The Effect of Mental Fatigue on The Risk of Falling

Laith Abuhaija

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Michael L. Madigan, Chair
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Ranjana Mehta

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ABSTRACT

Slips, trips, and falls are the costliest source of disabling injuries in the workplace, costing $18.6 billion annually. The purpose of this study was to investigate the effects of mental fatigue on gait variables associated with the risk of slipping and tripping. The study also investigated the efficacy of a 10-minute rest break in mitigating the effect of mental fatigue on those variables. Twenty healthy young adults (10 males and 10 females) participated and completed two experimental sessions. The order of sessions was counter-balanced for each participant. During the mental fatigue session, participants completed a computerized mentally fatiguing task for 90 minutes and performed a set of gait trials every 15 minutes throughout the task. During the control session, participants watched an emotionally neutral documentary in place of the mentally fatiguing task. After 90 minutes of the task or documentary, participants took a 10-minute break and then completed one last set of gait trials. Risk of slipping was inferred from the required coefficient of friction, heel contact velocity, and heel contact angle. Risk of tripping was inferred from minimum toe clearance and obstacle clearance. The results showed no increase in slip or trip risk. Rest breaks appeared to decrease levels of self-reported mental fatigue. However, they did not appear to have any mitigating effect on any of the gait variables that were measured.

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GENERAL AUDIENCE ABSTRACT

Slips, trips, and falls are the costliest source of disabling injuries in the workplace, costing $18.6 billion annually. The purpose of this study was to measure the effect of mental fatigue on the risk of falling. In this study, twenty healthy young adults (10 males and 10 females) completed two sessions. In the first session, the participants completed multiple walking sessions while performing a mentally fatiguing task. In the second session, the participants identical walking sessions, with the exception that instead of performing a mentally fatiguing task, they were watching a documentary. The study also aimed to study whether a 10-minute rest break could reduce the effect of mental fatigue on the participants' risk of falling. The results showed that mental fatigue had no effect on slip or trip risk. The rest break was successful at decreasing the self-reported mental fatigue rating but had no effect on the risk of slipping or tripping.

Table of Contents

BACKGROUND

According to the Bureau of Labor Statistics 2019 report, Falls were the second most common non-fatal cause of injury in the workplace in the United States between 2014 and 2019 (U.S. Bureau of Labor Statistics, 2019; Liberty Mutual 2020). In 2018, the annual incidence rate of slips, trips, and falls was 26.6 per 10,000 full time workers (U.S. Bureau of Labor Statistics, 2019). The incidence of falls is only expected to increase as the workforce ages. Currently, approximately 11% of the world's population is above the age of 60 and that number is expected to double by 2050 (Kanasi, Ayilavarapu, & Jones, 2016). Workers above the age of 55 who comprised just 12% of the workforce in 1997 accounted for 26% of fatal workplace falls (U.S. Bureau of Labor Statistics 2000). The share of workers above the age of 55 is projected to increase to about 24.8% of the workforce in 2024 (U.S. Bureau of Labor Statistics, 2017). In 2019, slips, trips, and falls cost American businesses an estimated $18.61 billion dollars, up from $17.54 billion the year before (Liberty Mutual, 2020). The rise in fall incidence is expected be accompanied by an increase in associated medical cost. Moreover, medical costs in the United States have been on a steep incline since the 1970s (Aaron C. Catlin & Cowan, 2015), which will be another driving factor in increasing the costs of falls in the United States.

Slips and trips are the most frequent cause of falls in the workplace (Courtney, Sorock, Manning, Collins, & Holbein-Jenny, 2001). During the construction of the Denver International Airport, the largest construction project in the world at the time, 85.6% of onsite, same-level falls were preceded by a slip or a trip (Lipscomb, Glazner, Bondy, Guarini, & Lezotte, 2006). A four-year study of a helicopter manufacturing plant attributed all same-level falls to either a slip or a trip (Amandus, Bell, Tiesman, & Biddle, 2012). In 1998, 77% of reported falls in the workplace in

Sweden were caused by either a trip or a slip (Courtney et al., 2001). The exact percentage of falls that are caused by slipping or tripping can vary between industries and work populations, but it is clear that they contribute to a substantial number of accidents. For example, slipping is responsible for 55% of falls that occur among hospital workers (T. K. Courtney et al., 2010), and tripping is responsible for 23-32% of falls in the workplace (Amandus et al., 2012; Lipscomb et al., 2006). Slips and trips are still a significant cause of injury even when they do not lead to a fall (Lipscomb et al., 2006) and cost over $2 billion annually (Liberty Mutual, 2020).

Slips are defined as the loss of balance due to insufficient friction between the foot or footwear and the walking surface. The required coefficient of friction (RCOF) the shear force at the shoe/floor interface required to prevent the shoe from translating relative to the floor. It is is a crucial predictor of risk of slipping (Beschorner, Albert, & Redfern, 2016). Simply put, a slip occurs when the available coefficient of friction (ACOF) at the shoe/surface interface is smaller than the RCOF. The ACOF depends upon the tribology of shoe sole and the characteristics of the walking surface, while the RCOF depends upon individual and gait characteristics friction. (Arena, Garman, Nussbaum, & Madigan, 2017). The risk of slipping is increased by either increasing the required friction or decreasing the available friction (Arena et al., 2017). The RCOF can be decreased by decreasing the heel contact velocity (HCV), shortening strides, and reducing heel contact angle (HCA) (Cham & Redfern, 2002). Other factors that decrease the RCOF include decreasing the magnitude of the surface angle (Beschorner et al., 2016; Cham & Redfern, 2002) and anticipating an increase in surface slipperiness (Cham & Redfern, 2002).

Trips are defined as the loss of balance due to contact with an obstruction or an uneven surface (U.S. Bureau of Labor Statistics, 2012). The risk if tripping is often inferred by the minimum toe clearance (MTC) (Barrett, Mills, & Begg, 2010; Garman, Franck, Nussbaum, & Madigan, 2015). MTC is defined as the minimum vertical distance between the lowest point of the foot of the swing leg and the walking surface during the swing phase of the gait cycle (Barrett et al., 2010). The risk of tripping increases with a decrease in the median of the MTC or an increase in MTC variability (Begg, Best, Dell'Oro, & Taylor, 2007).

Mental fatigue is one of the most significant causes of accidents in society today (Tanaka, Ishii, & Watanabe, 2014). Mental fatigue, sometimes referred to as cognitive fatigue, is a psychobiological state caused by prolonged periods of demanding cognitive activities (Grobe et al., 2017). It has been identified as a major occupational safety hazard due to its role in accidents in transportation, hospitals, and emergency operations (Williamson et al., 2011). The term “highway hypnosis” is commonly used to refer to the lack of awareness that occurs when driving on a long stretch of road that does not significantly change in shape. Between 1990 and 1994, prolonged sustained attention was the most salient contributing human factors to railway incidents in Australia (Edkins & Pollock, 1997). In the United Kingdom, about a fifth of accidents on motorways were attributed to symptoms of mental fatigue (Horne & Reyner, 1995). Mental fatigue temporarily impairs cognitive functioning which causes an increase in accidents and ultimately, injuries. (Williamson et al., 2011)

Activities such as driving (Marcora, Staiano, & Manning, 2009) and prolonged office work (van der Linden, Frese, & Meijman, 2003) are examples of daily activities that induce mental fatigue. Symptoms of mental fatigue include a loss of energy motivation (Boksem & Tops, 2008). Mental fatigue also reportedly causes boredom and sleepiness. (Tanaka et al., 2014). Prolonged performance of cognitively demanding tasks causes an increase in beta-frequency power in the pre-frontal cortex, which may cause to lower brain-alertness and arousal (Tanaka et al., 2014). The increase in beta-frequency powerbands is positively correlated with self-reported levels of boredom and sleepiness (Tanaka et al., 2014). Lastly, mental fatigue has been associated with decreased cognitive performance such as increased reaction time, an increased number of errors whilst performing cognitive tasks (Kato, Endo, & Kizuka, 2009) and poorer selective attention (Faber, Maurits, & Lorist, 2012). Mental fatigue causes a decrease in the brain's ability to suppress irrelevant data when presented with a large amount of information (Faber et al., 2012). The hindered ability to block out irrelevant information could lead to a higher percentage of decisions being made based on said irrelevant information. This would explain the increase in mistakes while performing cognitive tasks found in other studies.

