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Perception of safe horizontal reaching distance changes with repetitive occupational loading in novice lifters

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Abstract

Safe work behaviours rely on accurate perceptions of injury risks, and workers who have a misperception of risk can be injured. Despite the importance of perception-action coupling, little is known about modification of those perceptions with changing physical or cognitive STATE. It is hypothesized that changing values for perceived affordances could evidence these modifications. A better understanding of how worker characteristics (e.g., level of fatigue) affect perceptions of affordance and their corresponding behaviours, may help when developing strategies for ergonomic best practices, particularly in manual material handling (MMH) activities. The aim of this study was to compare safe perceptions of affordance from workers that completed repetitive STATE loading. Seventy-five novice MMH workers (23 male; mean age = 21.43, SD = 3.24) made perceived affordances of their safest horizontal reaching distance (acceptable limit) to complete a model task. STATE loading consisted of physical or cognitive fatigue or a control. The levels of fatigue were assessed at five-minute intervals using Ratings of Perceived Exertion (RPE) values and Multi-Fatigue Inventory (MFI) values, respectively. A significant main effect of TIME indicated a decrease of perceived safest reaching distance observed from baseline through subsequent measurements ($p<.001$). The magnitude of these changes did not differ significantly between groups, suggesting that general learning more than specific STATE loading may be a major contributor to modification of affordance perceptions. However, it remains important to consider TIME and STATE influences on perceptions for safe occupational handling. Novice workers' initial perceptions of safe working affordance may put them at risk for soft tissue injury. Physical and cognitive loading similarly affect perceived safe affordances.

Keywords: Affordance; Perception of safety; Physical fatigue; Cognitive fatigue; Manual materials handling; Ergonomics; Human factors

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1. Introduction

The ecology of human performance framework was developed to model the influence of one's abilities and perceptions on motor performance [1]. Workers with different sensorimotor, cognitive, and psychosocial abilities may make different work-related affordance perceptions, and subsequently prepare and produce different actions and behaviours. In this model, affordances are defined as a perceived resource or opportunity that the environment provides the worker. Transient changes in sensorimotor, cognitive, and psychosocial abilities are called state changes, and studies have suggested that perceptions of affordance can be affected by a subject's state. For example, people who completed an exhausting run or carried a heavy backpack perceived a hill as steeper than those who were rested and not wearing a backpack [2]. In a similar study, rock climbers who had climbed to fatigue decreased their perception of maximum reaching distance [3]. Behaviour-based safety programs have indirectly targeted the interaction between workers' perceptions of occupational affordance and workplace behaviours [4], recognizing that acute injuries may result if workers misperceive occupational affordances, and subsequently behave in risky fashion.

Less study has been directed at intersections between affordance and chronic musculoskeletal injury risks, and state influences on those same perceptions. Physical [5] and cognitive [6] fatigue are both musculoskeletal injury risk factors , and workers should decrease occupational affordances (and subsequently occupational loading) as physical fatigue increases. Landmark studies in occupational psychophysics [7] have defined progressively decreased maximum acceptable weight of lift with increasing repetition and duration of loading, but other distance-based lifting parameters have received less study. Given the importance of trunk postures in regulatory [8] and experimental [9] spinal loading, understanding work-related changes in perceived affordances may be critical for developing appropriate and dynamic occupational safety guidelines.

The aim of our study was to investigate whether perceptions of occupational affordance, specifically safe horizontal handling distances, change amongst novice workers exposed to repetitive occupational loading. We hypothesized that workers would decrease their perceived safe horizontal reaching distance following repetitive occupational loading. We also hypothesized that cognitive and physical loading, and high and low levels of loading, would have different effects on workers, with high physical loading leading to the greatest reductions to perceived safe reaching distance. These results could inform occupational safety programs, wherein different and progressive physical and administrative work controls might be employed to protect physically or cognitively fatigued workers.

