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# Gaze diversion affects cognitive and motor performance in young adults when stepping over obstacles

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ABSTRACT

*Background:* In many common multi-tasks, vision is used for two or more of the tasks, such as viewing cars, traffic signals, and the sidewalk curb at a crosswalk.

*Research Question:* How does gaze diversion affect adaptive locomotion in young adults?

*Methods:* Seventeen young adults completed a simple reaction time (RT) task while (1) standing and (2) during the approach to an obstacle on an 8 m walkway. Participants pressed a remote switch in response to a light cue (activated once during approach phase). The light cue was located either (1) on the obstacle (gaze diverted to obstacle) or (2) at eye level (gaze diverted away from obstacle). A gait baseline task with no RT task was included.

*Results:* An interaction was observed (task (standing versus walking) by gaze location (on versus away from obstacle), $p = 0.01$), where RT was not affected by the gaze location in the standing task, but RT was longer when gaze was diverted away from the obstacle in the gait task. Furthermore, trail foot placement was closer to the obstacle when the gaze was diverted away from the obstacle ($p = 0.002$), which increased risk of tripping.

*Significance:* Gaze diversion did not affect cognitive performance in the standing task, as information regarding the obstacle was not relevant for the standing task. However, completing a simple discrete visual cognitive task during obstacle crossing impaired both cognitive and gait performance, but only when gaze was diverted away from the obstacle. The impaired performance is likely due to the larger amount of structural interference when gaze was diverted away from the obstacle. These findings highlight the critical role of vision during the approach phase to an obstacle.

## 1. Introduction

During community mobility, multiple objects – such as sidewalks, traffic signals, approaching pedestrians – are visually scanned in order to adapt gait. When the same perceptual modality is used for more than one task, impaired performance may be related to structural interference, rather than insufficient cognitive resources (capacity interference) [1]. For example, when stepping over obstacles and completing a Stroop task, larger dual costs were observed for a visual Stroop task than an auditory Stroop task, which indicated that structural interference had a larger effect on performance than capacity interference [2]. This observation highlights the critical role of vision during adaptive gait, and demonstrates that multitasks involving gait must consider the role of structural interference when a concurrent cognitive task also relies on vision.

Maintaining gaze on a target allows optimal use of visual information to guide and plan stepping behavior [3]. However, when a visual cognitive task is located on a monitor or carried electronic device (e.g [4,5].), gaze is diverted *away* from the upcoming hazards (e.g. obstacle, stairs). Conversely, if gaze is diverted *to* the hazard by the cognitive task, visual information about the hazard and attending to the cognitive task can be gathered concurrently, which may reduce performance impairments. For example, during stair descent, performance was dependent on whether the location of a visual reaction time (RT) task either restricted or facilitated view of the stairs [4]. In the present study, we extended this approach by comparing the effect of gaze diversion directly to the hazard (an obstacle) versus away from the hazard, to further delineate the role of gaze diversion. We predicted that performance would be impaired when stepping over an obstacle and gaze was diverted away from the obstacle. Conversely, when standing, we predicted that performance would not be affected by diversion to or away from the obstacle since visual information about the obstacle