Overall, mental fatigue significantly compromises executive function (van der Linden et al., 2003), which is a collective term referring to mental processes that regulate, control, and manage other cognitive processes (Diamond, 2013; Wu, Nussbaum, & Madigan, 2016). Executive function is comprised of four distinct and connected categories: cognitive flexibility, goal setting, attentional control, and information processing (Anderson, 2002). Mentally fatigue targets working memory, a subcomponent of cognitive flexibility. Working memory refers to the information can be kept available in mind at any given time and the processing that occurs to maintain this information (Ricker, AuBuchon, & Cowan, 2010).

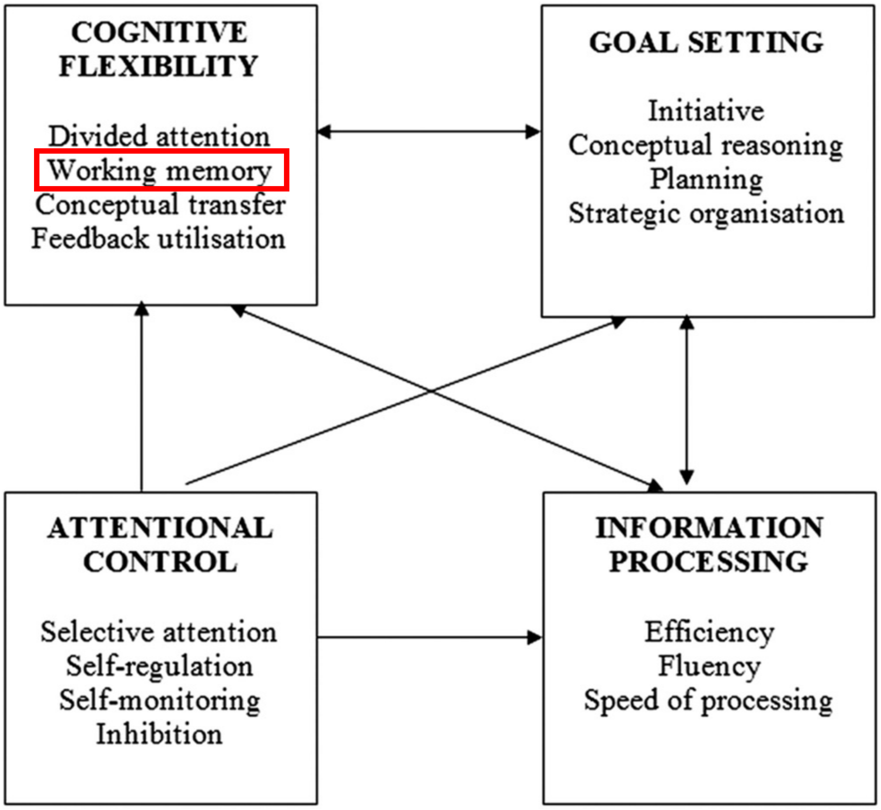

Figure 1: Model of executive function proposed by Anderson (2002)

Along with adversely affecting cognitive performance, mental fatigue can adversely affect physical performance. Mental fatigue can decrease time to exhaustion during high-intensity cycling exercises (Marcora et al., 2009). In this study, Marcora et. al (2009) studied the effect of mental fatigue on the ability to perform a continuous cycling task. Participants performed a continuous cycling task at 80% of their peak power output on a cycle ergometer under two conditions. In the experimental condition, participants performed a mentally fatiguing task for 90 minutes prior to beginning the cycling task. In the control condition, participants watched a 90-minute documentary prior to beginning the cycling task. Participants were found to reach perceived exhaustion significantly quicker under the experimental condition, despite there being no significant difference in cycling intensity under the two conditions. When compared to the control trials, mental fatigue had no significant effect on physiological responses such as heart rate, cardiac output, and oxygen consumption. The ability to perform intermittent high intensity running at certain speeds, required by many team sports such as soccer and rugby, rather than continuous exertion is also negatively affected by mental fatigue (Smith, Marcora, & Coutts, 2015). In this study, Smith et al. (2015) studied the effect of mental fatigue on intermittent running performance at various intensities. The experimental group performed a mentally fatiguing task for 90 minutes and the control group watched a 90-minute documentary. The running trials were performed on a treadmill at subjective speeds ranging from a light walk (20% of maximal effort) to a full sprint (100% of maximal effort). The study found that overall running speed and low intensity running speed in participants that were mentally fatigued were lower than in the control group. There were no significant differences found between the experimental and control group in most of the physiological variables such as heart rate and blood glucose concentration. The effect of mental fatigue on physical performance and endurance is attributed to an increased perception of the task demands more so than cardiorespiratory and musculoenergetic mechanisms (Marcora et al., 2009; Smith et al., 2015).

Another aspect of physical performance that mental fatigue can adversely affect is the increasing risk of slipping. Mental fatigue increases injury risk through inhibiting poor slip detection, increased slip initiation, and hindered reactive recovery response to slips (Lew & Qu, 2014). Lew and Qu (2014) recorded normal walking variables such as RCOF and HCV and slip variables such as slip distance of participants in the experimental group after they performed a mentally fatiguing task for 90 minutes and compared them to the control group who did not perform the task. A slip was induced for each participant in both groups at some point during their gait trials. Mental fatigue leads to a longer slip distance, higher RCOF, and lower HCV. The increase in slip distance indicates poorer slip detection and insufficient reactive recovery response to slips (Haynes & Lockhart, 2012). The increase in RCOF indicates an increase in risk of slip initiation and the decreased HCV implies that people afflicted with mental fatigue walk more cautiously to improve stability. The same phenomena can be observed in the gait of people suffering from dementia (Lockhart, Kim, Kapur, & Jarrott, 2009). The relation between people with dementia and people with mental fatigue could stem from the common symptom of declined mental capacity, albeit the decline caused by dementia is significantly more severe (Lew & Qu, 2014).

Another aspect of physical performance that mental fatigue can adversely affect is postural balance and the risk of falling while walking. Mental fatigue can increase the risk of tripping by increasing gait variability (Behrens et al., 2018) and decreasing postural control (Qu, Xie, Hu, & Zhang, 2020). Evidence suggests that there is an association between cognition and gait (Verlinden, van der Geest, Hofman, & Ikram, 2014). Poor cognitive function has been linked to poor gait performance (Grobe et al., 2017) while controlled acute stimulation of cognitive functioning with drugs, such as methylphenidate, has been linked with a decrease in gait variability (Ben-Itzhak, Giladi, Gruendlinger, & Hausdorff, 2008). Temporary cognitive impairment caused by mental fatigue increases gait variability (Behrens et al., 2018) which in turn increases risk of tripping (Begg et al., 2007). A decline in cognitive task performance can be observed in the use of dual-task paradigms in which postural control task and a cognitive task are performed simultaneously (Qu et al., 2020). This indicates that postural control is, in part, a cognitive tasks and shares overlapping cognitive resources (Qu et al., 2020). Mental fatigue could attenuate cognitive resource allocation to cognitively demanding tasks (Kato et al., 2009).

STUDY GOAL

The goal of this study was to investigate the effects of mental fatigue on gait variables associated with the risk of slipping and tripping among a sample of young working-age adults. Previous studies investigated the effects of mental fatigue by evaluating gait only before and after a mental fatiguing-inducing task. As such, it was unclear how the effects develop over time or respond to rest breaks. To address this gap in knowledge, we measured gait variables over set time intervals throughout a mentally fatiguing task. We hypothesized that mental fatigue would increase the risk of falling through gait alterations, and for these effects to show a clear progression over time. Moreover, we hypothesized that a 10-minute rest break could mitigate the effect of mental fatigue on the gait variables being studied. The results from this study would help further understand the effect of mental fatigue gait variables associated with the risk of slipping and tripping and potentially inform the development of administrative controls to mitigate the risk of falls in the workplace.

