Age-Dependent Differences in the Attentional Demands of Obstacle Negotiation

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**Background.** Although the attention directed to gait does increase as an impending obstacle nears, it remains unclear whether the allocation of attentional resources differs between the precrossing phase of obstacle negotiation and the crossing phase of this task. This study compared the attentional demands associated with steady-state walking and the precrossing and crossing phases of an obstacle-negotiation task between young and older adults.

**Methods.** Fifteen younger and 15 older adults participated in this study. Participants were required to perform a verbal reaction time task during three events: (1) steady-state unobstructed gait, (2) precrossing (the final full stride prior to obstacle crossing), and (3) obstacle crossing.

**Results.** The attention directed during precrossing exceeds that of steady-state walking for both younger and older adults. Younger adults direct more attention to gait during precrossing than they do during crossing. However, precrossing is equally attentionally demanding as crossing for older adults, and both of these events require more attention than does steady-state gait in this age group.

**Conclusions.** The task of obstacle negotiation, from precrossing through obstacle crossing, is attentionally demanding for elderly persons, and fall risk, due to a compromised availability of attentional resources, does occur prior to obstacle crossing in this age group.

TRIPPING is responsible for up to 50% of all falls among older adults (1), with the majority of trips arising from errors during obstacle negotiation (2). Age-dependent deterioration in the sensorimotor system predisposes older adults to biomechanical limitations that increase the risk of contacting an obstacle during crossing (3). As obstacle contact frequency increases, the probability of a fall episode also escalates. For this reason, biomechanical limitations that occur as a consequence of age-dependent sensorimotor deterioration are thought to provide partial explanation for the high rate of trip-induced falls among elderly persons. Further explanation for the frequency of trip-related falls among elderly persons is warranted by the finding that obstacle negotiation appears to stress the availability of cognitive resources, particularly among older adults. This finding is based on previous work demonstrating successful obstacle crossing to be compromised when participants were required to concurrently perform a cognitively demanding task (4,5). In this scenario, compromised motor performance reflects the phenomenon of dual task interference that is characteristic of the limited capacity model of attentional resources (6). Based on this model, compromised success, or contact during obstacle avoidance, implies this task to be an attentionally demanding process. Greater rates of error for older adults compared to younger adults (4,5) imply that the attentional demands of obstacle negotiation increase with age.

The notion that obstacle negotiation requires attentional resources provides extension to the current understanding that walking is not an automatic task and, on the contrary, draws attentional resources (7,8). Further exploration regarding the cognitive demands of gait demonstrated that imposed constraints to the walking pattern will increase the amount of attention that is directed to this task. For example, changes in the walking pattern emerging as a consequence of anxiety (9) or an imposed targeted stepping constraint (10,11) both increase the attention directed to walking. Moreover, the attentional demands of gait initiation exceed those of steady-state walking, and the attentional cost of walking is inversely related to target distance when a terminal stepping constraint is imposed (11). In summary, it is now apparent that, although steady-state walking is an attentionally demanding task, the amount of attention directed to gait depends on the complexity of the walking task and the constraints imposed upon the walking pattern. Furthermore, it is also apparent that obstacle negotiation is an attentionally demanding process and that the attention directed to walking increases during preparation for an impending contingency and during crossing.

Trips occur due to obstacle contact during crossing, and it is now apparent that trip risk will be enhanced if the availability of cognitive resources is compromised during this event (3,5). However, obstacle negotiation necessitates modifications to the gait pattern that occur at least two steps prior to crossing (12). Although the attention directed to gait does increase as an impending obstacle nears (11), it remains unclear whether the allocation of attentional resources differs between the precrossing phase of obstacle negotiation and the crossing phase of this task. If the attention required during precrossing equates to or exceeds that of crossing, then vulnerability for instability may precede the event of obstacle crossing. However, given the high prevalence of falls among elderly persons, we were also interested in determining whether age influences the allocation of attentional resources during the precrossing and crossing phases of the obstacle-negotiation task. This information will further our understanding regarding the reasons for the high prevalence of trip-related injuries among elderly persons by...
providing insight into the potential for event-dependent changes in attentional allocation during walking. Thus, the purposes of this study were to compare the attentional demands associated with the precrossing and crossing phases of an obstacle-negotiation task among younger and older adults and to determine whether the attentional requirements of precrossing and crossing differ from those of steady-state walking.