2. Methods

2.1. Participants and groups

Seventy-five novice lifters, aged 17 to 39 years (23 male; mean age and SD=21.43 ± 3.243 years) from various undergraduate classes at the University of Lethbridge (Lethbridge, AB) participated in exchange for course credit. All participants reported normal or corrected to normal vision. The participants provided informed written consent before enrollment into this study. The study was approved by the University of Lethbridge Ethics Committee. Each participant was randomly assigned to a physical, cognitive, or control STATE manipulation group, and all participants completed both a HIGH and LOW intensity testing session, one week apart, with start-order counter balanced between participants. The physical STATE manipulation group (n=30) held a manipulation suitcase (67.3 L, 2.5 kg) while performing step-ups. The HIGH intensity protocol used a step 24 cm high, whereas the LOW intensity protocol used a step 9.5 cm high. An electronic metronome was used during HIGH intensity sessions (48 bpm) and LOW intensity sessions (30 bpm) to keep pace with a stepping beat. The cognitive STATE manipulation group (n=30) tried to complete a 100 piece jigsaw puzzle (23 cm x 31 cm) with an age recommendation of 5+ years-old (Prime Motion 3185 J. B. Descamps, Lachine, QC, 2011). The puzzle was placed in a plastic bag and presented to the participants upon a table (107 cm [L] x 77 cm [W] x 69 cm [H]. The completed puzzle image was displayed on the puzzle box, which was kept in view of the participant. An electronic metronome was used during HIGH and LOW cognitive STATE manipulations to maintain consistency across the manipulations. The control STATE manipulation group (n=15) watched a passive television sit-com (WKRP in Cincinnati). An incandescent lab (60W, 130 V) was used to illuminate the STATE manipulation area for all groups.

2.2. Experimental procedure

The first experimental session started with the recording of participant height plus the completion of both a physical activity readiness questionnaire (PAR-Q+) [10] and a demographics questionnaire. During both experimental sessions, participants completed the perceived affordance protocol. Under this protocol, participant were asked to stand in a marked area on the floor (40 cm x 40 cm), facing a mounted suitcase. They were instructed not to touch the suitcase at any time during the task. The target suitcase (54.57 L) was attached by a custom mount to the handle of the linear motion device (LMD) attachment for the LIDO WorkSET system (Loredan Biomedical, Inc.). The LMD was positioned in the horizontal orientation (Figure 1). The mid-point of the suitcase was set to 53% of the participant's height above the floor. A nylon strap was attached to the handle of the LMD to allow the investigator to pull the suitcase horizontally away from the participant. A script involving an MMH task, adapted from [11], and instructions on how to perform the task was read to the participant prior to each affordance measure to ensure he or she had some mental image of the experimental task (Appendix A). Participants determined their safest perceived horizontal reaching distance (acceptable limit), using a psychophysical method, where their perceived safest horizontal reaching distance could be adjusted by asking the investigator to reposition the luggage as many times as necessary. The investigator measured and recorded the participant's perceived affordance of the suitcase out of the participant' field of view.

2.3. Measures

The MFI [12] with an adapted five-point scale was used to self-report cognitive and physical fatigue over short intervals. Previous research involving rating scales for measuring subjective fatigue use the MFI as it is better suited for measuring changes in fatigue over short intervals [13, 14]. Each participant was asked to complete the inventory answering the question "How do you feel at this exact moment". For each question, a 5-point rating scale consisted of anchors of 1 (no problem at all), 2, 3 (moderate problem), 4, 5 (severe problem).

The body part discomfort scale [15] was combined with a modified 5-point Borg's Rating of Perceived Exertion Scale (RPE) to self-report physical exertion for the physical fatigue test group. The participant was asked to complete a survey reporting "How do you feel at this exact moment". A 5-point scale for each body part in addition to the whole body using a scale. The scale consisted of numbers 6-20, with identifiers at 6 (no exertion), 11 (fairly light exertion), 14 (hard exertion), 17 (very hard exertion), and 20 (maximal exertion).

Fig. 1. Participant standing in a marked area in front of the target suitcase (54.57 L) mounted on the LMD of the LIDO WorkSET.

All STATE manipulation groups and control produced a baseline perceived affordance value at TIME 0. Participants were then asked to complete a questionnaire establishing levels of fatigue at TIME 0. The cognitive STATE manipulation group levels of fatigue were assessed using the MFI, and the physical STATE manipulation group levels of fatigue were assessed using the RPE questionnaire [12]. The control group completed the MFI at TIME 0 in session 1, and the RPE at TIME 0 in session 2. The measurements were used as baseline values.

After baselines were established, participants in all STATE manipulation groups were read a fixed script with a repetitive MMH task to complete (See Appendices B.1, B.2. B.3). A total of seven intervals, 5- minutes in duration, were performed with perceived affordance fatigue measures taken at T0 (baseline), T5, T10, T15, T20, T25, and T30.

