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Effects of Secondary Task on Obstacle Avoidance in Healthy Young Adults

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Abstract

Research studying attention and gait stability has suggested the process of recovering gait stability requires attentional resources, but the effect of performing a secondary task on stability during obstacle avoidance is poorly understood. Using a dual-task paradigm, the present experiment investigated the extent to which young adults are able to respond to a secondary auditory Stroop task (requiring executive attentional network resources) concurrently with obstacle crossing during gait as compared to performing unobstructed walking or sitting (control task). Our results demonstrated that as the level of difficulty in the postural task increased, there was a significant reduction in verbal response time from congruent to incongruent conditions in the Stroop task, but no differences in gait parameters, indicating that these postural tasks require attention, and that young adults use a strategy of modulating the auditory Stroop task performance while keeping stable gait performance under the dual-task situations. Our findings suggest the existence of a hierarchy of control within both postural task (obstacle avoidance requires the most information processing resources) and dual-task (with gait stability being a priority) conditions.

Introduction

A growing body of literature is showing that maintaining or regaining gait stability requires attentional resources, which provides additional evidence to support the concept that walking is not automatic but requires attentional resources (Lajoie et al. 1993; Lajoie et al. 1996; Sparrow et al. 2002; Beauchet et al 2005). Attentional resources are assumed to be limited (Neumann 1984). As a result, competition for attentional resources may occur during the

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performance of more than one attentionally demanding task and lead to task interference (Wickens 1989).

Research studying attention and gait stability has used dual-task paradigms in which balance control during locomotion (the primary task) and a secondary cognitive task were performed together. The degree to which performance on either one or both tasks declined has been used to show the extent of attentional resource sharing. A study by Lajoie et al. (1993) showed that simple reaction times were slower during walking than while sitting and narrow standing in young adults. No reduction in gait parameters associated with performing the secondary task was reported. In contrast, Ebersbach et al. (1995) found that double support time was significantly affected when a digit recall task was performed synchronously with walking. The authors also noted that performance of the gait task reduced performance on the digit recall task.

Many types of secondary tasks have been used to study attentional mechanisms using dual-task methodology. These include simple reaction time tasks involving the visual or auditory systems, the Stroop task, verbal memory tasks, and math calculation tasks, such as counting backwards by threes. Though these studies are interesting, they may be weakened by not differentiating between structural attentional interference and capacity attentional interference (Kahneman 1973) and by not using tasks for which attentional network processing requirements are known. Kahneman notes the importance of choosing tasks that do not introduce structural interference when analyzing capacity interference. To exclude the possibility of structural interference, it is therefore best to use secondary tasks that do not interfere with the visual or somatosensory control systems for locomotion. An auditory Stroop task (Cohen and Martin 1975) was employed as the secondary cognitive task in this study to minimize structural interference.

In addition, Posner (1994) and others have shown that a variety of attentional networks may be involved in information processing for different tasks. Research has provided evidence for the existence of different attentional systems, with the executive attentional system involved in higher level attentional processing, including conflict resolution, which may occur in dual-task situations. The Stroop task also requires executive attentional networks, so it is ideal for use as a secondary task since its attentional requirements are already known.

Previous dual-task research has mainly been limited to the study of balance control during stance and level walking; thus the effect of performing a secondary task on stability during obstacle avoidance is poorly understood. In this regard, both Chen et al. (1994) and Weerdesteyn et al. (2003) have demonstrated that obstacle avoidance success rate was degraded by the presence of a secondary task. However, the effect of obstacleavoidance on the secondary task is still unclear.

The first purpose of this study was to better understand the effect of a secondary task requiring executive attentional networks on obstacle avoidance in healthy young adults. The second purpose of this study was to further examine dual-task effects for obstacle avoidance at different heights and other less challenging postural tasks, including sitting and level walking. It was hypothesized that a greater dual-task impact would be demonstrated in young adults while performing an obstacle avoidance task with the secondary task as compared to level walking.

Methods

Participants

Approval for the use of human subjects was granted prior to testing by the University of Oregon Institutional Review Board. Written and verbal instructions of testing procedures were provided and written consent was obtained from each participant prior to testing. Twelve healthy young adults participated in this study (5 females/7 males; age = 22.8 ± 2.7 years; mass = 72.2 ± 14.3 kg; height = 172.3 ± 14.2 cm). Prior to experimental testing, each participant was screened for motor deficits using the Berg Balance Test and Dynamic Gait Index. Neuropsychological deficits were screened using a mini-mental state examination. None of the participants suffered from motor or neuropsychological disorders which could affect balance performance.

