mirror previous reports on cognitive/psychomotor measures [10,15]. This quadratic effect of increasing exercise intensity has been termed the "inverted-U" hypothesis and is thought to be due to a general-arousal effect of sub-maximal exercise [15]. Our results provide further support for this effect, demonstrating that initiation times for perceptual-motor responses are also improved through moderate intensity exercise. For athletes and individuals in active occupations, these results indicate that consideration should be given to providing a “warm-up”, at light to moderate intensities, before initiating strenuous or high-risk activities.

This is the first study to address the interactive effects of fatigue and load carriage on perceptual-motor coordination. It is surprising that no interaction was found, given the inextricable link between fatigue and load carriage [11,12]. However, there was also no detectable, independent effect of load carriage on RT or ACC, indicating that participants were able to successfully calibrate to the additional loads and maintain performance during perceptual trials. This is in-line with several previous studies assessing the effects of load carriage on the accuracy of perception of maximum jumping-reach height and horizontal jumping [17,18]. However, our results add significantly to these previous findings, demonstrating adequate recalibration in response to magnitudes of load that are more occupationally relevant (30% compared to 5-10% BW).

In addition, the current study provides contrasting results to two previous studies demonstrating significant decrements to perceptual-motor coordination in response to load carriage [29,30]. For one of these studies, no control condition was utilized [29]. However, a second study by Palmer et al. [30] found significant increases/reductions in RTs/ACC with 2.5 - 45% of BW loads. One explanation for our divergent findings may come from the dual-task paradigm utilized by Palmer et al. [30], with participants required to perform a drop-landing and then immediately react to a marksmanship task. Movement tasks during real-life scenarios are often coupled in a similar nature to this task. Therefore, this presents an interesting comparison for future research, addressing whether added attentional demands/task constraints mediate the effects of load carriage on perceptual-motor coordination. It also may be that a lack of exploration in the previous study can partially explain the differences in findings. The author’s do not report whether exploration was or was not allowed prior to performing the perceptual task. However, the current study did allow for some exploration, with familiarization trials given prior to each session and maximal jumping trials prior to each measurement point.

The current study holds several limitations, that should be recognized. First, we did not obtain kinematic measures during the perceptual task. This was due to pragmatic concerns related to completing trials as quickly as possible after each exercise stage. Previous studies have demonstrated alterations to movement strategies during an affordance-based task in response to load carriage. Consequently, we may not have captured some of these associated changes [30,31]. Finally, the stages of the IFP were determined using predicted maximal heart rates. However, age-predicted maximal heart rates have been shown to be accurate at a population level. Further, the mean maximal heart rate reached during the IFP was 98.62% of participant's predicted max.

In conclusion, the current study demonstrated deficits in the initation of perceptual-motor responses (increased RTs) after fatiguing exercise, in comparison to optimal RTs seen after light to moderate intensity exercise. However, no effect on perceptual accuracy was observed. These results point towards a trade-off between the speed and accuracy of responses during fatigue. For athletes and active occupations, such as police, firefighters and military, this delay in the initiation of a movement response has the potential to limit available affordances for movement, resulting in increased behavioral risk and serious outcomes. The current study also found a quadratic effect of increasing exercise intensity on perceptual-motor coordination, with improved initiation times for perceptual responses through moderate intensities, coupled with the maintenance of accuracy. These results indicate that warming-up prior to strenuous/demanding activities may help to mitigate the behavioral risk associated with inadequate perceptual-motor coordination. Finally, there appeared to be no effect of load carriage on perceptual responses.

Future research is needed to determine the load magnitudes, if any, beyond which action boundary perception accuracy is compromised.

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Figure Captions:

Figure 1: IFP stages and measures taken during and post-exercise

- HRR = heart rate reserve, HR = heart rate, RPE = rating of perceived exertion, POMS = Profiles of Mood-state questionnaire

Figure 2: Interaction of exercise intensity and load carriage on RT

- ms = milliseconds
- Error bars indicate 95% confidence intervals
- * indicates significantly different from baseline/fatiguing stages ($p<0.05$)

Figure 3: Percentage of participants scoring in "good" category for %AJ by exercise intensity

- Participants dichotomized at a cut-off of 83.33% for perception-action accuracy (i.e., >83.33% accuracy categorized as "good")

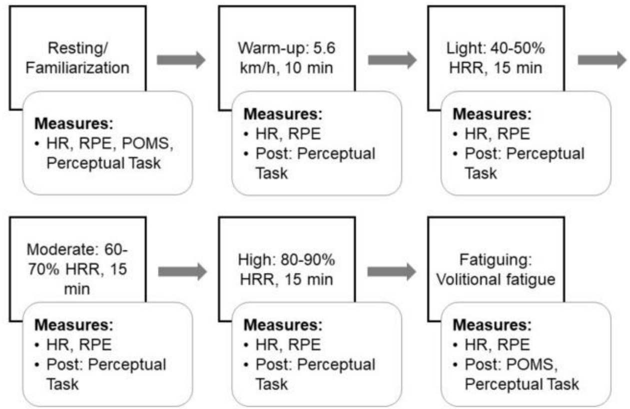
Figure 4: Mean perception-action accuracy by exercise intensity and load carriage condition