2.4. Data collection and analysis

Affordance data were processed offline using IBM SPSS Statistics 21 and Microsoft Excel (2007 edition). Data were normalized by dividing the recorded perceived safest horizontal reaching distance by the participant's height. The mean normalized horizontal affordance data were calculated for the baseline and 7 trials and reported as a percentage of height. Separate repeated measures ANOVA's were used to validate the intensity levels for both state (cognitive and physical fatigue) manipulation groups. There were no missing values for any of the variables, nor signs of skewness, kurtosis, or outliers. Mauchly's test for sphericity was significant for all ANOVAs so Greenhouse-Geisser corrections were used for all tests. Follow up polynomial contrasts were used when appropriate for with-in subject comparisons. Between-subject post-hoc tests using a Tukey (HSD) method were used when warranted.

3. Results

3.1. State manipulation

Figure 2 provides of RPE values for both HIGH and LOW physical STATE levels, compared to a control. The physical STATE manipulation resulted in a progressive increase in RPE at both intensity levels. A repeated measures ANOVA was used to determine whether a difference existed between the physical STATES and the control using RPE values. A significant main effect for TIME, F (3.309, 1186.248)=36.387, $p < .001$, $\eta^2=0.336$ and interaction effect between TIME x STATE, F (6.617, 1186.248)=15.261, $p < .001$, $\eta^2=0.298$ were determined. Follow-up polynomial contrasts also identified a significant linear value $p < .001$ for the 'TIME x STATE' interaction. Tests of between-subjects effects showed a significant difference for STATE (control, low-, and high physical exertion), F (2, 72)=28.53, $p < .001$, $\eta^2=0.442$. Post-Hoc tests using a Tukey (HSD) method produced a significant difference between the control and LOW physical loading p=.046, control and HIGH physical manipulation $p < .001$, as well as between low and high physical exertion $p < .001$. The high physical fatigue manipulation only recorded a maximum average value of approximately 14.2 (somewhat hard exertion) and the low physical fatigue manipulation recorded a maximum average value of 9.4 (light exertion).

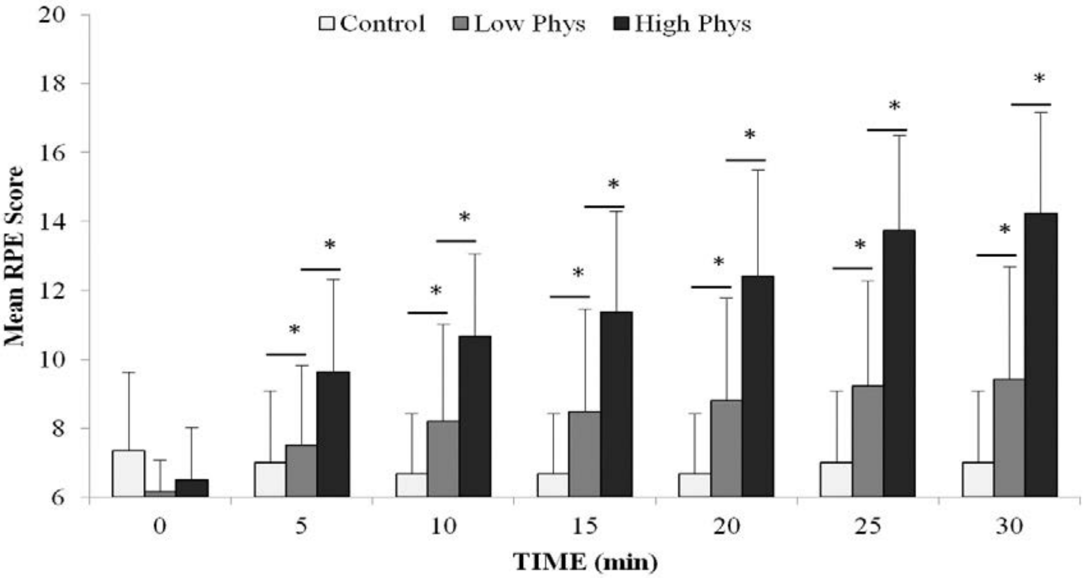

Fig. 2. Mean (n=15 control, n=30 low physical, n=30 high physical) RPE scores and standard deviation (indicated by error bars). Possible scores consisted of 6- no exertion, 11-, 14-moderate (somewhat hard) exertion, 17–, 20 – maximal exertion. Scoring number and scale description terms were taken directly from the Borg RPE scales (Borg, 1970, 1984, 1985, 1989).