Experimental apparatus

All data were collected in the Motion Analysis Laboratory of the University of Oregon. Three dimensional marker trajectories in space were collected by eight-camera motion analysis system (Motion Analysis, Santa Rosa, CA) with a sampling rate of 60Hz. The cameras were positioned surrounding an eight-meter long, and four-meter wide walkway. Twenty-nine retroreflective markers were placed bilaterally on bony landmarks of the body similar to previously validated marker setups (Hahn and Chou, 2004). Ground reaction forces and moments were collected by two in series force plates (Advanced Mechanical Technologies Inc. Watertown, MA) located in the center of the walkway separated by 25.9 cm. A lightweight PVC pipe crossbar (1/2″″ diameter, 1.3 m long) was used as an obstacle during obstacle-crossing trials. The crossbar sat atop two adjustable upright standards placed between the two force plates placed in a line. The obstacle was fashioned in such a way as to easily come loose and fall to the ground if struck by the participant. A marker was placed on the tip of each end of the crossbar so that its global position could be tracked.

An auditory Stroop task was implemented by SuperLab Pro v.2 (Cedrus, San Pedro, CA). Stimuli were relayed to the participant via two speakers facing the walkway located two meters behind the start position. Participant responses to the Stroop task were vocalized through a Radio telemetry head-mounted microphone (AKG Acoustics, Vienna, Austria). Four photocells (RadioShack, Fort Worth, TX) were located at specific locations down the length of the walkway (Figure 1). The first photocell was located 50 cm beyond the start position and served as the trigger for initiating the Stroop task program. The other three photocells were used to implement the Stroop stimuli. The second photocell beam passed 5 cm over the first force plate. The third photocell beam was located approximately 15 cm above the obstacle. The final photocell beam passed 20 cm over the second force plate. Photocells were strategically placed to implement a stimulus during approach, clearance and following clearance of the lead limb.

Experimental protocol

Testing began with eight seated Stroop trials. During each seated trial an auditory Stroop task was given twice. The Stroop task itself consisted of the computerized presentation of the words “high” or “low” spoken with a high or low pitch. Congruency between pitch and the word spoken was randomized. The goal for the participant was to indicate the pitch of the voice as quickly and accurately as possible while ignoring the actual word that was presented. Prior to actual collection, the participant was given an opportunity to hear each of the four possible stimuli and allowed several practice trials. Accuracy and reaction times were recorded during each trial. After marker placement, several walking practice trials were allowed so that participants could become comfortable walking with the marker set and the starting spot could be adjusted by the proctor to insure that the participant hit each force plate with the entire foot. This was done without telling the participants the reason, so that they did not make a conscious effort to hit the force plates. Participants were asked to perform level walking at a comfortable self-selected pace.

Motion data collection started with single-task walking in three different conditions: level walking and obstacle crossing over an obstacle set at 2.5% and 10% of the participant's body height. Dual-task conditions were then performed with Stroop congruency, walking condition, and location of stimulus presentation randomized for each trial. A single stimulus was presented during each trial, except during randomly dispersed catch trials (5%) in which no stimulus was presented. Vision of the walkway was occluded prior to each walking trial with a blind in front of the participant so that they could not preprocess the walking condition for that trial. After dual-task trials, another set of single task walking trials, and then another set of sitting trials were performed. Sixteen dual-task trials were given in level walking and 48 dual-task trials were provided for each obstacle avoidance at 2.5% and 10% when the Stroop task appeared during approach, clearance and following clearance of the lead limb. A total of 112 dual-task trials were completed for each participant for the locomotion part of the study.

Data Processing and Analysis

Analog signals from the two force plates, Stroop stimulus and microphone recordings were collected at 960Hz for six seconds per trial. EVaRT 4.4 (MotionAnalysis, Santa Rosa, CA) was used to track the markers in space. They were then filtered with a low-pass, fourth order Butterworth filter at a cutoff frequency of 8 Hz. Virtual markers were created at joint centers and combined with anthropometric data to determine center of mass (COM) location for each of thirteen segments (Winter, 1990). The thirteen different segments created were the head, trunk, two upper arms, two lower arms, pelvis, two thighs, two shanks, and two feet. COM data were truncated to one complete stride starting with heel strike on to the first force plate. Laboratory written programs (Motion Analysis Lab, University of Oregon) in Matlab 7.0 (Mathworks Inc., Natick, MA) were used to complete the processing of data.

