Effect of Locomotion Environment Familiarity and Cognitive Loading on Gait Control and Situation Awareness in Multitasking

Mohamed Sheik-Nainar[a], Carl Pankok, Jr.[b], Maryam Zahabi[b], David Kaber[b]

[a]Synaptics, Inc., San Jose, CA, USA; [b]Edward P. Fitts Department of Industrial and Systems Engineering, North Carolina State University, Raleigh, NC, USA

The present study sought to assess the influence of environment familiarization and multitasking involving cognitive performance during locomotion on the degree of proactive control for perturbations and situation awareness. Three independent variables were manipulated: *a priori* knowledge of the environment (through low, medium, and high fidelity training), navigation aid type (instruction-based and map-based, which imposed differing cognitive loads on walkers), and cueing of perturbations (visual only and a combination of visual and physical). Two response variables were collected, including push-off force and situation awareness query response accuracies. The results suggested that greater *a priori* knowledge resulted in greater proactive gait control as participants approached a locomotion hazard. However, the addition of physical cueing of perturbations (via a leash attached to participants' ankles, simulating forces associated with a slip or trip) did not result in greater proactive gait control. Furthermore, only the cognitive loading condition had an effect on situation awareness, where greater loading decreased the ability to project future states of the system, but facilitated both perception and comprehension of system stimuli.

Practitioner Summary: Results of this study emphasize the importance of prior experience and reduced cognitive load for facilitating proactive gait strategy in negotiating locomotion hazards.

Keywords: Multitasking, cognitive performance, locomotion, slips and trips, proactive gait control

1 Introduction

Locomotion is a day-to-day activity and is generally considered a secondary task in situations like walking and using a cell phone. Under multitasking conditions with physical and cognitive loads, recent studies have shown reductions in attentional resources leading to poor performance in either the primary or secondary task, or both (Bloem et al., 2001; Brown, Shumway-Cook, and Woollacott, 1999). Poor performance in locomotion, as a secondary task, could result in perturbations in gait (a slip or trip) or even a total loss of stability (fall). As long as a gait perturbation results in recoverable instability, it is of less concern; however, situations in which combined cognitive and physical loads exceed attentional resources can lead to falls causing critical injuries or fatalities. Unfortunately, research has shown that the number of slip-and-fall related accidents occurring in occupational settings is substantial (Lin, Chiou, and Cohen, 1995; Courtney et al., 2001; Yeoh, Lockhart, and Wu, 2013). The incidence rates of slips and falls may be attributable, in part, to losses of situation awareness (SA) on the locomotion environment under multitasking conditions as a result of reductions in attentional resources, leading to gait perturbations and unrecoverable states of instability.

1.1 Locomotion

Human walking is produced by continuous loss and recovery of balance in the plane of progression. The body leans forward to the limit of its stability causing the center of mass (COM) to move outside the base of support (BOS), which is recovered by the forward stepping foot and propelled over the stable foot. This cycle continues by carrying the center of mass alternatively over the left and right legs to produce locomotion. People walk in distinctive styles and this is commonly referred to as "gait". Typically the gait cycle begins from the contact of one heel with ground and continues through lifting of the toe off the ground at the same foot, at which point ground contact is broken; therefore one foot always remains in contact with the ground. This cycle includes two distinct phases of gait: single support and double support, meaning one or both feet are in contact with the ground.

Kinetic variables used in gait research consist of simple forces and higher order time derivatives of forces in various phases of the gait cycle. These are typically recorded using force plates fitted with a number of piezoelectric or strain-gauge sensors. One commonly measured gait variable is the push-off force (POF), which is defined as the force required to push the back leg forward past the front leg, changing the gait phase from double support to single support. The POF generates the momentum to move the center of mass over the base of support.

Human locomotion movements are normally automatic in nature and can be considered subconscious in the cycle of human information processing (Trew and Everett, 1997). They only come under voluntary or conscious control under special circumstances, such as during a perturbation. However, some research has presented results contrary to the belief that walking is an automatic form of motor-control behavior and has investigated the cognitive aspects of posture, balance and locomotion (e.g., Woollacott and Shumway-Cook, 2002). As an example, Kerr, Condon and McDonald (1985) identified attentional demands of posture control; Lajoie et al. (1993) showed that walking demands greater attentional resources than sitting or standing; and Ebersbach, Dimitrijevic, and Poewe (1995) showed that performance of a concurrent task has an effect on control of walking style.