**Methods**

**Participants**

All participants voluntarily provided written informed consent prior to beginning this study. Clearance to conduct this study was provided by the Human Research Ethics committee of the University of Lethbridge. Fifteen younger (YA; 9 male, 6 female; mean age ± standard deviation = 22.8 ± 2.5 years) and 15 older (OA; 4 male, 11 female; mean age ± standard deviation = 68.1 ± 3.9 years) individuals participated. All participants were free of neurological and orthopedic conditions that might affect gait and/or cognitive function. All older participants underwent a thorough neurological screening comprised of standard clinical tests of sensorimotor function, an electronystagmogram to exclude potential vestibular pathologies, and a complete Mini-Mental State Examination to confirm cognitive status. All tests of neurological status were performed by a neurologist. Participants wore a t-shirt or blouse, shorts, running shoes, and a safety harness over their clothes during testing.

**Protocol**

Participants were asked to walk at a self-determined velocity along the length of an 8.0-m walkway for each of 21 testing trials. The walkway was either obstructed by an obstacle (12 trials) or free from obstruction (9 trials). The obstacle was a foam block (60 cm wide × 22.5 cm high × 15 cm deep) placed at the midpoint of the walkway. In 6 of the 12 obstructed gait trials and 3 of the 9 unobstructed trials, participants were required to perform a Probe Reaction Time (RT) task. In each of the nine RT trials, participants responded to an auditory cue (buzzer) as quickly as possible, by loudly saying the word “top” (13). The word “top” was used because its meaning is unrelated to the postural task and the articulation of the hard consonant “t” provided a definitive signal for the calculation of RT. All participants reported that they could hear the buzzer without difficulty. Similarly, participants received three practice trials of unobstructed and three trials of obstructed walking prior to data collection, and all could perform the tasks without difficulty. The order of test trials was randomized between participants.

Participants were instructed to keep their arms crossed in front of their chest for the duration of testing, and to continue walking while responding to the buzzer stimulus. This restriction to arm movement served to ensure visibility of joint markers throughout testing. The buzzer was triggered during the single-limb support (SLS) phase in one of three events: (1) steady-state walking (WALK), during the 4th stride of the unobstructed walking trials; (2) precrossing (PRE), during the final full stride prior to crossing; and (3) obstacle crossing (CROSS), as the participant crossed over the obstacle.

**Instrumentation**

Passive, infrared-reflective markers were placed on 16 anatomical landmarks. These landmarks were the forehead, sacrum, and bilaterally on the temple, acromion process, lateral epicondyle of the humerus, greater trochanter of femur, fibular head, heel, and the base of the fifth metatarsal. Kinematic data were collected at a frequency of 120 Hz using a six-camera reflective marker data collection system (Peak Performance Technologies and Peak Motus 2000 software; Englewood, CO). Digital video data were also collected using frontal and sagittal views. These data were used to confirm successful obstacle crossing and to monitor obstacle contact frequency.

A custom designed auditory cue box (University of Lethbridge Technical Services Department) was used to provide the auditory stimulus for the RT trials. The stimulus consisted of a sounding buzzer, 500 ms in duration. The buzzer was programmed to trigger at toe-off to ensure that the participant was in SLS phase while responding to the auditory cue in each walking event. Toe-off events were detected by footswitches placed on the anterior aspect of the insoles of the participant’s shoes. A microphone headset and computer with an AW35 Pro Audio Card were used to capture the participant’s verbal response to the auditory stimulus (sampling frequency = 22.1 kHz). All analogue data were digitally sampled at 600 Hz and archived prior to further signal processing.

**Measures of Interest**

All data processing, beyond the compilation of obstacle contact frequency scores, was performed using custom written algorithms (Matlab; The MathWorks, Natick, MA). Raw marker coordinate data were filtered using a dual-pass 4th order digital Butterworth filter with a cut-off frequency of 3 Hz. Whole-body center of mass (COM) was calculated using a seven segment model; velocity was calculated using the finite differences method for differentiation.