The cognitive STATE manipulation led to a progressive increase in MFI for both intensity levels. A repeated measures ANOVA determined that no group effect existed between LOW and HIGH cognitive STATES, F (2, 72)=0.448, p < .641, η^2=0.012. A significant TIME effect, F (1.648, 118.670)=6.024, p < .001, η^2=0.206, suggests that within group MFI values increased from pre-test (M=1.504, SD=.5278) through TIME 30 (M=1.850, SD=.8054). This result indicates the tasks our cognitive loading and control groups performed were too similar.

3.2. Measured Affordances and Mechanical Effects

A significant main effect of ‘TIME’ indicated a decrease of perceived horizontal reaching distance observed from the baseline and through subsequent measurements throughout the duration of the experiment, F (2.959, 429.102)=14.711, p<.001, partial η^2=0.92. There were significant follow-up paired sample t-test results across all states from TIME 0 to TIME 15, after which only a non-significant decreasing trend occurred. All state manipulations and the control displayed significant decrease in mean perceived horizontal affordance (normalized) for safe MMH through time (Figure 3a). There was no effect for the interaction between TIME and STATE, F (11.837, 429.102)=0.654, partial η^2=0.018.

A repeated-measures ANOVA was used to determine whether perceived horizontal affordances for safe MMH change with time, and whether those changes were affected by state manipulation (cognitive –, physical exertion) at two-intensity levels (low, high) compared to a control. A significant effect for TIME, F (2.959, 429.102)=14.711, p<.001, η2=0.092. All state including the control displayed a significant decrease in mean perceived horizontal affordance for safe MMH through time. There was no effect for the interaction between ‘TIME’ and ‘STATE’, F (11.837, 429.102) =.654, η^2 =0.018.

The RWL for all state groups were calculated using the 1991 NIOSH lifting equation (RWL=LC x HM x VM x DM x AM x FM x CM). A 23 kg LC and calculated mean AM for each experimental state were used; all other multiplier values were set equal to 1. A one-way ANOVA was conducted to evaluate the relationship between RWL and STATE, F (4, 74)=0.137, p=.968, indicating no main effect for STATE.