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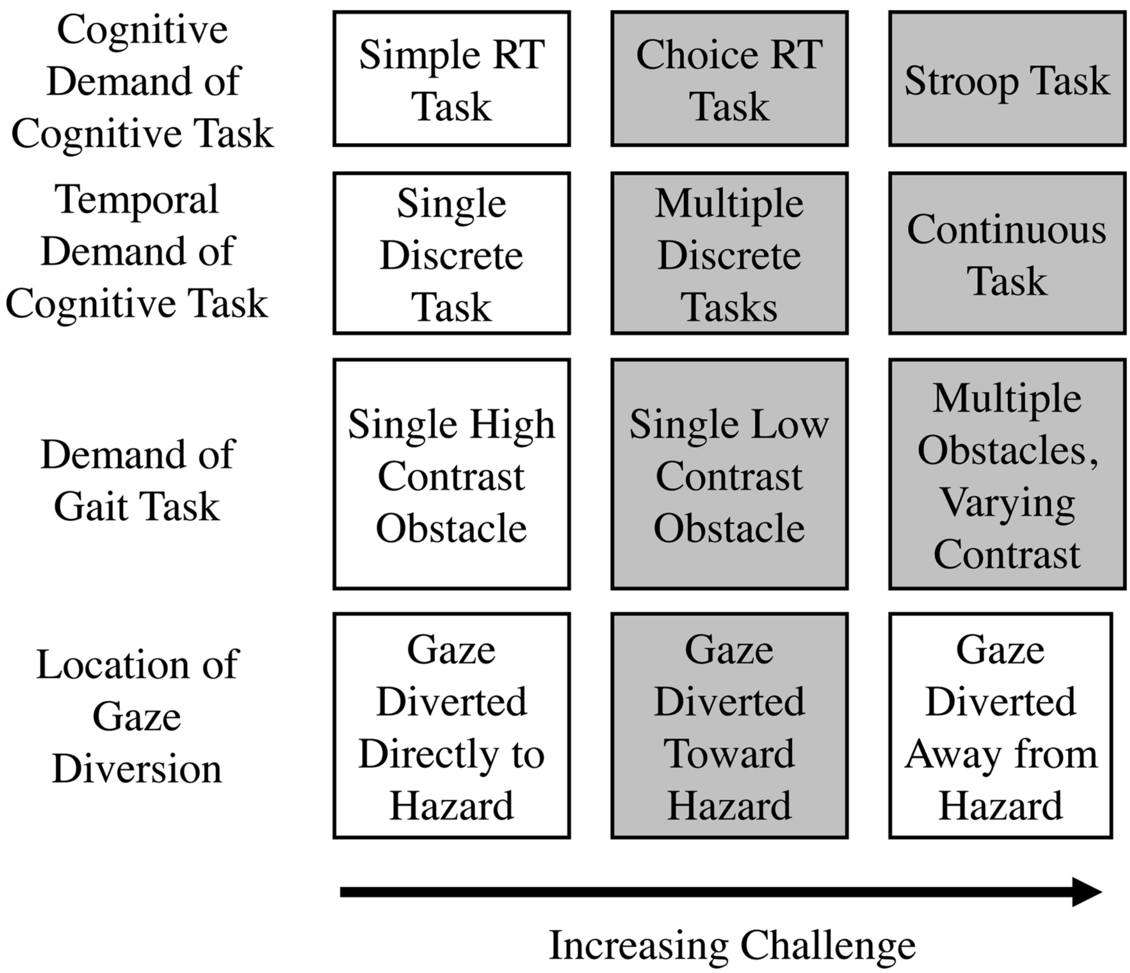


**Fig. 1.** Framework demonstrating example multitask research protocols during walking as a function of task difficulty. The tasks that are easier are on the left. White blocks indicate the tasks examined in this study.

(such as height and location) was not relevant for standing.

A wide range of cognitive and locomotor tasks have been examined, with higher challenge tasks leading to greater performance impairment [6,7]. A discrete simple RT and a single-height high-contrast obstacle were selected as relatively low challenge tasks (Fig. 1), as any change in performance with low performance tasks would provide strong evidence of the critical role of gaze diversion. When the RT task is on the obstacle (Fig. 2E), the obstacle and cue location can be foveated concurrently (Fig. 2E). Conversely, when the RT task is away from the obstacle (Fig. 2F), the walkway and cue location cannot be concurrently foveated. However, the discrete nature of the RT task allows visual sampling of the obstacle before and/or after the RT task, as intermittent sampling of the obstacle is sufficient (e.g. [8–10]). Therefore, the role of structural interference was examined by manipulating the location of a visual cognitive task, in order to facilitate or impair the ability to concurrently gather visual information for the cognitive and gait tasks.

The objective of this study was to understand how gaze diversion affects obstacle avoidance during walking in young adults. Gaze was diverted with a simple RT task while standing and while walking; the light cue appeared either on the obstacle or at eye level at the end of the walkway. During walking, the light cue was activated once during the approach to the obstacle, as visual information gathered during the approach is important for successful crossing [9,11–13]. We hypothesized that an interaction would be observed for RT and/or RT variability where during standing the location of the light cue will not affect RT length or variability, and during walking a shorter and/or less variable RT will be observed when the light cue is on the obstacle compared to eye level. We hypothesized that when gaze was diverted to the obstacle, gait parameters will not be different from baseline (no RT task), and when gaze was diverted away from the obstacle, gait will be modified. These findings will support the contention that when a task diverts gaze, impairments in performance are due not only to the cognitive demands of the task, but also to gaze diversion, and that gaze diversion is especially problematic when gaze is diverted away from the locomotor hazard.