1.2 Situation Awareness in Locomotion

Situation awareness has been defined as a cognitive construct critical to decision making and performance in complex tasks and systems control (Endsley, 1995). The concept of SA is based on human perception of elements in an environment (level 1 SA), operator relation of elements to task goals (level 2 SA), and predictions of future task states (level 3 SA) (Endsley, 1988). Anecdotally, aircraft pilots and air traffic controllers have been noted to refer to SA as “the picture” or their internal dynamic visual model of the current task situation (Endsley, 1995). This situation model has been found to be particularly important in multitasking situations in which humans must manage cognitive and physical workloads across tasks with often conflicting goals and competing demands (Perry et al., 2006). However, limited empirical research has investigated the role of SA in performance when operators must balance motor-control and cognitive tasks.

Since walking by itself can be considered an over-practiced motor-control task, it is unlikely that locomotors must maintain SA for successful performance. However, the extent to which situation assessment occurs during locomotion may be critical to dealing with spatial and temporal perturbations. SA may also be related to other cognitive processes that often occur during locomotion, such as navigation. Beyond this, SA may be particularly relevant during locomotion as part of multitasking, including performing a cognitive task like reading, talking, or sending a text message on a cell phone while pushing/pulling/carrying and maintaining balance and stability against perturbation hazards.

1.3 Locomotion Perturbations

Perturbations can be defined as any changes to current posture, either in quiet standing or while walking, caused by changes to the COM-BOS relationship resulting in a stepping response (in the case of standing) or temporary disruption to the walking rhythm. If a perturbation is significant enough to cause difficulties in recovery, it may result in a fall. There are a number of ways in which perturbations can occur during normal locomotion. The literature identifies the following perturbations: slipping, tripping, stumbling, loss of balance, dizziness, tiredness, underlay tipped/rolled/slid, vehicles in motion, jumping or diving and loss of grip (Courtney et al., 2001). Slips and trips are the most common perturbations to locomotion. Both can lead to falls, resulting in injuries and (in some cases) possibly fatalities.

In dealing with locomotion perturbations, walkers typically adopt one of three strategies: reactive, accommodation or avoidance. A reactive strategy is characterized by the changing of hip and knee angles upon encountering the perturbation (Cham and Redfern, 2001; Gielo-Perczak et al., 1999). No gait adjustment is made prior to the perturbation encounter. An accommodation strategy is adopted when the walker perceives the perturbation before the encounter, but cannot avoid the perturbation. Thus, the walker adjusts his or her gait to accommodate the hazard. Accommodation strategies involve modification of gait kinematics, such as stride length, frequency, direction and joint stiffness, sustained over several steps (Gronqvist et al., 2001). Finally, an avoidance strategy is adopted when the walker is able to avoid the perturbation completely. Avoidance strategies involve: (1) selection of an alternate foot placement by modulating step length and width; (2) increasing ground clearance to avoid hitting an obstacle on the ground and increasing head clearance to avoid hitting an obstacle above the ground; (3) changing the direction of locomotion when the obstacle cannot be stepped over or under; and (4) stopping. Both accommodation and avoidance are considered to be proactive control strategies.

1.4 Problem Statement

Typically, prediction and recovery from a perturbation to locomotion occurs within a very short period of time during which appropriate gait control has to be initiated in order to prevent a possible loss of balance. This gait control is a complex coordination of cognitive, sensory and musculoskeletal systems. In order to accurately coordinate these systems for control of balance and continued performance of simultaneous cognitive tasks, it is the contention of this research that a locomotor must have a complete up-to-date internal situation model of the surrounding environment and tasks. Thus, one has to perceive the changes in the physical environment, comprehend the meaning of these changes to locomotion behavior as well as cognitive workload, and project the implications of those changes with respect to successful task performance as well as maintaining balance and stability. Thus, the application of the construct of SA to understanding complex locomotion circumstances may be considered valid and appropriate.

2 Method

2.1 Participants

Twenty-four participants (12 male and 12 female) participated in the study. All participants had uncorrected or corrected 20/20 vision. The average age of the sample of participants was 22.5±3.0 years (22.2±2.9 for male and 22.8±3.2 for female participants). Participants were asked to walk at a treadmill speed that was most comfortable; the average speed was 2.1±0.2 mph (2.09±0.24 for male and 2.11±0.16 for female).