METHODS

A convenience sample of 20 participants aged 18-30 and sex-balanced was recruited from the university population. Participants were recruited using flyers posted around campus and email listservs. Mean (SD) age and BMI of the 20 participants were 21.8 (2.7), 21.9 (2.0) respectively. The exclusion criteria required that participants have no self-reported current or recent medical conditions or injuries that affect their gait or balance, not be obese ($BMI \geq 30\ kg/m^2$), and not be pregnant. These criteria aimed to exclude participants with potentially confounding factors that can affect balance and gait.

The sample size was estimated using data from a prior study (Lew & Qu, 2014). In this prior study, Lew and Qu (2014) investigated among young adults the effects of a 90-minute mentally fatiguing task on slip risk while walking (i.e., heel contact velocity or HCV, and required coefficient of friction or RCOF) and multiple measures of balance recovery responses to laboratory-induced slips. RCOF increased from 0.15 (0.03) before the mental fatigue intervention to 0.18 (0.03) after. Using these data with alpha = 0.05 and power = 80%, and conservatively estimating the correlation between RCOF before and after mental fatigue intervention as 0.3, the required number of participants would be 12. Anticipating a smaller effect size due to intermittent gait trials that may allow for some recovery from mental fatigue, we recruited 20 participants.

A crossover experimental design was employed. Each participant completed two experimental sessions, with the order of presentation of the two sessions counterbalanced across all participants (Figure 2). In the experimental session, participants first completed a set of gait trials where they walked repeatedly back-and-forth along a walkway for two minutes. Participants then performed a mentally fatiguing computer task for 90 minutes. During the mentally fatiguing task, the participants stopped every 15 minutes to complete 2 minutes of additional gait trials. Once the participants completed 90 minutes of mentally fatiguing task and the accompanying sets of gait trials, participants took a 10-minute rest break and then performed one last set of gait trials. In the control session, participants completed an identical protocol with the exception of the mentally fatiguing task being replaced with watching an emotionally-neutral documentary.

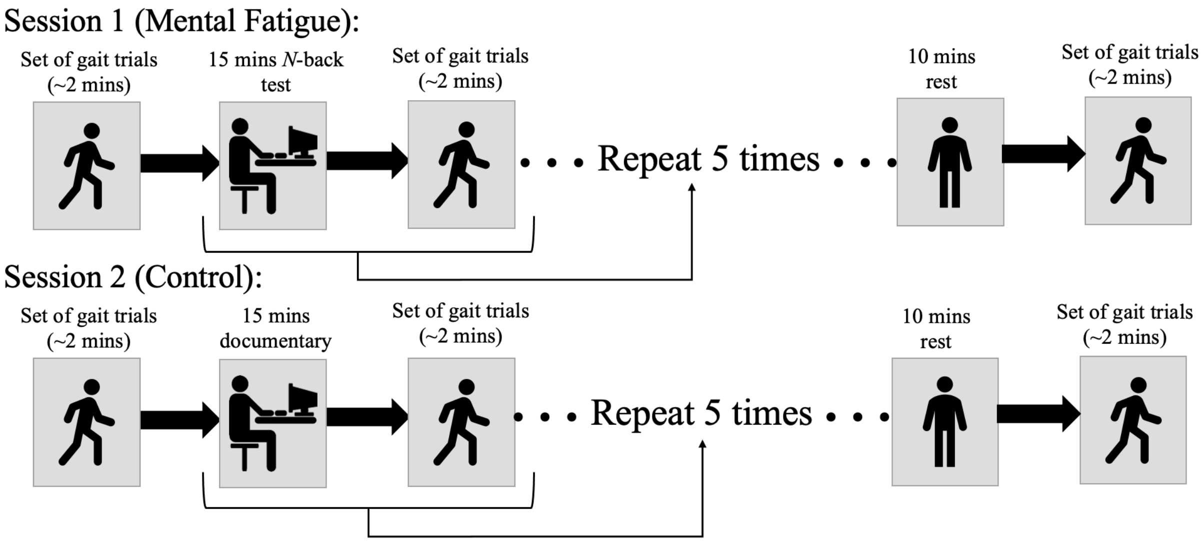

Figure 2: Experimental Protocol for sessions one and two

At the start of the first session, whether experimental or control, we measured and recorded basic demographic and anthropometric information including age, sex, height, weight, and dominant foot. The participants were then instructed to walk on a 12-meter platform at a speed 'like they have somewhere to go'. This was used to determine the optimal starting position along the walkway, so participants naturally stepped on the force plate located in the middle of the walkway. Moreover, the preferred walking speed was recorded, and the participants were instructed to either slow down or speed up if they were deviating from that speed throughout the rest of the protocol to reduce potentially confounding effects walking speed on our dependent variables.

During the experimental session, the participants first performed a practice set of gait trials that allowed participants to get familiar the protocol. The participants then completed the first mental fatigue survey. Once the survey was completed, the participants started their first set of gait trials. In each set of gait trials, the participants walked back and forth on the walkway eight times while looking forward at a photo at the end of the walkway. During each set of gait eight trials, the first four trials involve no obstacles, and the latter four trials included a 85-cm tall obstacle positioned near the middle of the walkway. Participants were told to look at the position of the obstacle prior to each walk down the walkway, but then gaze at the photo at the far end of the walkway while walking. The participants then completed a mental fatigue questionnaire described below. Participants then sat at a computer terminal for a 15-minute *n*-back test to induce mental fatigue. The 3-back test is a computerized test in which participants respond to a target on their screen by hitting the spacebar on a keyboard or a non-target appearing on the screen by not hitting anything on their keyboard. The screen displayed a 3x3 grid in which a blue circle appeared in one square on the grid at a time. Any time the blue circle appeared was called an event. A target event was any event in which the blue circle was in the same location on the grid as it was three events prior.

After the 15-minute *n*-back test, participants completed the mental fatigue questionnaire, and then two minutes of continuous gait trials. This cycle of a 15-minute *n*-back test, mental fatigue questionnaire, and gait trials was repeated until 90 minutes of the *n*-back test were completed. After the last *n*-back test, questionnaire, and gait trials, participants were provided a 10-minute rest break. Participants were allowed spend their break however they like (e.g., walking, sitting, using the restroom…etc.) but they were instructed to not to use their phones to avoid any effect of screen use. After the break, participants completed the mental fatigue questionnaire and one more set of gait trials.

The mental fatigue questionnaire included two parts. The first part was a single question asking participants to rate their level of mental fatigue on 1-10 scale (Garrison, 2020). The second part was the NASA Task Load Index (NASA-TLX) that assesses workload on six 10-point scales. The six scales assess mental demand, physical demand, temporal demand, performance, effort, and frustration (Hart & Staveland, 1988). Results from the six scales were summed with no weightings to determine the overall NASA-TLX score. Participants were asked to consider the mental fatiguing task when completing the NASA-TLX. (Participants did not complete the NASA-TLX prior to starting the *n*-back tests.)

During all gait trials, gait kinematics were sampled at 120 Hz using a motion capture system (Qualisys North America, Buffalo Grove, IL, USA). Passive reflective markers placed bilaterally on the shoes at the tip of the second metatarsal and heel, lateral malleolus, and acromion. Two markers were also placed on the stepping obstacle to facilitate the calculation of foot clearance. Ground reaction forces were sampled at 1200 Hz using a force platform (Bertec Corporation, Columbus, OH) integrated into the middle of the length of the walkway.