## 2. Methods

### 2.1. Participants

Seventeen healthy young-adults (20.9 ± 1.9 years, 1.66 ± 0.71 m, 67.4 ± 11.5 kg) received an honorarium for participation. Exclusion criteria included self-report of disease or disorder that affected the ability to walk, and uncorrected visual impairment. The protocol was approved by the local University Human Subjects Protection, and all participants provided informed consent.

### 2.2. Apparatus

Three-dimensional kinematics were collected at 250 Hz with an 8-camera motion capture system (Vicon Vero, Oxford, UK). Thirteen marker clusters were placed on the head, upper back, lower back, and bilaterally on the upper arms, lower arms, upper legs, lower legs, and feet. Anatomical points (distal aspect of second phalanx, fifth

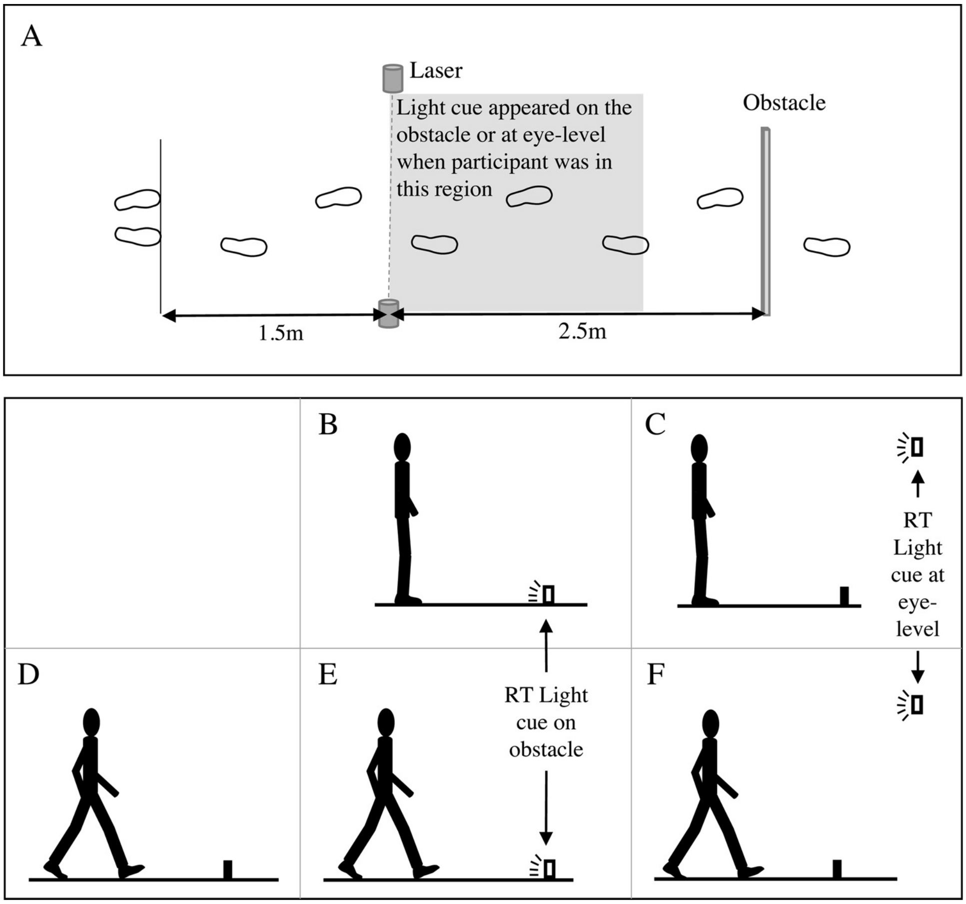


**Fig. 2.** Protocol schematic: Bird's eye view of the walkway (A). In the walking conditions, the light cue was activated 0–1.5 s after breaking laser beam, such that the light cue could appear at any time when the participant was in the gray region. When the light cue was activated, the mean trunk location was 1.98 ± 0.44 m, and the mean number of steps before the obstacle was 3.4 ± 0.8 steps. In the standing conditions, participants stood 1.5 m in front of the obstacle, and the experimenter triggered the light cue. Study conditions included: Standing with reaction task on obstacle (B), standing with reaction task at eye-level (C), walking baseline (no reaction task) (D), walking with reaction task on the obstacle (E), and walking with reaction task at eye-level (F). RT is reaction time. Note that condition (E) corresponds to the white boxes on the left side of Fig. 1 (simple discrete RT task, single high contrast obstacle, and gaze diverted directly to hazard). Condition (F) corresponds to the same RT and obstacle conditions, except gaze is diverted away from the obstacle (lower right box of Fig. 1).