The center of pressure (COP) in the global coordinate system was calculated using the measured ground reaction forces and moments for times when the feet were in contact with only the force plates. The whole-body COM was calculated from each segment's COM with a weighted sum method. The COM sagittal plane range of motion (AP ROM), the coronal plane range of motion (ML ROM), and the peak velocity in the A–P (AP V) and M–L directions (ML V) were recorded. Truncated COM data were time synchronized with the COP data to find the maximum horizontal separation distance between the COM and COP in both the sagittal plane (APmax) and coronal plane (MLmax). Velocities were estimated with the use of Woltring's generalized cross-validated spline algorithm (Woltring, 1986).

Gait velocity, stride length, and stride time were also calculated. Stride length and stride time of the crossing stride were determined from the position change of the heel marker and respective time change. Gait velocity was calculated from the position change of the body COM and time change during a complete stride. For obstacle-crossing trials, the toe-obstacle clearances (TOC) for the trailing and leading limbs were determined from the vertical position of the toe marker. Verbal reaction times (VRT) during Stroop tasks were calculated from the time difference between Stroop stimulus onset and the onset of the verbal response. A proctor recorded accuracy of the responses.

Statistical analyses were performed with SAS 9.0 (SAS Institute Inc., Cary, NC). A mixed model analysis of variance was used to compare the effects of postural condition (seated, unobstructed walking and obstacle avoidance at 2.5% and 10% of the body height), congruency, and single vs. dual-task. Gait parameters (gait velocity, stride time, stride length, AP ROM, ML ROM, AP V, ML V, APmax, MLmax, TOC) and VRT were used as dependent measurements Significance was set at $p < 0.05$.

Results

Postural Task

A comparison between over all single and dual-task conditions found no significant differences in gait parameters including gait velocity, stride time, stride length, range of motion and peak velocity of the A–P and M–L COM motion as well as A–P and M–L maximum horizontal distances between the COM and COP ($p > 0.05$) and toe-obstacle clearances for the trailing and leading limbs. This indicates that performing a secondary task did not affect gait stability in young adults.

When comparing the three walking conditions only during the dual-task situation, healthy young adults significantly reduced their gait velocity and stride length during obstacle avoidance at 2.5% of the body height. A significantly greater A–P range of motion between the COM and COP and a significant reduction in peak forward velocity of the COM ($p < 0.001$) were demonstrated in young adults while stepping over the higher obstacle. There were no significant differences among all conditions in gait parameters related to the COM motion in the frontal plane.

Secondary Auditory Stroop Task

For the VRT performance in healthy young participants, no significant differences were found when comparing the three stimuli locations (before obstacle, during obstacle crossing and after obstacle crossing). Interestingly, a significant interaction between the four postural conditions and congruency ($F_{3, 33} = 3.59$, $p < 0.05$) was found. Follow-up pair-wise comparisons indicated that VRT was significantly longer in the incongruent situation than in the congruent situation during sitting ($p < 0.01$) and level walking ($p < 0.01$). This difference in VRT between the congruent and incongruent conditions approached significance ($p = 0.053$) when crossing the obstacle at 2.5% of body height, but not in the most difficult walking condition of obstacle crossing at 10% of body height ($p > 0.05$).

The congruency effect (difference in VRT between congruent and incongruent situation) was significantly reduced from seated to 2.5 % obstacle crossing, and no significant congruency effect was found in obstacle avoidance at 10% of body height. In addition, by using a planned contrast comparison to compare the two levels of difficulty of the postural task, a significantly smaller congruency effect was shown in the more difficult tasks (obstacle avoidance) than in the less difficult tasks (seated and level walking) (Figure 2). This suggests that obstacle avoidance is more attentionally demanding regardless of the height of the obstacle under dual-task situations.

Discussion

Previous studies have confirmed that locomotion is not traditionally considered to be automatic, but instead requires minimal attentional resources to maintain or regain gait stability (Lajoie et al. 1993; Lajoie et al. 1996; Ebersbach et al. 1995; Sparrow et al. 2002; Beauchet et al. 2005). Increased attentional resources may be required while performing a more challenging task such as obstacle avoidance with a secondary task. It is important to understand the effects of dual-task interference when stepping over an object, since these situations come up often in daily life (e.g., talking to a friend while stepping over a curb). The aim of this study was to investigate the interaction between an auditory Stroop task, requiring executive attentional networks and an obstacle avoidance task. Our findings showed that obstacle avoidance influenced the performance of the secondary Stroop task, but gait performance was not affected by the secondary task. Comparing the four different postural conditions, congruency differences in the Stroop task were reduced as the difficulty of the postural task increased.