Five dependent variables were used to measure slip and trip risk during the gait trials. Slip risk was measured using RCOF, HCV, and HCA. RCOF was calculated as the peak of the ratio of the resultant horizontal ground reaction force and the vertical ground reaction force near heel strike (Lew & Qu, 2014). HCV was the anteroposterior speed of the heel marker at heel contact (Lew & Qu, 2014). HCA was measured as the angle between the toe, heel, and ground where an angle of zero degrees indicated the foot was completely flat on the ground (Cham & Redfern, 2002). An increase in slip initiation risk would be suggested from an increase in RCOF, HCV, and HCA. Trip risk was measured using minimum toe clearance (MTC) and obstacle clearance. MTC was the minimum height of the toe marker during the local minimum near the middle of swing, normalized by the height of this marker while standing (Barrett, Mills, & Begg, 2010). Obstacle clearance was the vertical distance between the toe marker (normalized by the height of this marker while standing) and the mean height of the obstacle markers at the instant when their anteroposterior coordinates were equal. An increase in trip risk would be suggested by a decrease in MTC and obstacle clearance.

Two statistical analyses were performed. First, mental fatigue was investigated using a priori pairwise comparisons between sessions at each time point subsequent to a two-way analysis of variance (ANOVA) with factors of session (mental fatigue or control), time (0, 15, 30, 45, 60, 75, 90 minutes), and session x time. Dependent variables for this analysis included subjective mental fatigue ratings and NASA TLX scores. Second, measures of gait, slip risk, and trip risk were investigated using a priori pairwise comparisons between sessions at each time point subsequent to a three-way ANOVA with factors of session, time, trial, and session x time. Dependent variables for this analysis included RCOF, HCA, HCV, MTC, and obstacle clearance. To achieve residuals that approximated a normal distribution, a square root transformation was used on HCV and a log transformation was used on RCOF. Statistical analyses were performed using JMP, and the significance level was ≤ .05 with no correction to control family-wise type-I error rate.

RESULTS

The mental fatigue rating and NASA-TLX score differed between sessions at selected time points. Mental fatigue rating did not differ between sessions at 0 minutes, and was higher during the mental fatigue session at 15-90 minutes compared to the control session (Figure 3). TLX score was not measured at 0 minutes, and was higher during the mental fatigue session at 15-90 minutes compared to the control group (Figure 4). *N*-back scores increased in the first hour then seemingly plateaued (Figure 5).

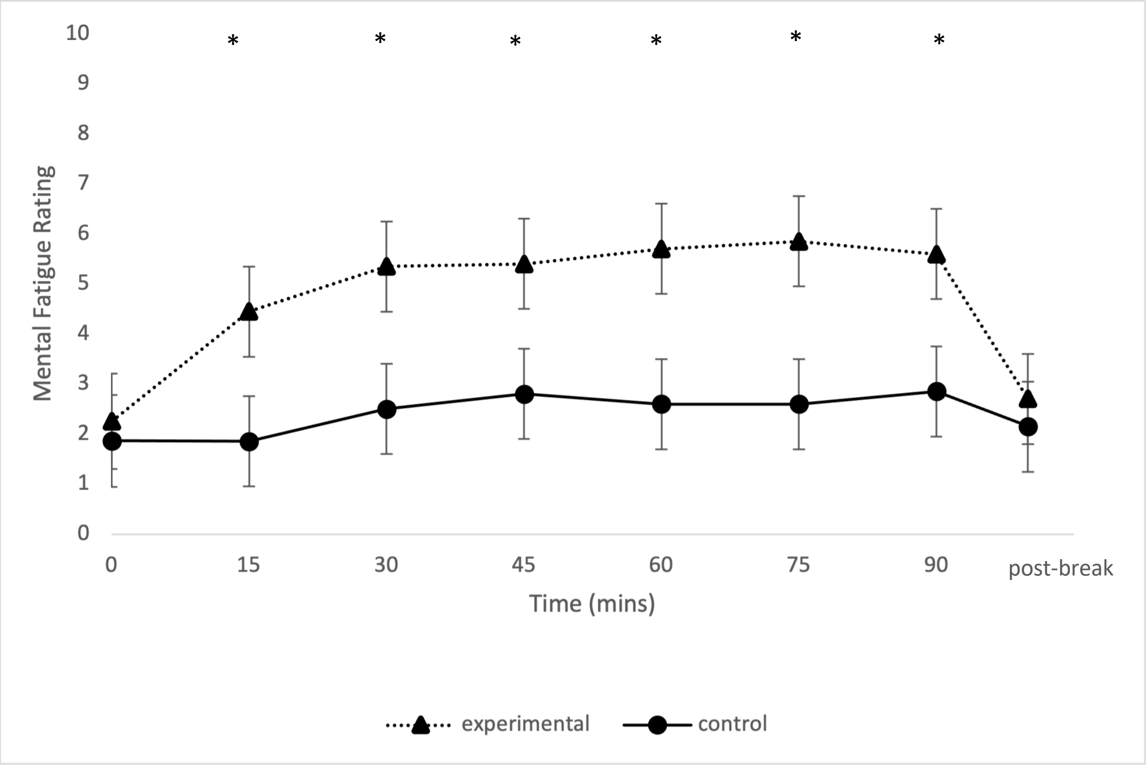

Figure 3: Subjective mental fatigue rating over time ± upper/lower 95%. * *p < .05*.