metatarsal head, dorsal calcaneus) were digitized bilaterally. The obstacles were flat black Masonite, designed to tip if contacted, and were 100 cm by 0.8 cm (width by depth). Obstacle height was 25.5 ± 0.8% of leg length; participants with leg length greater than 86 cm used a 23.5 cm obstacle, the remaining participants used a 21 cm obstacle (similar to [10]). Four markers were placed at each obstacle corner.

### 2.3. Reaction time task

Participants pressed a remote switch as quickly as possible when a light cue was illuminated. The light cue was either (1) a continuous LED strip outlining the four edges of the obstacle, or (2) an identical LED light at eye level at the end of the 8 m walkway (Fig. 2). The light was illuminated once (duration 300 ms) in each walking trial when the participant was in the light-cue-activation region (gray region in Fig. 2A). During the approach phase, the participant broke the laser beam projected across the walkway (2.5 m before the obstacle), which activated the light cue after a random interval (0–1.5 s). During standing conditions, the participant stood 1.5 m from the obstacle and the light cue was activated randomly by computer (10 cues in 90 s).

### 2.4. Procedure

Five conditions included: standing with RT task on obstacle, standing with RT task at eye level, walking baseline (no RT task), walking with RT cue on obstacle, and walking with RT cue at eye level (Fig. 2). If the obstacle was contacted, the trial was not included in the analysis, and the trial was repeated. Two blocks were collected: in block one the five conditions were block-randomized with 10 trials of each condition, and this was repeated in block two, with a different order of conditions. One hundred trials (50 in each block) were collected for each participant (40 standing trials, 60 successful gait trials). A five-minute rest was provided between blocks.

At the start of each condition, the participant was told if there would be a RT task, and the light cue location (obstacle or eye level). When there was a RT task, participants were instructed "Please react as quickly as possible to the light cue" in order to increase the likelihood that their gaze would be diverted to the obstacle or to the end of walkway, and to promote similar prioritization across participants, as instruction affects task prioritization (e.g. [14]).

### 2.5. Data analysis and statistics

Data analysis was completed with Motion Monitor (IST Inc., IL, USA) and custom software in Matlab R2014a (Mathworks Inc., MA, USA). Kinematic data was filtered with a zero-lag, fourth-order, low-pass Butterworth filter, with cut-off frequency 12 Hz. RT was the difference between onsets of the light stimulus and remote button. Seven trials (0.5% of all trials) were removed due to potential anticipatory behavior (RT < 120 ms) [15]. No loss of attention trials were observed (RT > 1100 ms) [15]. Heel contact frames were determined by kinematic algorithm [16] to identify three steps: (1) the penultimate step before the obstacle, (2) the lead step over the obstacle, and (3) the trail step over the obstacle. Center of mass (COM) velocity was determined by differentiating the COM displacement; the anterior-posterior COM velocity was averaged in the three steps to quantify gait speed. Minimum foot clearance was the minimum value of toe and heel clearance ([17]), where toe (heel) clearance was the vertical distance between the toe (heel) and the obstacle at the frame when the toe (heel) crossed the obstacle. Horizontal foot placement pre-obstacle (post-obstacle) was the anterior-posterior position of the toe marker during stance prior to crossing the obstacle (heel marker during stance after crossing the obstacle). Clearance and foot placement measures were calculated for both the lead and trail limbs. Variability was the standard deviation of each measure.

Statistical analyses were completed with SAS 9.3 (SAS Institute, Cary N.C.). RT measures (RT and RT variability) were examined with a two-way ANOVA (task (standing versus walking) by location of stimulus (obstacle versus eye level)). Gait measures (gait speed, foot clearance, foot clearance variability, foot placement, and foot placement variability) were examined with a one-way ANOVA with three levels (baseline versus obstacle versus eye level). For both ANOVAs, a generalized linear mixed model ANOVA was used to allow the residuals to vary. A Kenward-Roger correction was applied to account for missing trials due to anticipatory RT (see above) and obstacle contact trials. Significance level was $p \leq 0.01$ due to the large number of dependent measures.