These findings provide an extension of the study by Lajoie et al. (1993) and indicate that attentional demands increase as a function of the type of postural task being performed from sitting through walking to obstacle crossing in healthy young adults.

Recent dual-task studies examined the attentional demands of locomotion (Gage et al. 2003) and obstacle avoidance (Brown et al. 2005). Participants were asked to respond to an auditory cue during unobstructed or obstructed walking. Both studies showed that gait patterns were not affected in young participants while concurrently performing the secondary task. Similar results were found in the current study, which showed that the range of motion and peak A-P velocity of the COM and A-P maximum horizontal separation distance between the COM and COP were not modified while performing the auditory Stroop task and obstacle avoidance task simultaneously. These results may be explained if young adults prioritize gait stability in the dual-task environment. Previous research on dual-task paradigms using quiet stance (Siu and Woollacott 2006) and perturbed stance (Brauer et al. 2001) as the postural tasks also showed that participants prioritized balance over the secondary task, such that postural stability was not influenced by a concurrent cognitive task. The prioritization of postural stability has been explained by the “posture first hypothesis” proposed by Shumway-Cook et al (1997). This hypothesis suggests that individuals who are in a situation where the threat of injury is increased will prioritize postural control or gait stability over the performance of a second simultaneous task in order to reduce falling and injury.

In contrast with the work of Chen et al. (1994) and Weerdesteyn et al. (2003) whose findings imply that the performance of obstacle avoidance was affected by the concurrent secondary task, as indicated by the increased rates of failure on the avoidance, our findings showed no changes in the performance of obstacle avoidance while performing the auditory Stroop task. It is possible that our paradigm was slightly different in that the obstacle setting was neither a projected light beam (Chen et al. 1994) nor a sudden dropped wooden obstacle (Weerdesteyn et al. 2003). Our obstacle was presented in the middle of the walking path throughout the trial. Perhaps stepping over a physically stable obstacle was less attentionally demanding than those unpredicted obstacle designs. In addition, a limitation of using COP-COM differences for measuring stability is that the period of observation is limited and thus events occurring outside of this time window are not measured. It is possible that some changes in stability may have occurred at other times in the gait cycle.

Although young participants in this study were able to respond to the auditory Stroop task without modifying their gait performance, the VRT results in the auditory Stroop task were influenced by the concurrent obstacle avoidance task. In particular, the congruency effect (i.e., incongruent stimuli requiring longer RTs) was diminished when the difficulty of the postural task increased (Figure 2). Stepping over a higher obstacle requires significantly increased A–P range of motion; peak A–P velocity of the COM and A–P maximum horizontal separation distance between the COM and COP. It is possible that under such circumstances young adults allocate more attention to the obstacle clearance and respond to the Stroop task inefficiently.

The congruency effect seen in this study is in line with the results of Gage et al. (2003), who found that the phase-dependent relationship for reaction time performance disappeared when a postural threat increased. Gage et al. (2003) studied the relationship between anxiety and the attentional demands of locomotion by asking participants to walk at ground level or an elevated level. They found that attentional demands of locomotion varied with the phase of the gait cycle for young adults when at ground level. However, when young participants walked at an elevated level, gait performance was not different during single and double support phases. Together with the findings from Gage et al. (2003), the diminished congruency effect in the current study suggests that the secondary Stroop task performance becomes unbiased (with congruent and incongruent tasks being performed nearly equally) while maintaining gait stability in a situation with a high risk of falling in healthy young adults.

It is also possible that more attentional resources were required for young adults to maintain stability during obstacle avoidance; a participant's attention could be diverted away from the conflicting information in the Stroop task and lead to a diminished congruency effect. Kahneman and Chajczyk (1983) found a reduction of the Stroop effect when additional distractors were given on the screen, which served to reduce the conflict effect of the color word. In the current study, the postural task could act in a similar manner. When the difficulty of the postural task increased, it is possible that attentional resources were withdrawn from the Stroop task, and as a result, the secondary performance was degraded. This reduced conflict effect may also explain why the incongruent VRT remained the same as the postural task requirements increased with obstacle avoidance, even though these conditions might be expected to increase the congruency effect.