2.2 Apparatus and Scenario

A virtual reality locomotion interface (VRLI) was used in this experiment, including a Kistler-Gaitway instrumented treadmill, a rear-projection screen displaying the virtual locomotion environment (VLE), and active light shutter goggles to cause perception of a three dimensional scene by participants (see Figure 1). The treadmill contained a single force plate under the treadmill belt, which was used to measure the POF of participants at any moment in time. The graphics in the VLE flowed in conjunction with the speed on the treadmill. Finally, the system contained a safety harness suspended from a wood canopy around the treadmill to prevent participants from falling while walking on the treadmill. This system was previously validated for locomotion research (Sheik-Nainar and Kaber, 2007).

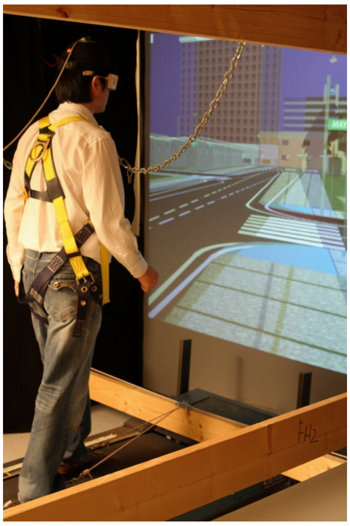

Figure 1: Photo of example VRLI setup for experiment.

During the experiment, participants were asked to walk through a suburban VLE from a starting location to a destination. Before beginning the trial, participants were provided with a plan-view map of the VLE with the start and end locations marked along with a route. Upon approaching an intersection, an audio cue was played to prompt participants to report the direction they should take to continue on the defined route. Even if a participant responded with the wrong direction, the VLE kept the participant on the correct route and the experimenter marked the response as being incorrect. While walking through the VLE, participants were posed with SA probes, which targeted awareness of various objects in the environment. Furthermore, participants encountered locomotion hazards as they navigated the VLE, including puddles (slips) and potholes (trips). Physical cueing of hazards was also administered by pulling ankle leashes attached to the participants' legs; a forward pull was used to simulate the forces associated with a slip, and a rearward pull was used to simulate a trip.

2.3 Independent Variables and Experiment Design

Three independent variables were manipulated as part of the experiment. Navigation aid type (NT) was manipulated as either map-based (MBN) or instruction (direction)-based (IBN) and was a between-subject variable; half of the participants were randomly assigned to the map group, while the other half were assigned to the instruction group. The map-based group relied only on the plan-view map to navigate the VLE while the instruction-based group was provided with navigation assistance through verbal instructions during the trials, including specific turn commands. The instruction-based group was also required to report their current location, including the current street name and the next/previous intersecting street names. The NT variable was manipulated to vary cognitive load, with the instruction-based group experiencing higher loading than the map-based group (as verified through condition pilot testing and workload analysis).

The second independent variable was *a priori* knowledge (AK), which had levels of low, medium, and high based on the fidelity of the VLE presented during the training session. The AK was also manipulated as a between-subjects variable with the differences in training regimens identified in Table 2. The final independent variable manipulation was the perturbation cueing (PC) with visual-only (VC) and visual-and-physical conditions (VPC) presented within-subjects. In the visual-only PC manipulation, participants saw the puddle or pothole in the VLE but the ankle leashes were not pulled. In the visual-and-physical condition, participants saw the hazards and experienced the physical simulation of the hazard by the pulling of the ankle leashes in real time.

Table 2: Description of training scenarios for the three levels of *a priori* knowledge.

Level of AK	Description of Training Scenario
Low	Sidewalk containing no buildings or other features as presented in the VLE used in the experiment trials
Medium	Same VLE as used in the experiment trials, but no physical cueing of locomotion perturbations
High	Same VLE and physical perturbation cueing as used in the experiment trials

2.4 Dependent Variables

The dependent variables measured in the experiment included the POF and SA query response accuracy (QRA). The POF was defined as the peak force generated by the trailing limb to propel the body forward. It was expected that an increase in POF would be associated with more proactive gait control (to push the body past the hazard). A real-time probe measure of SA was used in the experiment to pose SA queries to participants without freezing the scenarios. A total of 9 probes, 3 at each level of SA, were presented during each 5-minute walking trial. Example questions included: “How many turns have you made so far?”; “How many blocks are you from your destination?”; “What will be your next turn?”; “What were the last intersecting streets?”; “Is there a change in the walking surface?”; “Do you need to change your walking speed?”