## 3. Results

### 3.1. Obstacle contacts

Eight of the 17 subjects (47%) contacted the obstacle: Six contacted the obstacle once, one contacted twice, and one contacted three times, for a total of 11 contacts in 1020 walking trials (1.1%). Nine of the 11 contacts were with the trail limb (82%); three, two, and six contacts occurred during baseline, RT cue on obstacle, and RT cue at eye level, respectively.

### 3.2. RT measures

As hypothesized, an interaction of task by location was observed for RT ($F(1, 80.1$[1]$) = 6.73$; $p = 0.01$; Fig. 3A). Post hoc analyses revealed that RT was significantly longer by 27 ms (10%) when gaze was diverted away from the obstacle, but RT was only different in the gait task. Only a main effect of task was observed for RT variability, with 32 ms (56%) greater variability in the gait task ($F(1, 30) = 20.62$; $p < 0.001$; Fig. 3B).

### 3.3. Gait measures

Significant changes were only observed in trail foot placement and gait speed. The placement of the trail foot was significantly affected by the RT manipulation ($F(2, 32) = 7.41$; $p = 0.002$; Fig. 4). Post hoc analyses revealed that the when the gaze was diverted away from the obstacle, the trail foot was placed 2.7 cm (12%) closer to the obstacle when compared to gaze diverted to the obstacle. Gait speed during (1) the step before the obstacle and (2) the lead foot crossing step was significantly affected by the RT manipulation ($F(2, 32) = 6.87$; $p = 0.003$, and $F(2, 32) = 6.40$; $p = 0.005$; Fig. 5A,B). Post hoc analyses revealed that, in the step before the obstacle, the two tasks with RT were faster than gait baseline (0.04 m/s (4%) faster for RT cue on obstacle, and 0.03 m/s (3%) faster for RT cue away from obstacle). For the lead step crossing, gait speed was faster when gaze was diverted to the obstacle relative to baseline 0.04 m/s (3%), but the other conditions were not different.

## 4. Discussion

The goal of this study was to advance fundamental understanding of the role of gaze diversion during adaptive locomotion. The current knowledge was extended as follows: (1) using a relatively low challenge cognitive task to provide a rigorous test of the role of gaze diversion, (2) comparing gaze diverted directly to a hazard versus away from a hazard, and (3) comparing tasks that are dependent on visual information regarding the hazard (obstacle crossing) versus not dependent on visual information regarding the hazard (standing). In the walking task, the cognitive and motor performance impairments observed when gaze was diverted away from the obstacle were not observed when gaze was diverted to the obstacle. In the standing task, no cognitive impairments were observed with gaze diversion. These findings highlight the critical role of vision during the approach phase to an obstacle, and demonstrate that structural interference must be considered when examining visual cognitive tasks during adaptive gait.

No cognitive or foot motion impairments were observed when the light cue was on the obstacle, indicating that sufficient cognitive resources were available to concurrently complete a discrete simple RT task while walking up to an obstacle. Conversely, both cognitive and gait performance were impaired when the light cue was away from the obstacle. The impairments occurred even though the participant could divert gaze as needed to foveate on the obstacle, or view the obstacle in the peripheral visual field. The impairments are relevant: A 27 ms increase in RT is equivalent to 49 years of aging (increase 0.55 ms/year in simple RT; [18]), and placing the trail foot closer to the obstacle increases trip risk [17,19]. Furthermore, obstacle contacts increased twofold when gaze was diverted, consistent with the higher trip risk. Since the cognitive demand of the RT task was the same in both RT cue locations, the decrement resulted from differing levels of structural interference in the two cue locations. For the obstacle light cue location, attending to the RT task on the obstacle and visually identifying obstacle characteristics are not incompatible [1], reflecting lower levels of structural interference compared to light cue location away from the obstacle. These effects occurred despite the opportunity to visually sample the obstacle before and/or after the discrete RT task. Thus, it appears that the ability to visually monitor foot placement online while in the light-cue-activation region (Fig. 2A) is critical. The findings reported here are in parallel with [2,4], and further establish the critical impact of gaze diversion during obstacle crossing.

