The effect of the visual characteristics of obstacles on risk of tripping and gait parameters during locomotion

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Abstract:

Purpose: Injuries from falls are a serious health issue. Approaches to preventing falls should consider increasing relevant visual information of an obstacle. Obstacle parameters, such as position and height, may be specified by the visible structure of an obstacle. The present study examined the relationship between visible structure of an obstacle and locomotor behaviour. This relationship may be modified as a function of experience with navigating obstacles. Since workers at construction sites must navigate through cluttered environments with varied obstacles, these workers may have superior skills at avoiding obstacles. Therefore, the effect of work experience was also examined.

Methods: Nine construction workers and 10 age- and gender-matched control subjects participated. Subjects stepped over obstacles in an 8 m walkway. Three different obstacles were examined, arranged according to a hierarchy ranging from most to least visible structure: a solid obstacle, a three-edge outline obstacle and a top-edge obstacle. The obstacles were 10, 20 or 30 cm high. In addition, visual information was decreased with goggles which obstructed the lower visual field, removing information of the obstacle and foot-relative-to-obstacle in the two steps before the obstacle. All conditions were presented randomly.

Results: Higher risk of contact and higher lead and trail toe clearance variability were observed for the top-edge obstacle. Higher risk of contact was observed when the lower visual field was obstructed and for the 30 cm obstacle. Work experience did not influence risk of contact. Construction workers had lower trail toe clearances and lower trail toe clearance variability for the 10 cm obstacle, but were not different from controls for the 30 cm obstacle.

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Conclusions: Decreased visible structure of an obstacle resulted in increased gait variability and increased risk of contact. The changes are consistent with decreased accuracy of the sensory-to-motor transformation used to control the lead and trail limb during obstacle crossing when only the top-edge was visible. There is some evidence that construction workers were better able to transform the visual information to motor actions, as reflected by decreased gait variability, but these findings were not supported by decreased risk of obstacle contact.

Keywords: falls | gait | locomotion | obstacles | tripping | vision

Article:

INTRODUCTION

It is well known that falls in older adults are common events which can have dramatic consequences.[1–3] The incidence of fall-related injuries is predicted to increase with the growing population of older adults.[4,5] Decades of theoretical research have increased our knowledge of the mechanisms of balance and mobility, yet the number of people falling and sustaining injuries have not decreased.[6] While much research has focused on how internal factors can modify mobility and balance,[7–9] it is also important to consider how extrinsic factors – such as visual cues in the environment – may promote mobility and balance.

Community mobility requires the management of obstacles such as stairs, curbs, and uneven surfaces.[10] Vision is used to identify and subsequently avoid or accommodate obstacles typically found in the community. Visible obstacle properties, such as height and width, are used to alter the gait pattern to avoid the obstacle.[11] Increased visual structure in the environment facilitates performance in aiming studies with the upper limb[12,13] and in locomotor tasks.[14,15] It is argued that visual structure specifies the spatial characteristics of the relation between a human and the environment via optic flow.[16] Conversely, a visual illusion can underspecify the information in the environment and skew performance when aiming for targets with the upper limb,[17] or when stepping over obstacles,[18] climbing stairs[19] or stepping on a target.[20,21] When visual structure is obscured through decreased vision, performance is also affected.[22,23] These findings highlight the importance of visual structure to the control of adaptive locomotion.

However, it is unknown how specific visual characteristics of the obstacle contribute to successful gait adaptation. For example, the top of the obstacle provides important information regarding the minimal height needed to raise the foot for successful clearance. Is view of the top edge of an obstacle adequate for successful avoidance, or is relevant information also provided by view of the side edges? Binocular disparity information would be the same whether viewing all edges of an obstacle or just the top edge. Similar visual information for all edges vs the top edge only would also be expected from sources such as convergence, accommodation, optical flow and motion parallax. However, another source of visual information, height in visual field, may not differentiate between a taller obstacle at a closer distance vs a shorter obstacle at a farther distance when only the top edge is visible (see *Figure 1*). That is, both the height and position of the obstacle will be underspecified. When height in visual field information is not available, can the obstacle be successfully negotiated?