- Error bars indicate 95% confidence interval

Supplemental Figure Captions:

Supplemental Figure 1: Experimental set-up for the perceptual task and example of two response types

- A: Starting position, B: Jumping to indicate the marker is within reach, C: Stepping off to indicate the marker is not within reach



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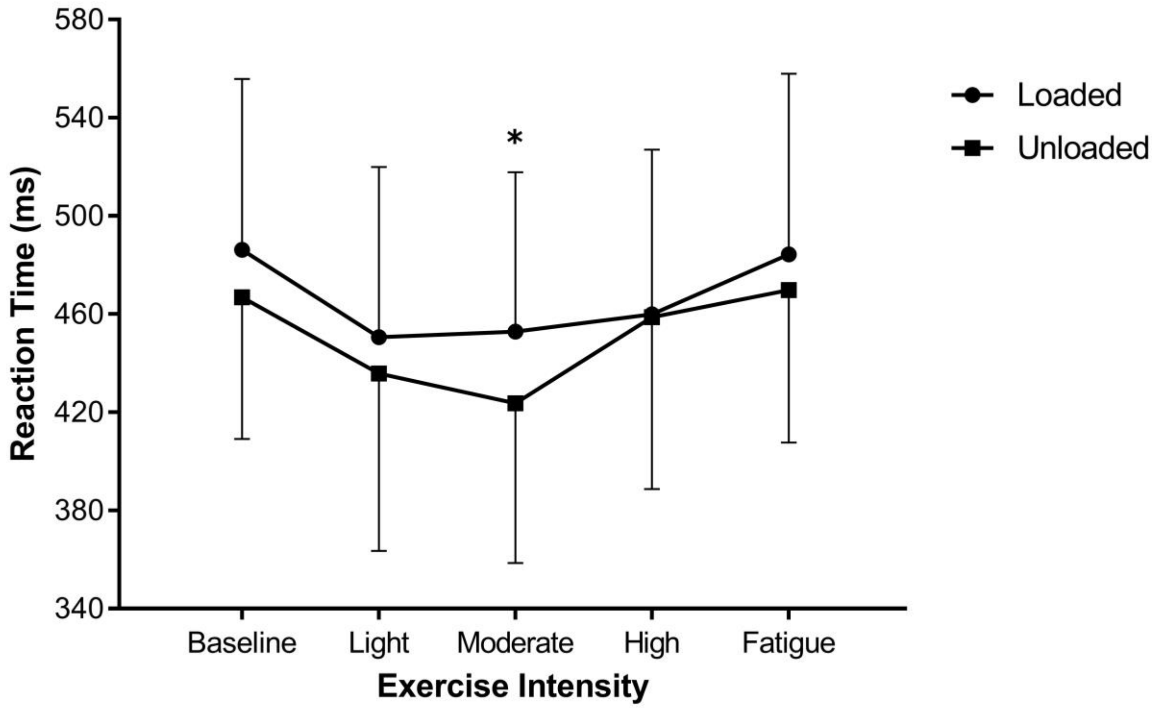

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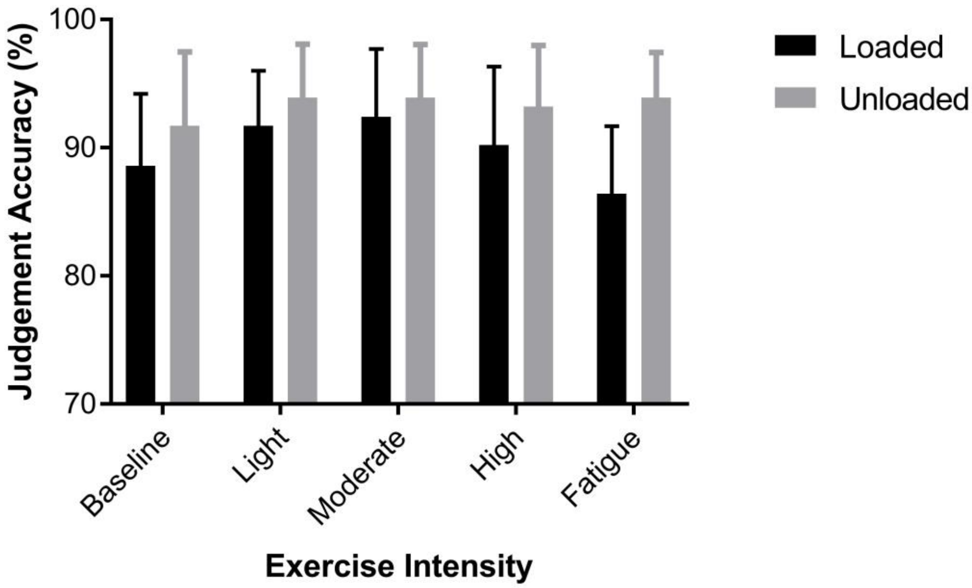