For the VRT performance, surprisingly, we did not find significant differences when comparing the three stimulus locations (before obstacle, during obstacle crossing and after obstacle crossing). These results are inconsistent with a pervious study from Brown (2005). Their data revealed a significant increase in VRT when the auditory cue appeared before the obstacle avoidance, suggesting precrossing is more attentionally demanding than crossing for younger adults. The inconsistent results between the current study and the study from Brown (2005) may be due to the potential effects of the type of secondary task used. A simple reaction time task was used in the study from Brown, but an auditory Stroop task was used in this study. Further study is required to compare the dual-task interference of the different types of secondary tasks used in younger adults.

Conclusion

To our knowledge, this was the first study to investigate the attentional requirements of an obstacle avoidance task with different obstacle heights under dual-task conditions, using the auditory Stroop task as the secondary task. Our findings demonstrated that an increased postural challenge leads to a greater impact on the Stroop task performance (diminished congruency effect) during obstacle avoidance from 2.5% to 10% of body height in healthy young adults. Since gait parameters were not changed when comparing single to dual-task conditions, this suggests that gait stability is a priority in young adults while stepping over an obstacle with a concurrent secondary task. These findings provide an extension of the study by Lajoie et al. (1993) and indicate attentional demands increase as a function of the type of postural task being performed from sitting to obstacle crossing in healthy young adults.

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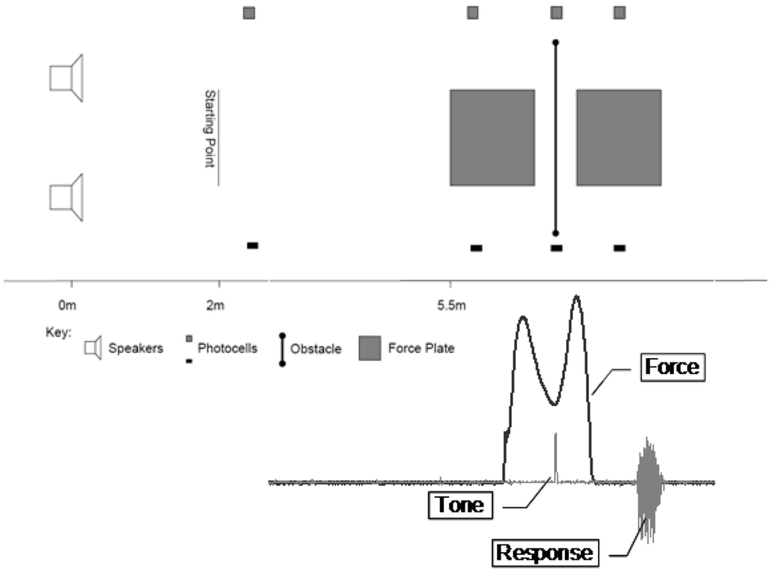
Starting Point
0m
2m
5.5m
Key:
Speakers
Photocells
Obstacle
Force Plate
Force
Tone
Response

Figure 1.

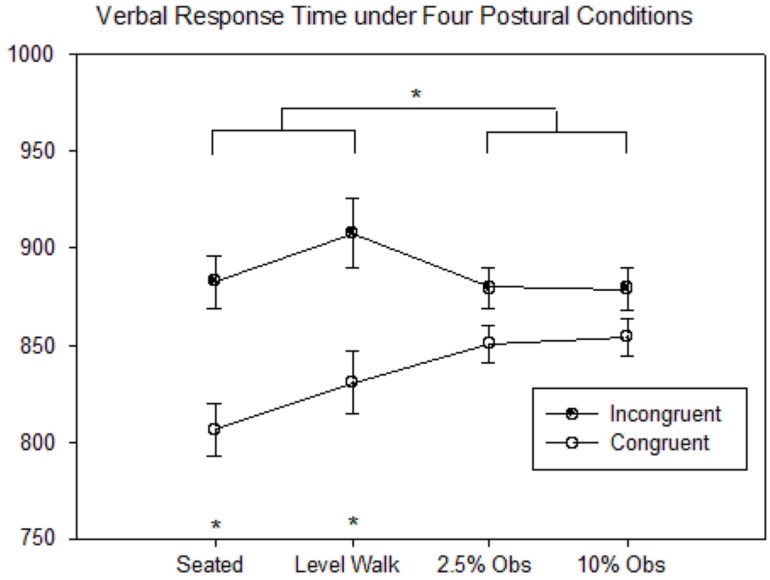
Verbal Response Time under Four Postural Conditions
1000
950
900
850
800
750
*
*
*
Incongruent
Congruent
Seated
Level Walk
2.5% Obs
10% Obs

Figure 2.