Kinematic data from each gait event (WALK, PRE, and CROSS) were isolated from the data set using the event of heel contact, obtained from the filtered velocity signal of the heel marker (14). The relative duration of the SLS phase, the length of the stride, and the mean COM velocity were calculated for WALK, PRE, and CROSS. These kinematic measures were used to determine whether responding to the RT probe influenced gait and/or negotiation kinematics as per our previous work in this area (9). RT scores were used to assess changes in attentional resource allocation, and were determined as the period between the onset of the auditory stimulus and the onset of the verbal response (9,15).

**Statistical Analysis**

An independent mixed factor [Age (young/old) × Action (WALK/PRE/CROSS)] repeated measures multivariate analysis of variance (RM MANOVA) was used to determine whether performing the Probe RT task influenced gait and/or obstacle-negotiation kinematics. The measures of SLS duration, stride length, and COM velocity were included in this analysis. The attentional demands associated with each gait event were assessed using a mixed factor (Age × Action) repeated measures analysis of variance (RM ANOVA) with
repeated measures on Action. RM ANOVAs and t tests were used in the post hoc analysis of significant RM MANOVA and RM ANOVA results with alpha set to 0.05.

RESULTS
There were no unsuccessful crossings or obstacle contacts recorded in this study. Comparison of gait, precrossing, and crossing step kinematics confirmed that the RT probe did not influence stride length, COM velocity, or SLS duration in any of these events for younger or older adults (F2,56 = 1.36, p = .14, F2,56 = .362).

Older adults had significantly longer RT scores than did younger adults (F1,28 = 6.84, p = .014), and RT scores were significantly different between actions (F2,56 = 10.23, p < .001). The longest RT scores emerged during precrossing: (RT PRE: t29 = 3.88, p = .001, RT CROSS vs RT PRE: t29 = 2.39, p = .023), whereas obstacle crossing showed significantly longer RT scores than did unobstructed steady-state walking (t29 = 2.25, p = .032).

A significant Age × Action interaction revealed that the RT scores for each gait action differed between age groups (F2,56 = 3.43, p = .039). Specifically, among younger adults, precrossing showed significantly longer RT scores than did walking and obstacle crossing: (RT WALK vs RT PRE: t14 = 2.61, p = .021; RT CROSS vs RT PRE: t14 = 3.36, p = .005); however, no significant differences emerged between walking and obstacle crossing in this age group (p > .05). Among older adults, precrossing and crossing showed significantly longer RT scores than did walking: (RT CROSS vs RT WALK: t14 = 2.67, p = .018; RT WALK vs RT PRE: t14 = 3.42, p = .004); however, RT scores during precrossing did not differ from those during obstacle crossing (p > .05). These findings are illustrated in Figure 1.

DISCUSSION
We compared the attentional demands associated with obstacle negotiation for younger and older adults. Because crossing an obstacle imposes alterations to the walking pattern that occur prior to and during crossing (3,16), we compared the allocation of attentional resources for the precrossing and the crossing phases of the obstacle-negotiation process. Our rationale for this investigation was to explore the possibility that vulnerability for instability due to a compromised availability of cognitive resources may precede the event of obstacle crossing. These findings also extend current knowledge regarding the cognitive requirements of gait and gait-dependent tasks.

As demonstrated previously, preparing for an obstacle contingency does increase the attention required for walking (10). Preparation for obstacle crossing imposes alterations to the gait pattern that serve to decrease the walking velocity (3,17). These adjustments occur as early as two steps prior to obstacle crossing (3). As suggested by Sparrow and colleagues (10), alterations in locomotor dynamics may provide an explanation for the increase in attentional requirements observed during preparation. Although this may be the case, an additional possibility is that added attention is required during the precrossing phase of negotiation to permit visual regulation of stepping parameters. Indeed, the precrossing phase of obstacle negotiation is a visually guided process (17) and Sparrow and colleagues (10) have suggested that visually dependent regulation of gait does incur an additional attentional cost. Thus, we propose that alterations in attentional allocation during the precrossing phase of obstacle negotiation reflect the cost associated with visual regulation of gait.