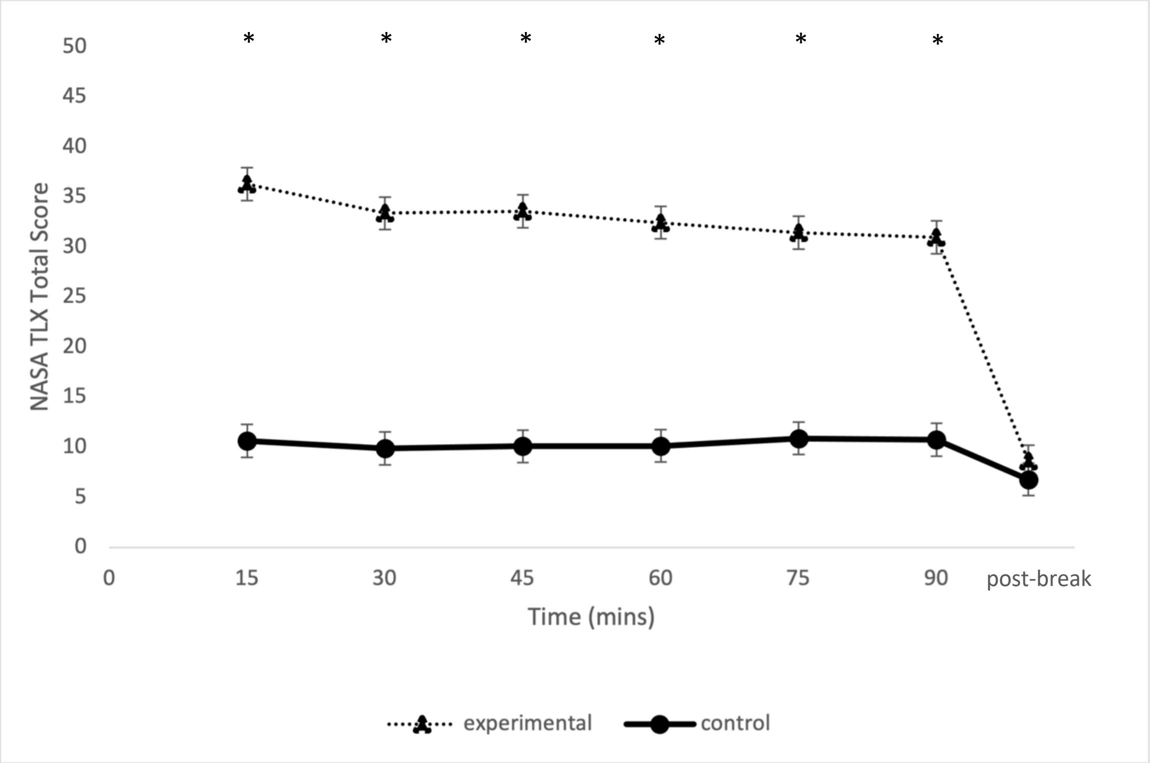

*Figure 4: Raw TLX score over time ± upper/lower 95%. * p < .05.*

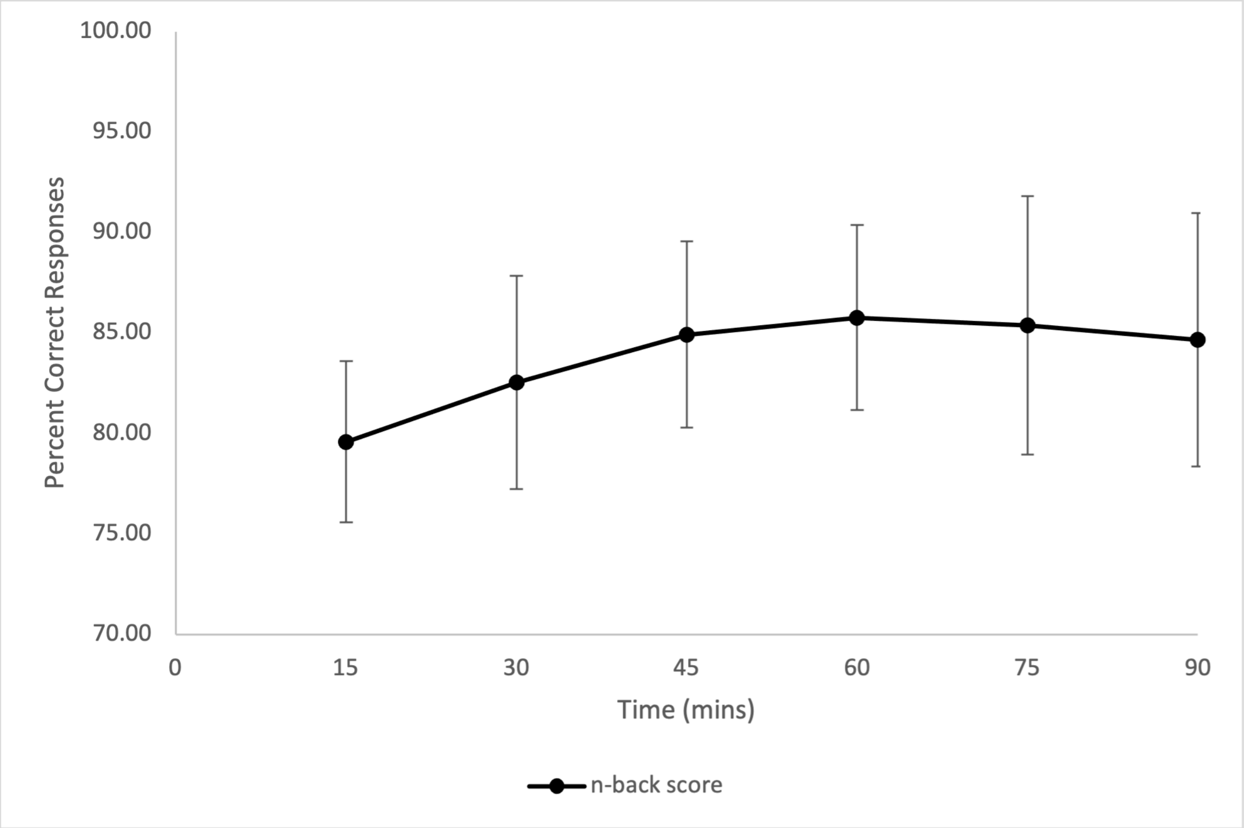

*Figure 5: n-back score over time ± upper/lower 95%. * p < .05.*

Measures of slip and trip risk during gait exhibited some differences between sessions at selected times. Gait speed did not differ between sessions at 0 minutes and was faster during the mental fatigue session at 75 minutes and after the rest break compared to the control session (Figure 6). Step length did not differ between sessions at 0 minutes and was longer during the mental fatigue session at 30-90 minutes and after the rest break, compared to the control session (Figure 7). RCOF and HCA did not differ between sessions at any time (Figures 8-9). HCV did not differ between sessions at 0 minutes, was higher during the mental fatigue session at 15 minutes, and lower during the mental fatigue session at 90 minutes compared to the control session (Figure 10). MTC was lower during the mental fatigue session at times 0, 30-60, and 90 minutes compared to the control session (Figure 11). Obstacle clearance was higher during the mental fatigue session at 15 minutes compared to the control session (Figure 12). P-values from ANOVAs are shown in Tables 1 and 2.

*Table 1: P-Values of subjective mental fatigue ratings and raw NASA TLX scores. * significant ($p < 0.05$)*

Source	Mental Fatigue Rating	TLX Score
Time	<0.001*	<0.001*
Session	<0.001*	<0.001*
Session x time	<0.001*	<0.001*

*Table 2: P-Values of Gait Measures. *significant ($p < 0.05$)*

	Gait Speed	Step Length	RCOF	HCA	HCV	MTC	Obstacle Clearance
Session	0.003*	<0.0001*	0.995	0.075	0.648	<0.001*	0.068
Time	0.008*	0.095	0.278	0.112	0.195	0.069	0.288
Trial	<0.001*	0.127	0.110	0.640	<0.001*	0.856	0.333
Session x Time	0.151	0.111	.966	0.999	0.001*	0.628	0.113
Effect Size of Session (Cohen's d)	0.689	2.75	0.09	0.966	0.344	2.63	0.779