The observation that foot clearance was not affected by gaze diversion indicates that visual information regarding obstacle height was sufficient, whereas as the impaired foot placement indicates that visual information about obstacle position was not sufficient. These findings are consistent with the observation that, during the approach phase, there is greater flexibility in when obstacle height information is visually sampled versus obstacle location information [13]. Obstacle height information could have been gathered before or after the region where the light cue appeared, but this strategy was insufficient for obstacle position information.

Higher RT variability for walking versus standing (Fig. 3B) is consistent with impaired cognitive performance [20], and likely demonstrates the higher cognitive demands of walking relative to standing [21]. However, no change in RT was observed across standing and walking when the RT cue was on the obstacle (Fig. 3A), which is in contrast with other research which has identified increased RT for walking [21–23]. The discrepancy likely results from the discrete simple RT and the prioritization instruction of the current study. Other studies examined either choice RT [4,5,24], or if simple RT was used, it was a continuous RT task or the number of presentations was unknown [4,24].

The unexpected observation was faster gait speed with the RT task (Fig. 5). Faster speed has also been unexpectedly observed with fatigue [25,26], and may reflect a strategy to increase gait stability [27]. However, the change in speed is small (4%) and not likely to affect stability in young adults. Instead, it is more likely that participants slowed down in the light-cue-activation region (Fig. 2A), and then increased speed after to compensate. A similar strategy was observed in virtual reality where reduced speed occurred during the approach (when obstacle position information was not available) followed by acceleration after obstacle position information became available [13]. Unfortunately, this strategy could not be quantified as the light-cue-activation region was outside the motion capture volume.

The findings reported here reinforce the approach of making curbs, stairs, and doorway thresholds highly visible to reduce fall-risk (e.g.

[1] Degrees of freedom term has decimal due to Kenward-Roger correction.

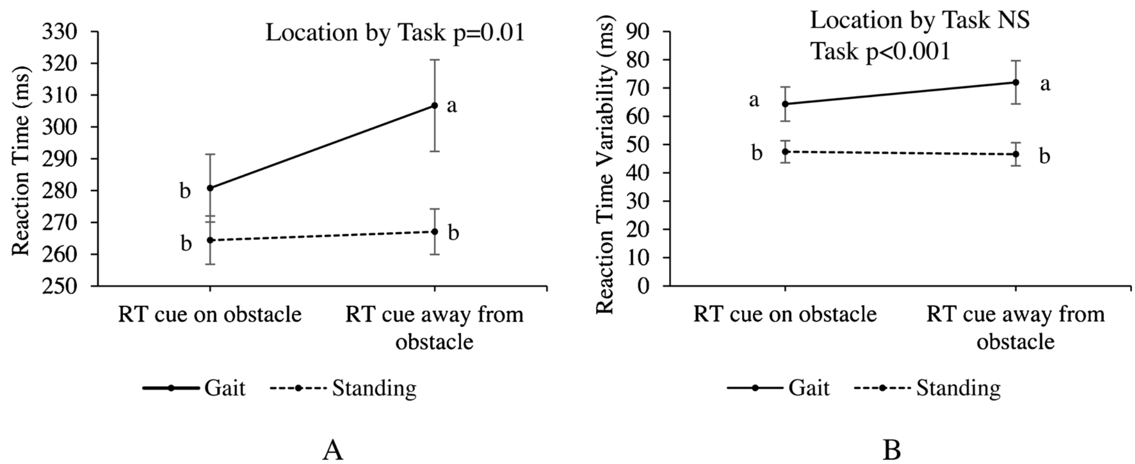


**Fig. 3.** Average reaction time (RT) as a function of RT cue location and task (A). RT variability as a function of RT cue location and task (B). Solid line is the gait task, dashed line is the standing task. Error bars represent standard error. NS indicates not significant. Different letters (a, b) indicate statistically significant differences.

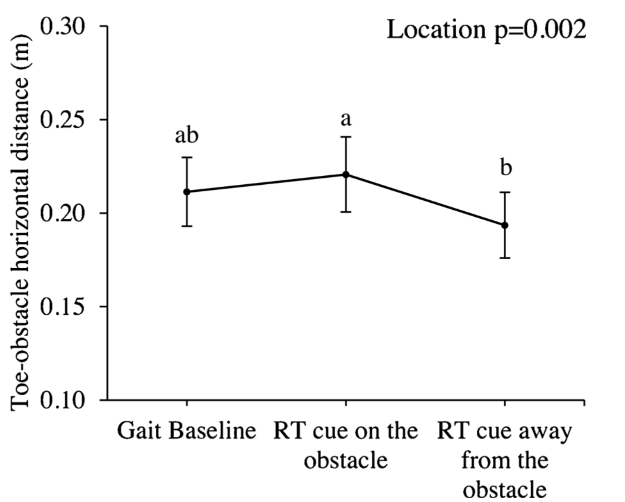


**Fig. 4.** Trail toe-obstacle horizontal distance (distance between trail toe and obstacle). Different letters (a, b) indicate statistically significant differences.