2.5 Hypotheses

It was expected that higher levels of AK would promote higher “mental model” fidelity, which would, in turn, promote more proactive gait control as evinced by larger POFs at perturbations (Hypothesis 1). It was also expected that the instruction-based NT would result in higher cognitive loading, leading to less proactive gait control, and consequently lower POFs at perturbations than the map-based NT condition (Hypothesis 2). Similar to the effect of AK, it was expected that the visual and physical cueing conditions would yield higher mental model fidelity and promote more proactive gait control as evidenced by higher POFs (Hypothesis 3). Regarding the effect of the independent variables on QRA, higher levels of AK were expected to increase QRA (Hypothesis 4). Conversely, the increased cognitive loading resulting from the instruction-based navigation was expected to have a detrimental effect on the QRA (Hypothesis 5). Finally, the high fidelity visual and physical cueing of perturbations was also expected to facilitate QRA (Hypothesis 6).

2.6 Procedure

In order to ensure consistency in delivery of the experiment, all instructions to participants were pre-recorded and played through computer speakers. When participants came into the lab, they were given an overview of the experiment and procedures to be followed. They were then presented with an informed consent form and given time to understand the potential risks and benefits of the experiment. Following this, anthropometric data such as gender, age, height, and weight were recorded. Participants were then provided with a warm-up period to stretch their lower leg muscles followed by a 10-minute warm-up walk on the treadmill. This step was followed by another 5-min walk on the treadmill with leashes strapped around participant ankles (using Velcro straps) and connected to recoil systems. The intent of this walk was for participants to become accustomed to any resistance in the recoils.

Following this, participants were presented with the Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) and they completed a first form to reveal baseline ratings of any symptoms. Participants were then introduced to the VRLI and practiced walking in a VLE. Subsequently, participants were trained on the navigation task, which was dependent on their AK group assignment. If assigned to the instruction-based group, participants were also trained on self-reporting of location and receiving on-line navigation instructions. All participants received instructions on how to make turn requests in order to negotiate corners in the VLEs and how to verbally request display of the electronic map through the VLE. Finally, subjects were provided with examples of SA probes similar to those to be administered during the navigation task. Additional training was provided if participants had difficulty performing the task. Following this, they received a 5-minute break.

After the break, all participants were given instructions on the experiment trials, specifically the possible appearance of virtual perturbations with or without a physical perturbation during navigation. They were advised to exercise caution in walking as they would in a real-life situation. Each participant completed four trials of approximately 5-minutes in duration. Before performing a trial, they were given the map of the test VLE with the predefined route marked clearly from the start to end location. Participants were offered a 5-minute break at the end of the 2nd trial. Participants were administered SSQs throughout the training and testing trials in order to ensure no onset of sickness. In total, the experiment lasted approximately 2 hours, for which participants were compensated $20.

2.7 Data Analyses

Before analysing the response measures, all POF values were normalized by calculating z-scores based on the means and standard deviations of the POF for each participant walking under a baseline condition containing no locomotion perturbations. This allowed for comparisons across participants assigned to the various experimental conditions. All POF z-scores and QRA values were analysed using an analysis of variance (ANOVA) model including the following terms: trial order, AK, NT, PC, and all interactions between AK, NT, and PC. All post-hoc analyses were conducted using Duncan's Multiple Range test with a significance criterion of $\alpha=0.05$.

3 Results

3.1 Push-Off Force

An ANOVA on the POF z-scores revealed significant main effects due to PC ($F(1,336)=4.29$; $p<0.05$), trial order ($F(1,336)=8.0$; $p<0.05$) and individual differences ($F(17,336)=18.08$; $p<0.0001$). There were also significant two-way interactions between NT and PC ($F(1,336)=5.94$; $p<0.05$) as well as AK and PC ($F(2,336)=4.86$; $p<0.05$) and a significant 3-way interaction between NT, AK and PC ($F(2,336)=19.61$; $p<0.0001$).