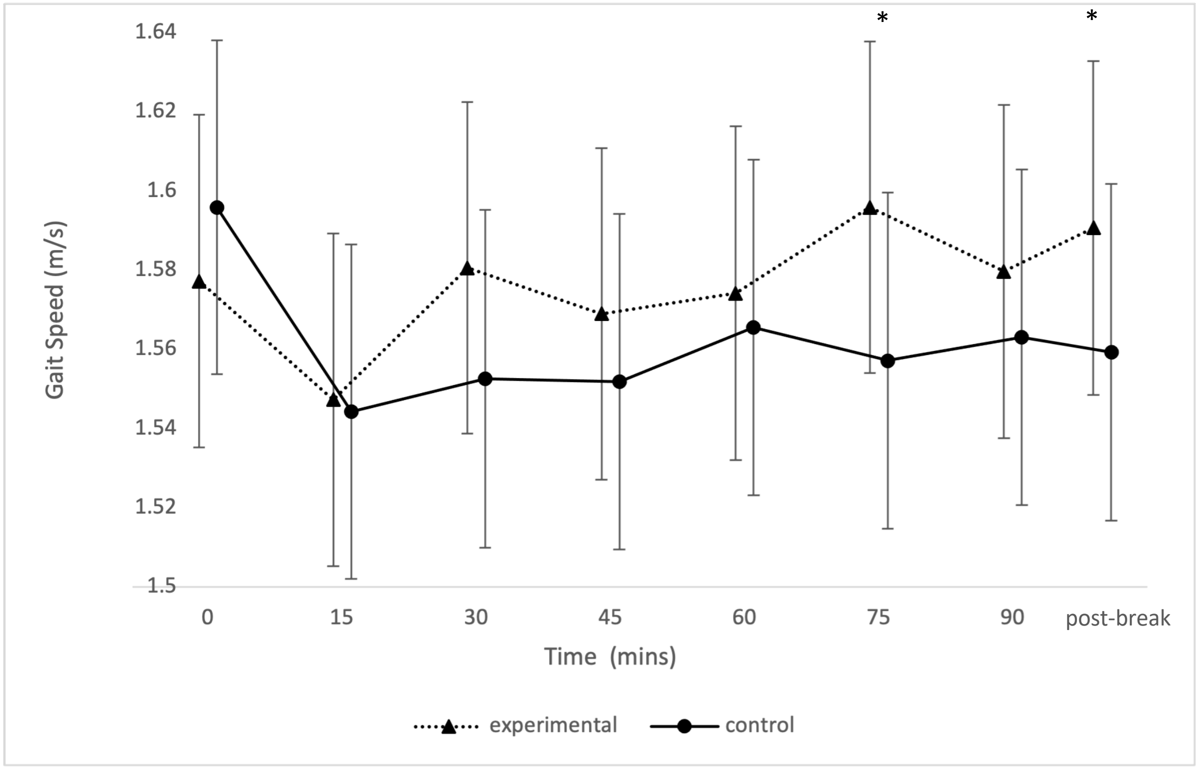

*Figure 6: Gait speed over time ± upper/lower 95%. * p < .05.*

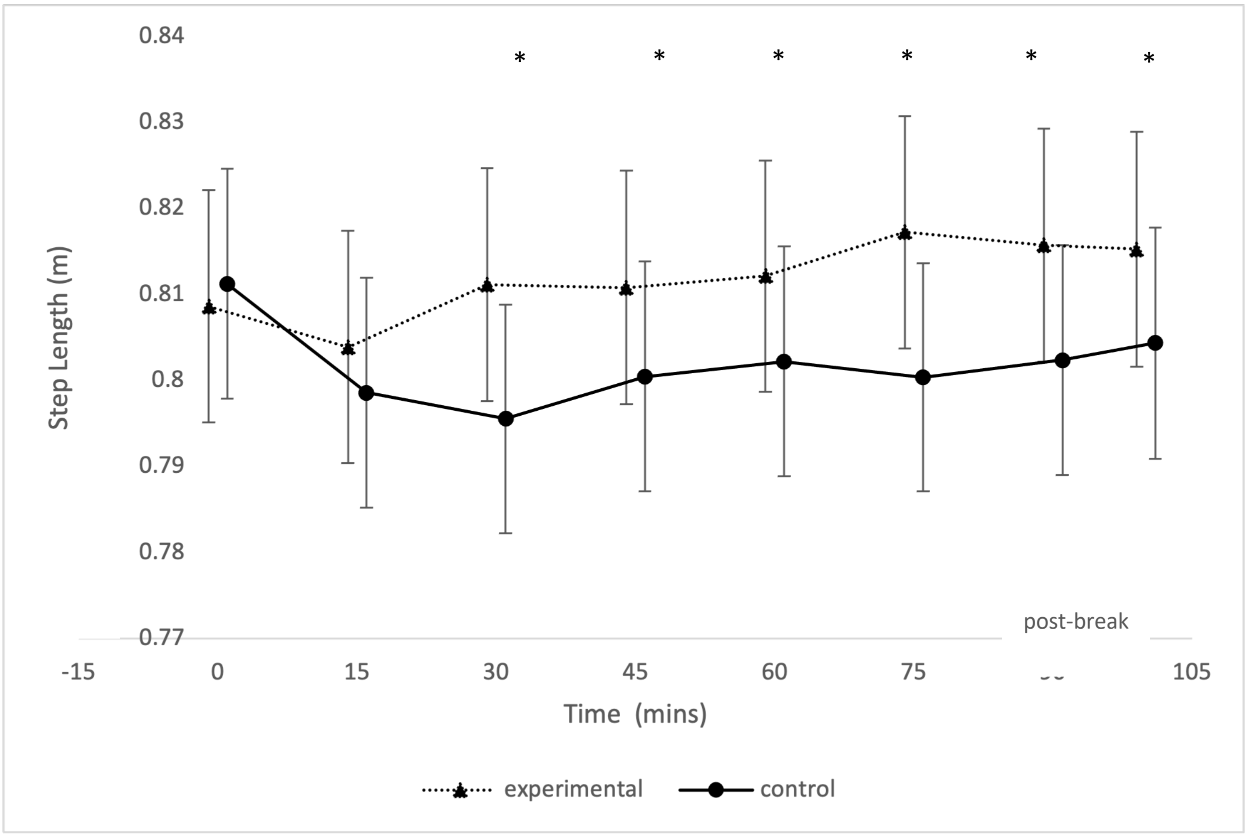

*Figure 7: Step length over time ± upper/lower 95%. * p < .05.*

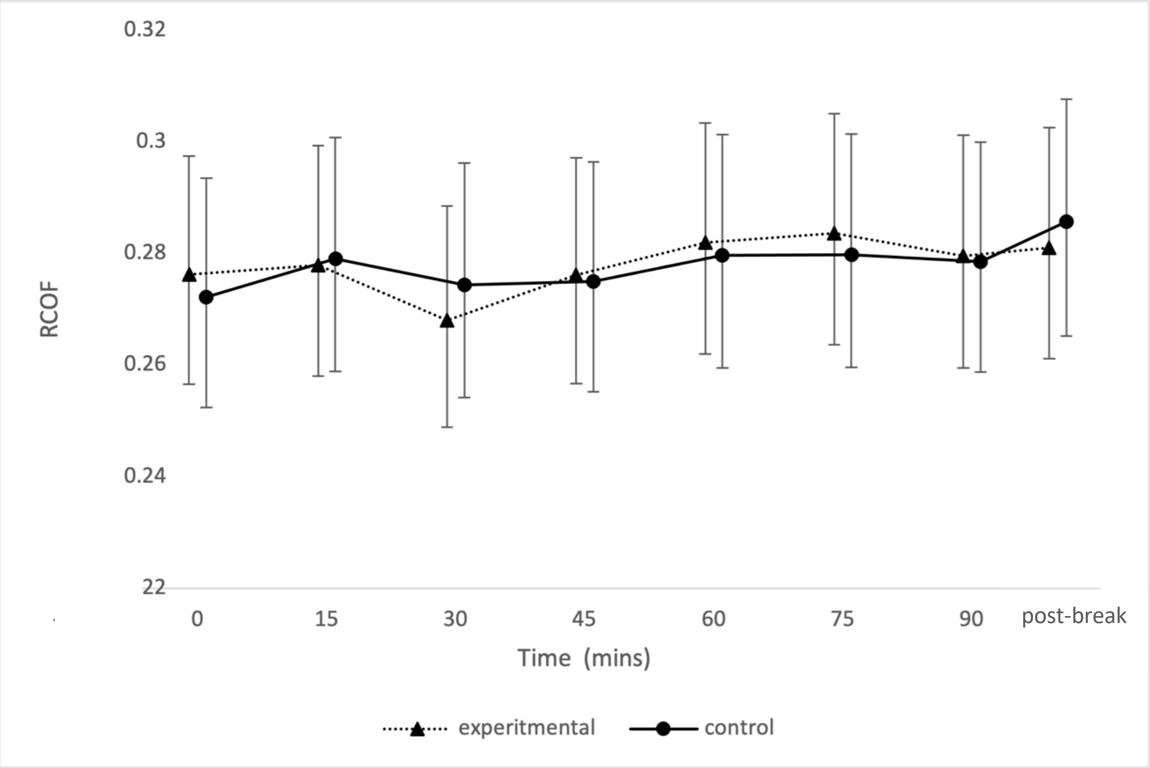

*Figure 8: RCOF over time ± upper/lower 95%. * p < .05.*

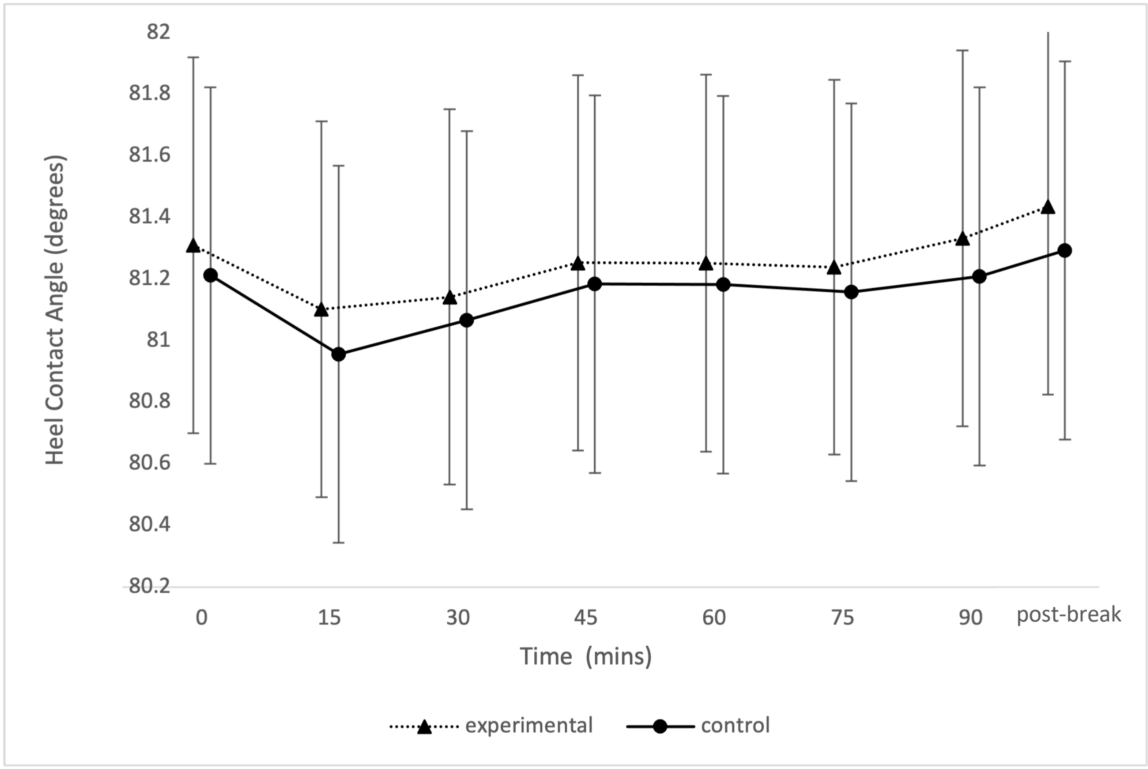

*Figure 9: HCA over time ± upper/lower 95%. * p < .05.*

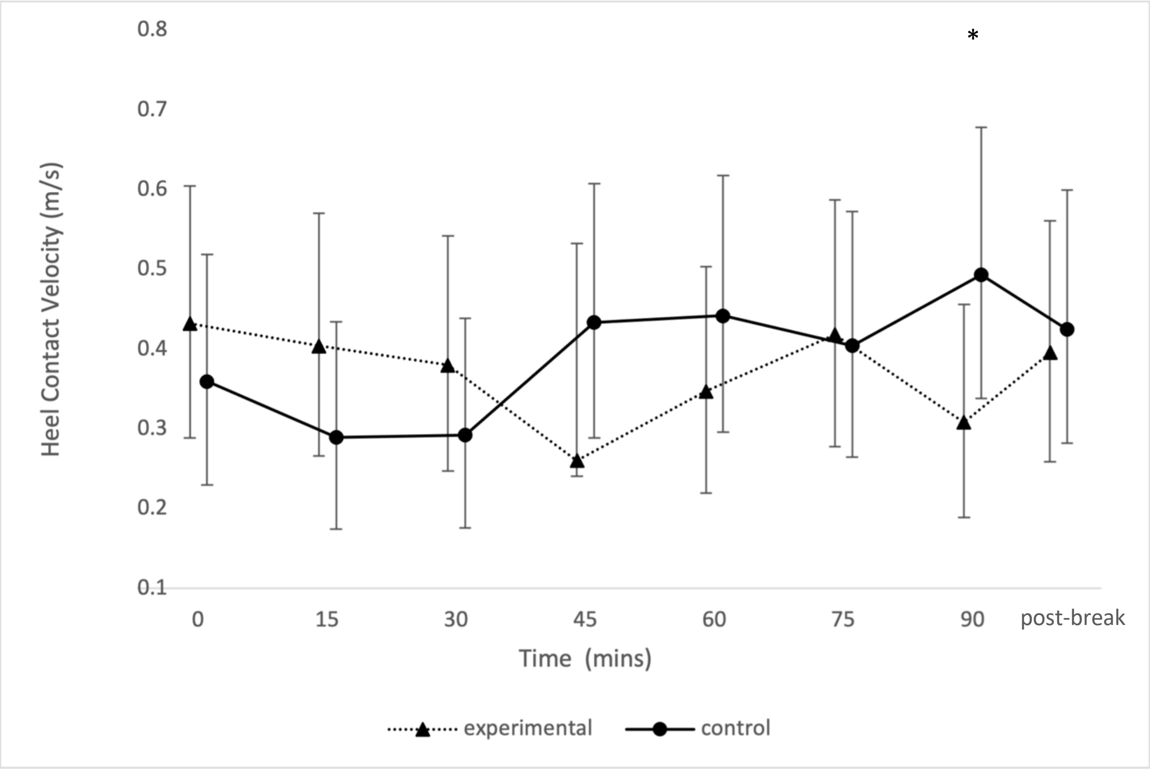

*Figure 10: HCV over time ± upper/lower 95%. * p < .05.*

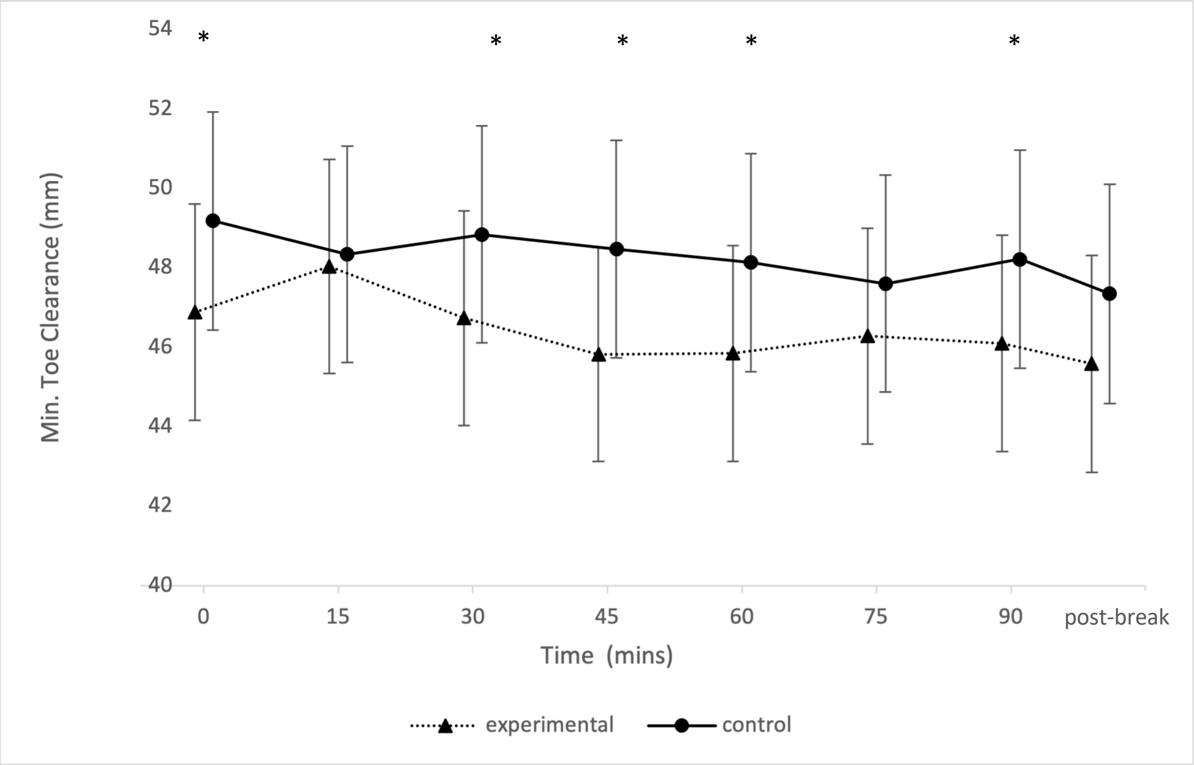

*Figure 11: MTC over time ± upper/lower 95%. * p < .05.*

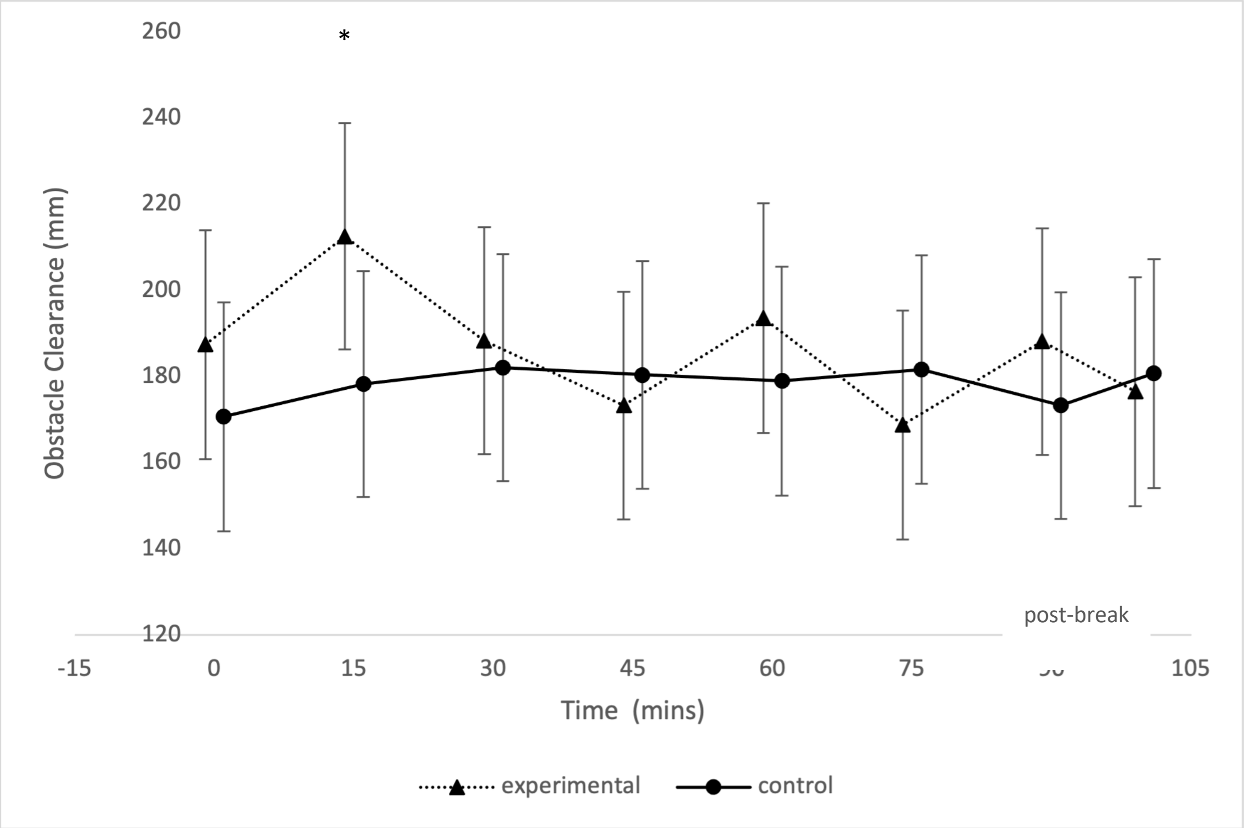

*Figure 12: Obstacle clearance over time ± upper/lower 95%. * p < .05.*

DISCUSSION

The purpose of this study was to investigate the effects of mental fatigue on gait variables associated with the risk of slipping and tripping among a sample of young working-age adults, as well as the effect of rest break on these variables. Moreover, understanding how any such effects develop over time can potentially inform the development of administrative controls to mitigate the risk of falls in the workplace. The n-back results did not show signs of decreased performance. However, the results from the mental fatigue survey and the NASA TLX raw scores were higher during the mental fatigue session compared to the control session. This indicated that the *n*-back test was successful in inducing mental fatigue among our participants.

Our first hypothesis was that mental fatigue would increase the risk of slipping and tripping, and that these effects to show a clear progression over time. Our results did not provide clear support for this hypothesis. Our results showed no increase in slip risk during the mental fatigue session compared to the control session. RCOF and HCA did not differ between the mental fatigue and control sessions at any time during the first 90 minutes of the protocol (i.e., before the rest break). These findings differed from Lew and Qu (2014) who reported a 0.3 increase in RCOF after a 90-minute mentally fatiguing computer task similar to the *n*-back test used here. HCV, although not exhibiting a clear monotonic trend over time, was 0.15 m/s slower during the mental