It is interesting that older adults dedicate the same amount of attention to crossing as they do to precrossing, yet younger adults dedicate less attention to crossing than to precrossing. A possible explanation is that older adults visually fixate on the obstacle during crossing, whereas younger adults do not. Although the work of Patla and Vickers (17) indicates that visual fixation on the impending obstacle was confined to the approach phase of obstacle negotiation, their study was restricted to younger adults. Older adults are more conservative when crossing obstacles than are younger adults (3,18), and directing visual gaze toward the obstacle during crossing would conform with a conservative strategy to ensure that contact is prevented. Thus, in sum, we suggest that age-dependent differences in the strategy for the allocation of attentional resources between precrossing and crossing may reflect a tendency of older adults to direct visual
gaze toward the object during crossing. Further study is warranted to confirm this hypothesis.

Finally, obstacle crossing demands more attention than walking for older adults, but not for younger adults. This finding contradicts the work of Weerdesteyn and colleagues (5) and Chen and colleagues (4) whose findings imply that obstacle crossing demands more attention than does walking in both older and younger adults. The obstacle-negotiation task in these previous studies required participants to avoid an obstacle that suddenly appeared in the gait path. Our paradigm, in contrast, required participants to negotiate an obstacle that was present from trial onset. Perhaps formulating the motor plan for reorganizing limb dynamics for obstacle crossing occurs during the precrossing phase; such planning would not be permitted in the sudden-obstacle paradigm, thereby imposing further cognitive demand onto the crossing phase of the negotiation task. It is interesting that similar attentional demands between walking and crossing in younger adults implies that executing the movement patterns for obstacle crossing does not require any more cognitive resources than does steady-state gait for this age group. That the attentional demands for these actions differs for older adults indicates that crossing an obstacle requires more cognitive resources than does walking for this age group. Older adults cross obstacles in a more conservative manner than do younger adults (3,19). Moreover, negotiating obstacles imposes fear of falling among many elderly persons (20); previous work from our laboratory implies that fear of falling increases the attention allocated to gait tasks (9). These factors, together with the proposed possibility that older adults visually fixate on the obstacle during crossing, provide an explanation for the observed age-dependent differences in the attentional demands of obstacle crossing.

Indeed, one point to consider is that, given the gender imbalance of our participant samples, the possibility for gender-dependent anthropometric differences due to leg length may influence the difficulty of obstacle crossing and may consequently increase the attention required for this task. However, the height of the obstacle used in the present study was chosen to approximate that of a sidewalk curb. Thus, we expect that familiarity with object dimensions would temper any difficulty associated with the task. Nevertheless, a comparison of participant anthropometrics between groups indicated that the participant groups did not differ in height ($p > .05$) or in leg length ($p > .05$).

Conclusion

Our findings extend those of Sparrow and colleagues (10) to confirm that the precrossing phase of obstacle negotiation demands more attention than does steady-state unobstructed walking for younger and older adults. The findings from our work are that the attention directed to crossing does not differ from that of steady-state walking in younger adults. On the contrary, we also found that precrossing and crossing are equally attentionally demanding among older adults, and that both of these events require more attention than does steady-state gait in this age group. The major implications of our findings are that the task of obstacle negotiation, from precrossing through obstacle crossing, is attentionally demanding for elderly persons, and that a possibility for instability due to a compromised availability of attentional resources does occur prior to the event of obstacle crossing in this age group.

Acknowledgments

This research is supported by grants to Dr. Brown from the Alberta Heritage Foundation for Medical Research (AHFMR) (grant 19990609) and the Medical Services Incorporated (MSI) foundation (grant 739).

We gratefully acknowledge the contributions of Kendra Massie, Clint Wutzke, and Sarah Tiede for assistance on data collections and data analysis; Greg Tompkins and Frank Klassen for equipment construction and hardware technical assistance; Stephanie Cooper for manuscript formatting; and T. R. Winder for neurological screening.

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Received September 11, 2003
Accepted April 21, 2004
Decision Editor: John E. Morley, MB, BCh