Regarding the PC effect, visual cueing produced higher POFs ($p<0.05$; mean z-score=0.152; SE=0.15) compared to visual and physical cueing (mean z-score=-0.100; SE=0.20). ANOVA results on the trial order main effect revealed that participants produced significantly higher ($p<0.05$) POFs during the second trial (mean z-score=0.071; SE=0.17) compared to the first trial (mean z-score=-0.014; SE=0.17). Further analysis of the two-way interaction between AK and PC showed that, in general, z-scores on the POF values increased linearly with increasing AK (see Figure) for both PC conditions. Additional analysis of the two-way interaction between NT and PC revealed significantly higher ($p<0.05$) POF z-scores under MBN compared to IBN for both PC conditions, according the Duncan's Multiple Range post-hoc test. Further analysis of the three-way interaction between NT, AK and PC revealed IBN under high AK and VPC to produce the highest POF z-scores (mean=1.469; SE=0.25), while IBN under low AK and VPC produced the lowest (mean=-1.359; SE=0.63; see Figure 3).

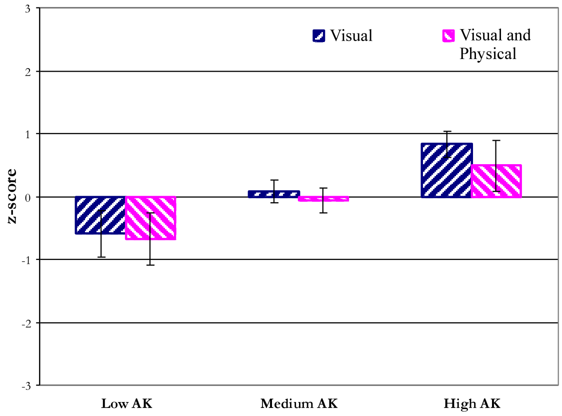

Figure 2: POF z-scores plotted against AK for VC and VPC conditions

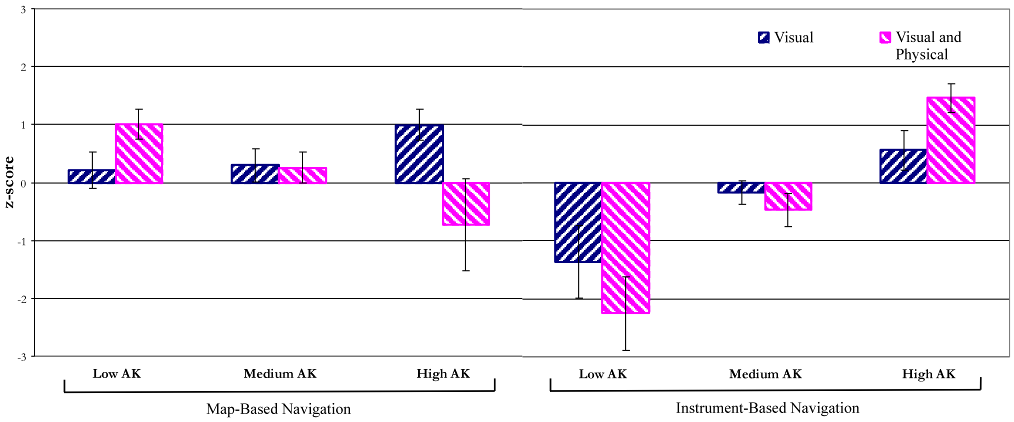

Figure 3: POF z-scores plotted against AK within NT for VC and VPC conditions.

3.2 Situation Awareness Query Response Accuracy

An ANOVA on overall SA scores failed to reveal any significant main effects due to NT, AK or PC or interaction effects. However, an ANOVA on SA scores by level revealed a significant interaction between NT and SA level ($F(2,231)=3.84$; $p<0.05$). Further analysis of the two-way interaction showed that there was a significant difference ($p<0.05$) between mean SA score under IBN vs. MBN at level 2 (mean=63.271; SE=4.14) and level 3 SA (mean=48.234; SE=4.30). Figure 4 provides a graphical representation of the two-way interaction between NT and SA levels. It can be observed that the scores under the instruction-based

NT show a higher trend compared to map-based for level 1 and 2 SA. For level 3 SA, it can be observed that map-based NT (mean=61.854; SE=3.73) resulted in higher scores compared to instruction-based navigation (mean=48.234; SE=4.30).