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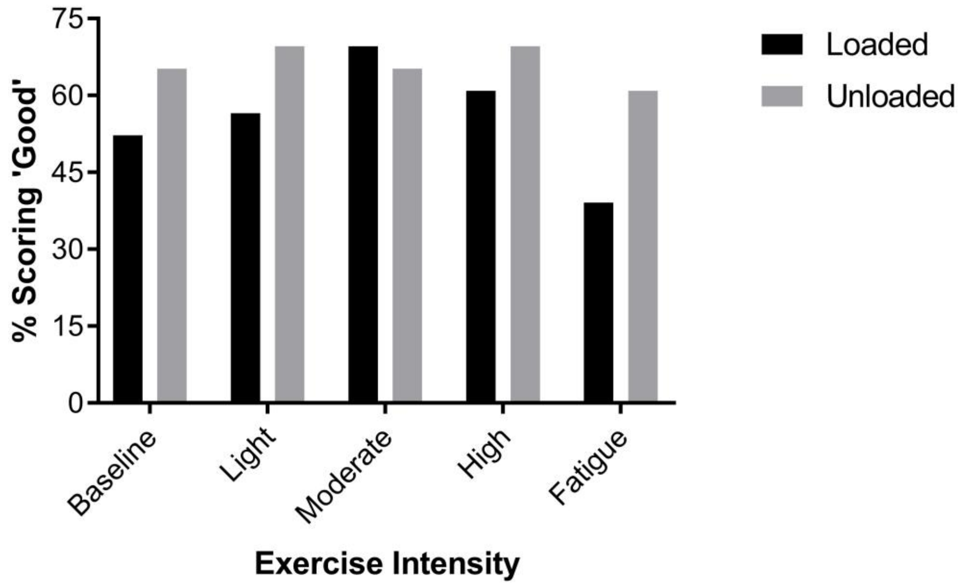

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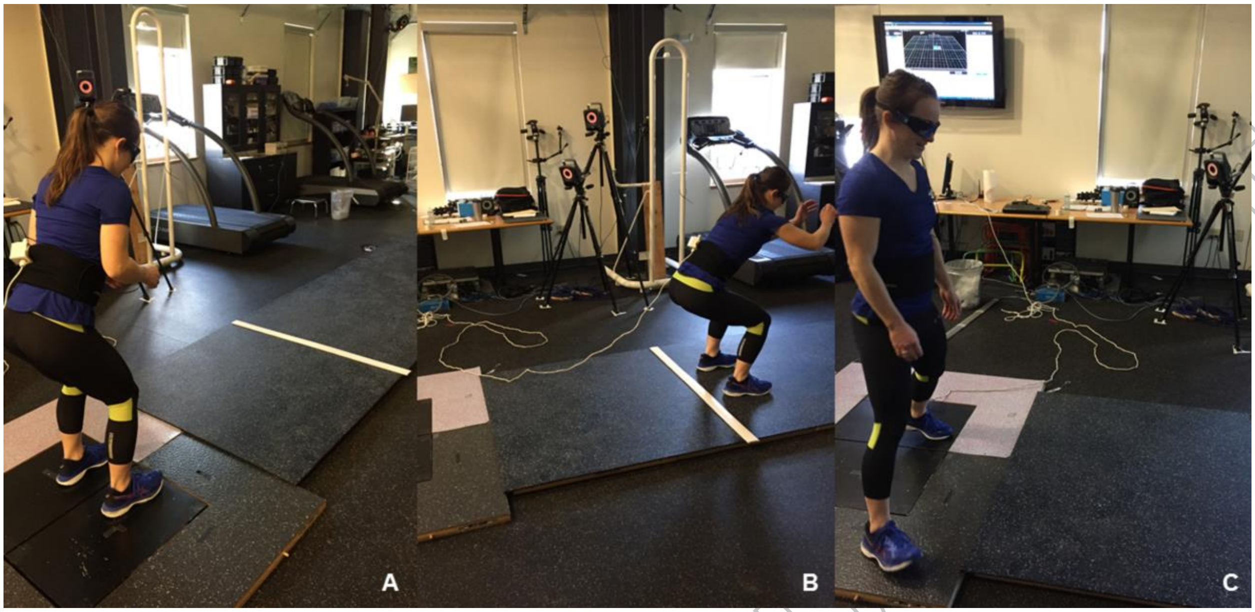

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