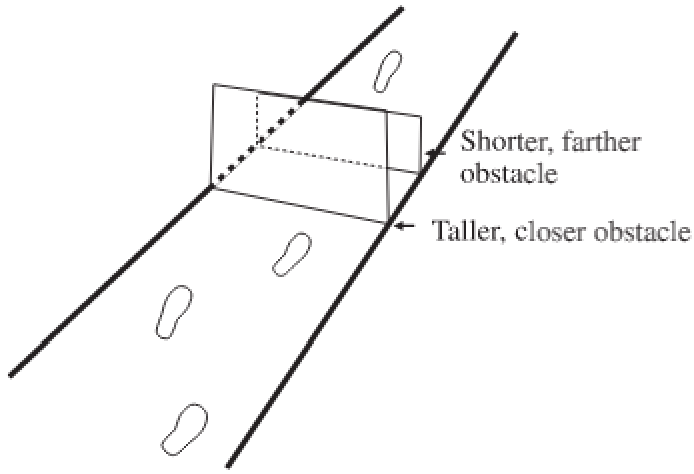

Figure 1. Depiction of walkway with two different obstacles: a taller obstacle and a shorter obstacle placed farther down the walkway. The top edges of the two different obstacles occupy the same vertical position in the visual field. This figure demonstrates that if only the top edge is visible, the height and position of the obstacle are under-specified.

Another factor to consider is the amount of information available from a solid obstacle vs an obstacle with only the outline visible. With a solid obstacle the view of the ground behind the obstacle is obstructed, and the plane of the obstacle surface is immediately available which may facilitate specification of obstacle position and height. Conversely, the ground behind an outlined obstacle is visible and the obstacle plane is defined only by the outline, which may compromise the ability to determine obstacle position and/or height. Therefore, three obstacles were examined in this study, arranged according to a hierarchy ranging from most to least visible structure: a solid obstacle, a three-edge outline obstacle and a top-edge obstacle.

Visual information is used in advance to plan for obstacle avoidance (i.e., feedforward), and in an on-line manner to modify the behaviour during the approach and crossing of the obstacle (i.e., feedback).[24,25] That is, obstacle height and position in the pathway are visually perceived, and this information is updated in an on-line manner to approach and clear the obstacle. The on-line foot-obstacle information can be removed with goggles which block the lower visual field, forcing the subject to rely on feedforward information determined earlier in the approach phase. Thus, performance should decrease since the ability to finely tune locomotor control will be diminished due to the absence of on-line information.

Stepping over obstacles is an everyday task,[10] but it is more common for those who work regularly in cluttered environments, such as construction workers. Workers who specialize in roof repair (commonly called ‘roofers’) had higher toe clearances during steady state gait and when stepping onto a curb.[26] It was argued that exposure to challenging environments may have resulted in behaviour that reduced risk of tripping. General construction workers often carry loads that obstruct the visual field when navigating cluttered environments, potentially leading to more finely tuned adaptive locomotor control to avoid a trip.

The purpose of this study was to examine the effect of decreased visible structure of an obstacle on adaptive gait patterns. It was hypothesized that as visible structure decreased, subjects would exhibit increased obstacle contacts, larger toe clearances, larger horizontal distances, and gait patterns would become more variable. A further decrement in performance was expected when the foot-obstacle information was not updated in an on-line manner during approach and clearance due to lower visual field obstruction. It was hypothesized that the construction workers would be less affected by the decreased visible structure and the lower visual field obstruction than the control subjects.

METHODS

Two subject groups were examined: construction workers (n = 9 males, 25.3 ± 5.3 years) matched by age and gender to control subjects (n = 10 males, 26.4 ± 3.8 years). Construction workers were recruited from local construction companies, and controls were recruited from the university community. The construction workers had worked full-time in construction (i.e. building offices or dwellings, etc.) for at least 2 years. None of the workers were exclusive to one particular area, such as masonry or roofing. At the worksite, the workers performed a variety of tasks such as demolition, framing, drywall installation and flooring installation. Control subjects reported that they had no experience navigating construction worksites in the last 2 years. Participants were free of any disorders that would affect their gait, as verified by self-report. Participants had normal or corrected to normal vision. If corrective lenses (either contacts or glasses) were needed for driving, they were worn for the testing. Procedures were approved by the local Institutional Review Board and all participants signed an informed consent. Participants were paid $50 at the completion of the study.

Subjects wore their own comfortable walking shoes, walked down an 8 m walkway, stepped over an obstacle placed halfway down the walkway, and continued walking. The flooring was similar to a traditional hardwood basketball court: 3.8 cm wide slats, no visible wood grain, but darker lines between the slats. The walkway went from one corner to the opposite corner of a rectangular lab, so the wooden slats were at an angle of about 30° to the walkway.