fatigue session at 90 minutes. This finding was consistent with Lew and Qu (2014) who also reported 0.15 m/s slower HCV after a 90-minute mentally fatiguing task. Lew and Qu (2014) attributed the decrease in HCV to the participants walking more carefully while mentally fatigued to improve their postural stability. However, this explanation is not necessarily consistent with a faster gait speed and longer step lengths later in the protocol (Figures 5-6).

Our results with respect to the effects of mental fatigue on risk of tripping were ambiguous. While MTC was 2-3 mm lower during the mental fatigue session than the control session at multiple times during the first 90 minutes of the protocol, MTC was also lower during the mental fatigue session at 0 minutes. Thus, it is unclear how much of the lower MTC values later in the protocol may have been due to mental fatigue versus a potential bias identified at the start of the protocols. Obstacle clearance also did not suggest and effect on trip risk as no differences between sessions. To our knowledge, there has been no previous studies on the effect of mental fatigue on MTC and obstacle clearance to able to compare our findings.

The second hypothesis was that a 10-minute rest break would mitigate the adverse effect of mental fatigue on risk of slipping and tripping. This hypothesis was not supported by our results. For the effect of mental fatigue to be mitigated by a rest break, the results must have shown a clear change in direction of trends during the rest, and for the direction of change in the mental fatigue session to be toward lower risk. Thus, the mental fatigue rating and TLX score showed clear recovery after the rest break (Figures 3-4). Risk of slipping variables RCOF and HCA showed no difference between the mental fatigue and control sessions at any time. Thus, they did not exhibit any clear benefits from the rest break. HCV differed between sessions at 90 minutes and not after the rest break, but the direction of change of HCV within the mental fatigue session was toward an increased risk of slipping. Risk of tripping variable MTC also differed between sessions at 90 minutes and not after the rest break, but the direction of change of MTC after the rest break did not indicate a decrease in trip risk. Obstacle clearance did not differ between sessions at both 90 minutes and after the rest break. Thus, none of our risk of slipping or tripping variables were beneficially affected by the rest break.