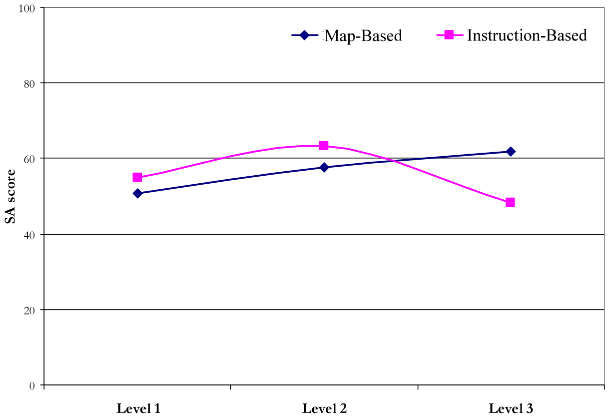

Figure 4. SA score by level plotted against NT.

4 Discussion

As mentioned previously, increased POF in advance of a locomotion hazard was considered to be indicative of greater proactive gait control. Higher values of POF suggest locomotor attempts to control foot landings in order to proactively prepare for encountering a perturbation. Hypothesis 1 stated that increasing AK would result in increasing POF and this expectation was supported by the interaction of AK with PC as well as the significant three-way interaction also involving the NT manipulation. In general, POF increased as AK increased across both levels of PC, particularly for the instruction-based NT (high cognitive workload group). This suggests that the higher-fidelity training simulations promoted more accurate mental models of the VLE, which promoted proactive gait control in anticipation of a locomotion hazard.

Hypothesis 2 stated that instruction-based NT would lead to lower POFs than map-based NT due to the increased cognitive load imposed by the instruction-based task distracting from concurrent proactive gait control. The two-way interaction between NT and PC showed that the POF responses were significantly different and higher for the MBN group compared to IBN group for both PC conditions. Furthermore, the three-way interaction between AK, NT, and PC revealed that POF was lower for the IBN group with low and medium AK, but not for the high AK group. This suggests that the increased cognitive loading associated with the instruction-based NT had a much greater effect on participants who had a lower fidelity mental model of the VLE due to their assigned training condition. In general, these results support Hypothesis 2, particularly for participants who were part of the low and medium AK groups.

Hypothesis 3 posited that the perturbation condition with visual and physical cueing would result in higher POFs than the visual-only condition. The main effect of PC refuted this hypothesis, as did the interactions of PC with the other independent variables. It is possible that, as a result of participants being unaware of the actual severity of perturbations when no physical cues were presented, they overestimated severity and made excessive gait control adjustments. On the other hand, when physical cues were presented, participants knew the degree of perturbation severity and adjusted their gait accordingly.

Regarding SA QRA, Hypotheses 4 and 6 were refuted by the results. That is, the hypothesized increased fidelity of the mental models formulated as a result of exposure to the higher fidelity (AK) training conditions and the inclusion of physical cueing had no effect on overall SA QRA or on the QRA at any of the 3 levels of SA. However, there was a significant interaction between the SA levels and NT. The IBN condition promoted levels 1 and 2 SA compared to the MBN condition, but the trend was reversed for level 3 SA. This suggests that the information that the instruction-based group were required to report facilitated perception (level 1 SA) and comprehension (level 2 SA) of stimuli in the system, but the increased cognitive loading associated with the instruction-based NT hindered participant ability to project future states compared to the map-based NT condition. In general, the results refute Hypothesis 5 for levels 1 and 2 SA, but support the hypothesis for level 3 SA.

5 Conclusion

The trends of the results obtained in this study suggest that *a priori* knowledge (AK) manipulation had the largest effect on proactive gait control as compared to navigation aiding condition and perturbation cueing type; the majority of the interaction results were driven by the AK manipulation. We noted that increasing AK resulted in increased proactive gait control, as evidenced by the increasing POF. SA was affected only by the cognitive loading imposed by the navigation aiding condition; the hypothesized mental model formulations associated with AK and PC had no significant effect on SA. It is possible that the visual cue of gait perturbations was sufficient for locomotor SA vs. the visual and physical cueing condition. In general, the results point to a complex relationship between SA and proactive gait control. Considering all response measures, it is clear that an accurate internal mental model of a locomotion environment (through high fidelity training) is important for proactive gait control when encountering locomotion hazards.