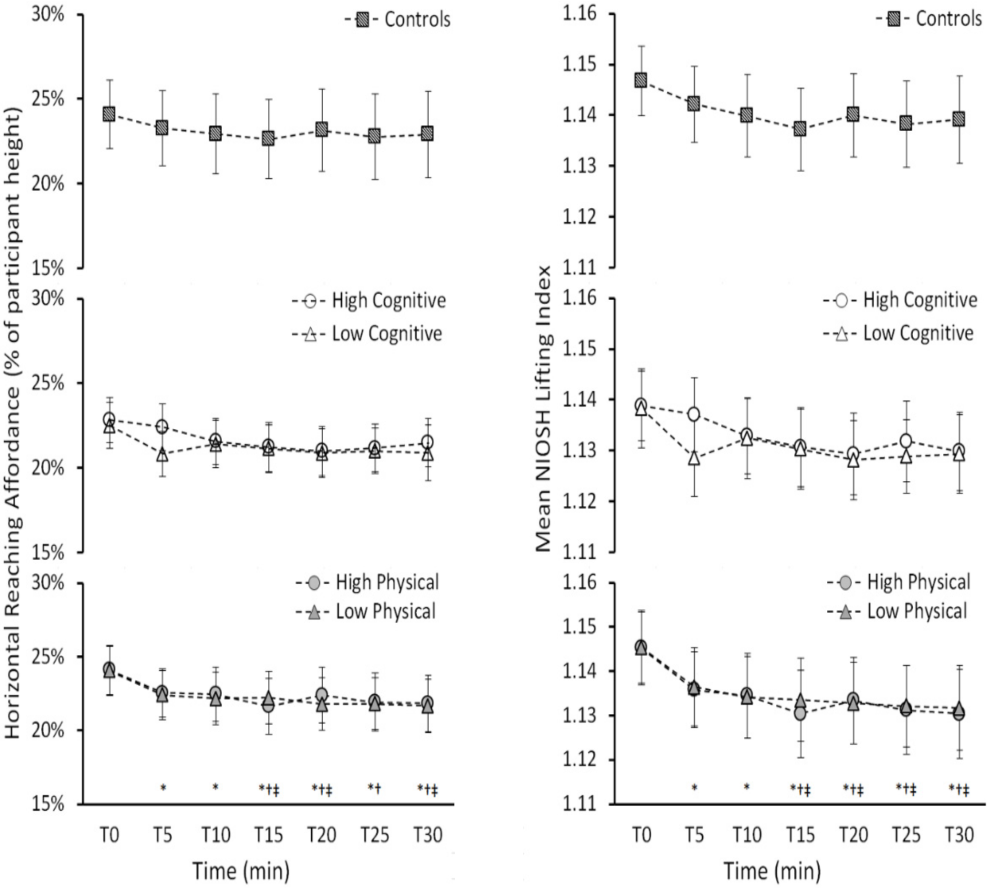

Fig. 3. (a) Mean perceived affordance (n=15) for each state manipulation; (b) Mean NIOSH lifting index (LI) for safe MMH (normalised by height). Affordance and LI were calculated pre-test (T 0) and in 5 minute intervals (5, 10, 15, 20, 25, and 30 minutes post T0). The measurements were recorded immediately after each 5 minute intervals state manipulation. * denotes p<0.05 from baseline (T0), † p<0.05 from T5, ‡ denotes P<0.05 from T10.

There was an effect of TIME, showing an increase in RWL from TIME 0 (M=20.15 kg, SD=0.75) to TIME 30 (M =20.35 kg, SD=0.88), F (3.081, 446.712)=18.393, $p < .001$, $\eta^2=0.113$. The NIOSH LI (Figure 3b) displays the reciprocal of the RWL with a decline over TIME, F (3.278, 475.284)=16.465, $p < .001$, $\eta^2=10.2$, indicating that asymmetrical angles based on perceptions were decreasing. It should be noted that including horizontal, coupling, and frequency relevant to this task, would have raised initial LI values and posed a greater initial risk of injury to workers.

4. Discussion

This study aimed to investigate whether perceived affordances for safe horizontal reaching change amongst novice workers exposed to repetitive occupational loading. Results indicate that perceived affordances decrease repeated affordance making. Mechanical effects of lateral reaching distance are reflected in the calculated NIOSH lifting index (LI) values, when workers were consistently at risk (LI >1.0) for lifting and related low back pain and injury [8]. These LI values were similar amongst all occupational loading groups, including control. Interestingly, the decrease in perceived affordance and LI occurred more prominently during the initial 15 minutes of loading, followed by an asymptotic phase through the final 15 minutes of loading. These results are supported by with a study where rock climber's perceptions of maximum vertical reaching distance decreased at the beginning of their trials when their RPE values were low [3]. This suggests changes of perceived affordances may not be strictly affected by a worker's state, but by experience from performing the perceptions. If a worker's accurate perceptions of safe affordance improve through experience, whether feedback is provided or not, workers that do not adjust their action / behaviour accordingly may be more prone to acute musculoskeletal injury [16, 17]. Workers need to be able to recognize changes in their capabilities, as these changes can occur subtly with increased occupational loading [3]. Recognizing these changes may allow workers to make short-term choices that mirror the coupling between their perception of safe affordances and actual capabilities and potentially reduce acute musculoskeletal injury. These results may inform occupational safety programs, wherein different and progressive physical and administrative work controls might be employed to protect physically or cognitively fatigued workers. Novice workers should be aware that their perceptions may vary considerably until (and after) accurate perceived affordances are formed.

Our second prediction that cognitive and physical loading, and high and low intensities of loading, would have different effects on workers, was not substantiated. Surprisingly, all groups displayed similar trends, also implying that a worker's state may have a minor effect on perceived affordances. Occupational safety programs should recognize that work controls should be given the same consideration to protect physically or cognitively fatigued workers as all groups displayed a significant decrease of safest horizontal reaching distances over the duration of the experiment from the baseline, prior to occupational loading.

To conclude, the observed change in perceived affordance may have been due to an experience effect, where practice with making perceived-safe affordance judgements were sufficient to bring about change.

Appendix A. Perceived Affordance Script

You are a baggage handler at an international airport. Your job is transferring suitcases horizontally from the baggage train on your right to a baggage conveyor on your left. This task is performed 5 times per minute for an 8 hour shift, which would include 7 hours of work and 1 hour of breaks. We want you to set the horizontal reaching distance for this task in such a way that you handle the bags as safely as possible, without causing pain or discomfort in your hands, arm, or back after that 8 hour period. You will select your safest horizontal reach distance by having the luggage moved closer or further away from you. Adjusting the safest horizontal distance is not a simple task – only you know how you feel, and where the luggage should be positioned for the safest horizontal transfer. If you feel the luggage is too close, have it moved further away. If you feel it is too far away have it moved closer. You have to many enough adjustments so that the luggage is set at your safest horizontal position. You can never make too many adjustments, but you can make too few.

Appendix B. STATE manipulation scripts.