There are several limitations to this study. First, impaired performance may be related to the longer distance to the RT cue located at the end of the walkway versus the obstacle cue. However, this is unlikely as distance did not affect cognitive performance while standing. Second, we do not have a measure of gaze behavior to confirm that gaze was diverted to or away from the obstacle. However, changes in foot placement when the light cue was located away from the obstacle were also previously observed with visual manipulations (e.g. [8,11]). Third, slower subjects would have greater distance – and thus time – to sample the obstacle after the RT task was completed, leading to better performance in slower walkers. Similarly, as noted above, slower speed could be a strategy to improve performance. Despite this variability, significant differences were still observed, emphasizing the robustness of these observations. Fourth, we do not have a measure of motor performance in the standing task since the standing region was outside the volume of the motion capture system. Finally, performance when the light cue was on the obstacle may be related to the light cue characteristics: a bright LED strip outlining the obstacle edges. Since obstacle crossing performance is improved when all four edges are visible [30], the four-edge light cue may have facilitated performance more than a light cue centered on the obstacle. Although the current protocol cannot distinguish between the effect of gaze diversion versus the emphasis of salient features, parallel findings with similar research [2,4] support the interpretation that improved performance is related to

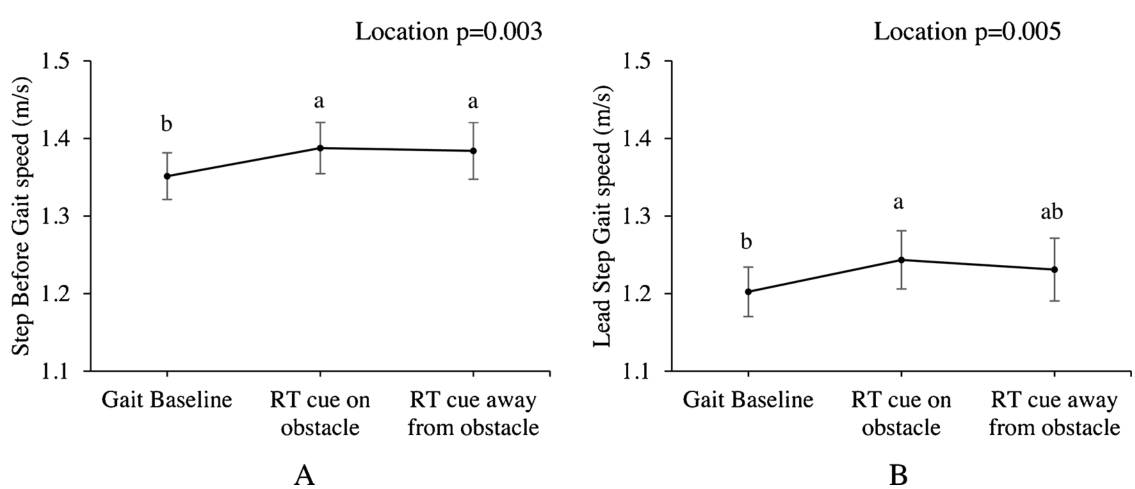


**Fig. 5.** Gait speeds of one step before the obstacle (A) and the first obstacle crossing lead step (B). Error bars represent standard error. Different letters (a, b) indicate statistically significant differences.

[28]), and support the placement of relevant cues in the location where pedestrians gaze, such street-embedded pedestrian lights [29]. The current protocol should be extended to populations with compromised balance to facilitate the development of effective interventions.

gaze diversion.

## 5. Summary

When vision was used for both the gait task and a concurrent cognitive task, the amount of structural interference contributed to the performance impairment. Changes in foot placement before the obstacle, but not in clearance measures, reinforces the contention that there is greater flexibility in when obstacle size information is visually sampled than when obstacle location information is sampled.

## Declaration of Competing Interest

The authors declare that there are no conflicts of interest.

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