Acknowledgement

Carl Pankok's and David Kaber's work on this research was supported in part by a grant from the U.S. National Institute for Occupational Safety and Health [grant number NIOSH: No.2 T42 OH008673-13]. The opinions expressed in this report are those of the authors and do not necessarily reflect the views of NIOSH.

References

Bloem, B. R., V. V. Valkenburg, M. Slabbekoorn, and M. D. Wilemsen. 2001. "The Multiple Task Test- Development and Normal Strategies." Gait and Posture 14: 191-202.

Brown, L, A. Shumway-Cook, and M. Woollacott. 1999. "Attentional Demands and Postural Recovery: The Effects of Aging." Journal of Gerontology 54A: M165-M171.

Cham, R. and M. S. Redfern. 2001. "Lower Extremity Corrective Reactions to Slip Events." Journal of Biomechanics 34 (11): 1439-1445.

Courtney, T. K., G. S. Sorock, D. P. Manning, J. M. Collins, and M. A. Holbein-Jenny. 2001. "Occupational Slip, Trip, and Fall-Related Injuries - Can the Contribution of Slipperiness be Isolated?" Ergonomics 44 (13): 1118-1137.

Ebersbach, G., M.R. Dimitrijevic, and W. Poewe. 1995. "Influence of Concurrent Tasks on Gait: A Dual-Task Approach." Perceptual and Motor Skills 81 (1): 107-113.

Endsley, M. R. 1988. "Design and Evaluation for Situation Awareness Enhancement." In Proceedings of the Human Factors Society 32nd Annual Meeting, 97-101, Santa Monica, CA: HFES.

Endsley, M. R. 1995. "Toward a Theory of Situation Awareness in Dynamic Systems." Human Factors 37 (1): 32-64.

Gielo-Perczak, K., D. A. Winter, and A. E. Patla. 1999. "Analysis of the Combined Effects of Stiffness and Damping of Body System on the Strategy of the Control During Quiet Standing." Proceedings of the XVIIth Congress of the International Society of Biomechanics, Calgary: ISB.

Grönqvist, R., J. Abeysekera, G. Garg, S. M. Hsiang, T. B. Leamon, D. J. Newman, K. Gielo-Perczak, T. E. Lockhart, and Y. C. Pai. 2001. "Human-Centered Approaches in Slipperiness Measurement." Ergonomics 44 (13): 1167-1199.

Kennedy, R. S., N. E. Lane, K. S. Berbaum, and M. G. Lilienthal. 1993. "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness." International Journal of Aviation Psychology 3 (3): 203-220.

Kerr, B., S. M. Condon, and L. A. McDonald. 1985. "Cognitive Spatial Processing and the Regulation of Posture." Journal of Experimental Psychology: Human Perception and Performance 11: 617-622.

Lajoie, Y., N. Teasdale, C. Bard, and M. Fleury. 1993. "Attentional Demands for Static and Dynamic Equilibrium." Experimental Brain Research 97: 139-144.

Lin, L. J., F. T. Chiou, and H. H. Cohen. 1995. "Slip and Fall Prevention: A Review of Research, Practice and Regulations." Journal of Safety Research 26 (4): 203-212.

Perry, C. M., M. A. Sheik-Nainar, N. Segall, R. Ma, and D. B. Kaber. 2007. "The Effects of Physical Workload on Situation Awareness and Cognitive Task Performance in Multitasking." Theoretical Issues in Ergonomics Science 9 (2): 95-113.

Sheik-Nainar, M.A. and D.B. Kaber. 2007. "The Utility of A Virtual Reality Locomotion Interface for Studying Gait Behavior." Human Factors 49: 696-709.

Trew, M. and T. Everett. 1997. Human Movement, 3rd Edition. New York: Churchill Livingstone.

Woollacott, M. and A. Shumway-Cook. 2002. "Attention and the Control of Posture and Gait: A Review of an Emerging Area of Research." Gait & Posture 16: 1-14.

Yeoh, H.T., T.E. Lockhart, and X. Wu. 2013. "Nonfatal Occupational Falls on the Same Level." Ergonomics 56 (2): 153-165.