Gait speed and step length both were higher during the mental fatigue session over the first 90 minutes of the protocol. However, exploring the inclusion of these as covariates in our statistical analyses of risk of slipping and tripping measured did not affect our results to a meaningful extent.

The difference in results between the current study and prior studies may be due to differences in protocol. In our study, the participants were interrupted while performing their mentally fatiguing task every 15 minutes to perform the gait trials. Prior studies that investigated the effect of mental fatigue on gait required participants to complete 90 minutes of a fatiguing task before measuring gait. While our questionnaire results show clear increases in mental fatigue over the 90 minute protocol and some recovery after the rest break, some recovery may have occurred prior to or during gait trials and thus mitigated the effects of mental fatigue on gait.

This study had several limitations. First, the participants had to stop working on the *n*-back test to perform the gait trials. It is possible that the gait trials acted as small rest-breaks, and therefore not slowing the rate at which mental fatigue could accumulate enough to have effects large enough to alter gait patterns. Second, the participants were mostly college students in engineering, and it is thus unclear how these results would generalize to other populations. Third, there were five force samples that were lost early in the experiment that were not discovered in time due to temporary technical issues with the equipment.

In conclusion, our findings did not support clear adverse effects of mental fatigue on risk of slipping or tripping during gait, or clear benefits of a 10-minute rest break on this risk. Because these results are not consistent with prior studies, additional studies appear warranted to clarify the relationship between mental fatigue and fall risk.

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