B.1. Low/High Cognitive

You are an employee that has been assigned the task of working on this puzzle. You have (30, 25, 20, 15, 10, 5) minutes remaining. *Low Cognitive:* You can work at your own pace with no pressure to complete this puzzle. [Start metronome 30 bpm] Ready? Begin. *High Cognitive:* You only have (30, 25, 20, 15, 10, 5) minutes remaining. You need to work as fast as you possibly can. It is very important that you finish this puzzle in the allotted time. We will critique your progress by recording the number of completed pieces every 5 minutes. We will evaluate your overall performance based on the time it takes you to complete the puzzle. [Start metronome @ 48 bpm] Ready? Begin.

B.2. Low/High Physical

You are an employee that has been assigned the task of carrying suitcases up a step to where they will be stored. You have (30, 25, 20, 15, 10, 5) minutes remaining. Please step to the beat of the metronome. [Start metronome @ 48 bpm (High Physical) or 30 bmp (Low Physical)] Ready? Begin.

B.3. Control

You are an employee that is on a break. During your break you have decided to watch a television sit-com. You have (30, 25, 20, 15, 10, 5) minutes remaining. [Start Metronome @30 bpm] Ready? Begin.

References

[1] Dunn, W., C. Brown, and A. Mcguigan, The Ecology of Human-Performance - a Framework for Considering the Effect of Context. American Journal of Occupational Therapy, 1994. 48(7): p. 595-607.

[2] Bhalla, M. and D.R. Proffitt, Visual-motor recalibration in geographical slant perception. Journal of Experimental Psychology-Human Perception and Performance, 1999. 25(4): p. 1076-1096.

[3] Pijpers, J.R., R.R.D. Oudejans, and F.C. Bakker, Changes in the perception of action possibilities while climbing to fatigue on a climbing wall. Journal of Sports Sciences, 2007. 25(1): p. 97-110.

[4] Geller, E.S., Behavior-based safety and occupational risk management. Behavior Modification, 2005. 29(3): p. 539-561.

[5] Mehta, J.P., S.A. Lavender, and R.J. Jagacinski, Physiological and biomechanical responses to a prolonged repetitive asymmetric lifting activity. Ergonomics, 2014. 57(4): p. 575-588.

[6] Caruso, C.C., Possible Broad Impacts of Long Work Hours. Industrial Health, 2006. 44(4): p. 531-536.

[7] Snook, S.H., Design of manual handling tasks. Ergonomics, 1978. 21(5): p. 404-405.

[8] Waters, T.R., et al., Revised NIOSH equation for the design and evaluuation of manual lifting tasks. Ergonomics, 1993. 36(7): p. 749-776.

[9] McGill, S.M., R.W. Norman, and J. Cholewicki, A simple polynomial that predicts low-back compression during complex 3-D tasks. Ergonomics, 1996. 39(9): p. 1107-1118.

[10] Warburton, D.E.R., et al., Evidence-based risk assessment and recommendations for physical activity clearance: an introduction. Applied Physiology Nutrition and Metabolism-Physiologie Appliquee Nutrition Et Metabolisme, 2011. 36: p. S1-S2.

[11] Potvin, J.R., et al., A psychophysical study to determine acceptable limits for repetitive hwand impact severity during automotive trim installation. International Journal of Industrial Ergonomics, 2000. 26(6): p. 625-637.

[12] Paul, R.H., et al., Coginitive and Physical Fatigue in Multiple Sclerosis: Relations Between Self-Report and Objective Performance. Applied Neuropsychology, 1998. 5(3): p. 143-148.

[13] Krupp, L.B., et al., The fatigue severity scale: Application to patients with multiple-sclerosis and systemic lupus-erythematosus. Archives of Neurology, 1989. 46(10): p. 1121-1123.

[14] Smets, E.M.A., et al., The multidimensional fatigue inventory (MFI): Psychometric qualities of an intrument to assess fatigue. Journal of Psychosomatic Research, 1995. 39(3): p. 315-325.

[15] Corlett, E.N. and R.P. Bishop, Technique for assessing postural discomfort. Ergonomics, 1976. 19(2): p. 175-182.

[16] Yasuda, M., J. Wagman, and T. Higuchi, Can perception of aperture passability be improved immediately after practice in actual passage? Dissociation between walking and wheelchair use. Experimental Brain Research, 2014. 232(3): p. 753-764.

[17] Wagman, J.B., D.M. McBride, and A.J. Trefzger, Perceptual experience and posttest improvements in perceptual accuracy and consistency. Perception & Psychophysics, 2008. 70(6): p. 1060-1067.