The independent variables were visual obstruction, visible structure and obstacle height. Regarding visual obstruction, subjects either had full vision or lower visual field occlusion. Basketball goggles were used to obstruct vision of the lower limbs and the pathway in front of the subjects (*Figure 2a*). Subjects were free to look at the obstacle if they needed to during obstacle crossing by simply tilting their head forward. It should be noted that the time in the approach phase when the obstacle is visually obstructed is dependent on subject height, subject head angle and obstacle height. However, the view of the foot relative to the obstacle (termed exproprioception) is never available, so our conclusions are limited to the effect of obstructed exproprioception. The visible structure conditions were solid, three-edge outline or top-edge (*Figure 2b*, bottom panel of *Figure 3*). In order to reduce familiarity that would result from using the same obstacle height repeatedly,[18] three obstacle heights were examined (10, 20 and 30 cm). A full factorial design was used, resulting in 18 conditions (two visual obstruction levels by three obstacle conditions by three obstacle heights). Eight trials of each condition were collected, resulting in 144 trials. All conditions were presented randomly.

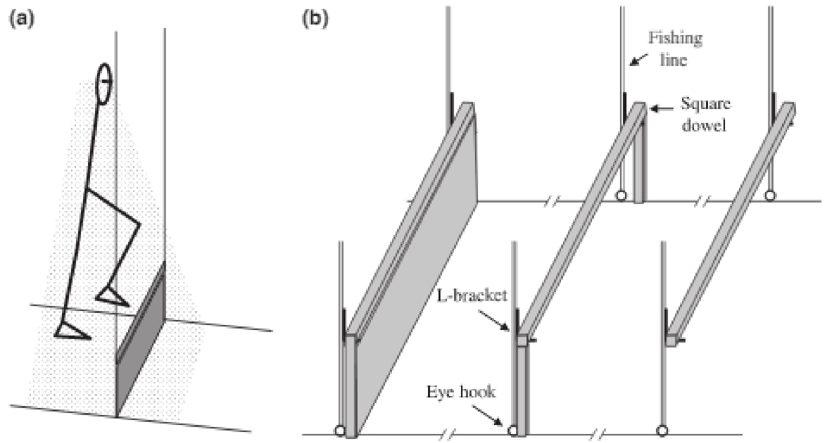

Figure 2. The visual obstruction provided by the goggles is shown by the grey shaded area (a). The design of the visible structure conditions: solid, three-edge outline and top-edge (b).

The obstacles were 80 cm wide by 0.5 cm deep. Fishing line was run from eye hooks attached at the ceiling and floor, on both sides of the walkway (*Figure 2b*); the fishing line was strung through both eye hooks and tied in the center so the line was taut. Small L-brackets were attached to the fishing line; the fishing line could be adjusted so the L-brackets could be positioned at multiple heights. All obstacles were suspended from the L-brackets and would simply fall forward if contacted, and would not cause the subject to lose balance. The solid obstacle was a flat piece of balsa wood suspended from a wooden dowel which rested on the L-brackets. In the three-edge outline obstacle condition, two vertical dowels were suspended from a wooden dowel which rested on the L-brackets. The top-edge obstacle was a wooden dowel which rested on the L-brackets. The eye hooks at the ceiling were fixed, and the eye hooks at the floor were located in runners that ran parallel to the walkway. The floor eye hooks could be slid along the runners in the anterior-posterior plane, allowing for randomized obstacle placement within 0.5 m, so subjects could not memorize the exact location of the obstacle. Note that while the visibility of the obstacle decreased from solid to outline to top-edge, view of the environment behind the obstacle was only obstructed by the solid obstacle.

To ensure the fishing line structure around the obstacles was not visible, the study was conducted in low light. One 40 W bulb was placed 2 m from the start of the walkway (i.e. about 6 m from the obstacle), giving a lux level of 0.1 at the obstacle. Glow-in-the-dark tape was added to increase visibility of the obstacles. The tape covered the flat surface of the solid obstacle, the three dowels of the three-edge outline obstacle, and the single dowel of the top-edge obstacle.

Movement data was collected at 60 Hz with two Optotrak 3020 sensors (http://www.ndigital.com); both sensors were placed on the right side of the walkway. Four infra-red emitting diodes were placed on the lateral aspect of the right foot at the toe and heel, and on the medial aspect of the left foot at the toe and heel. Two diodes were placed on the right side of the head at the temple and 2.5 cm below the temple marker. One diode was placed on the top of the obstacle. Data were filtered at 8 Hz with a 4th order zero-phase-shift low-pass Butterworth digital filter.

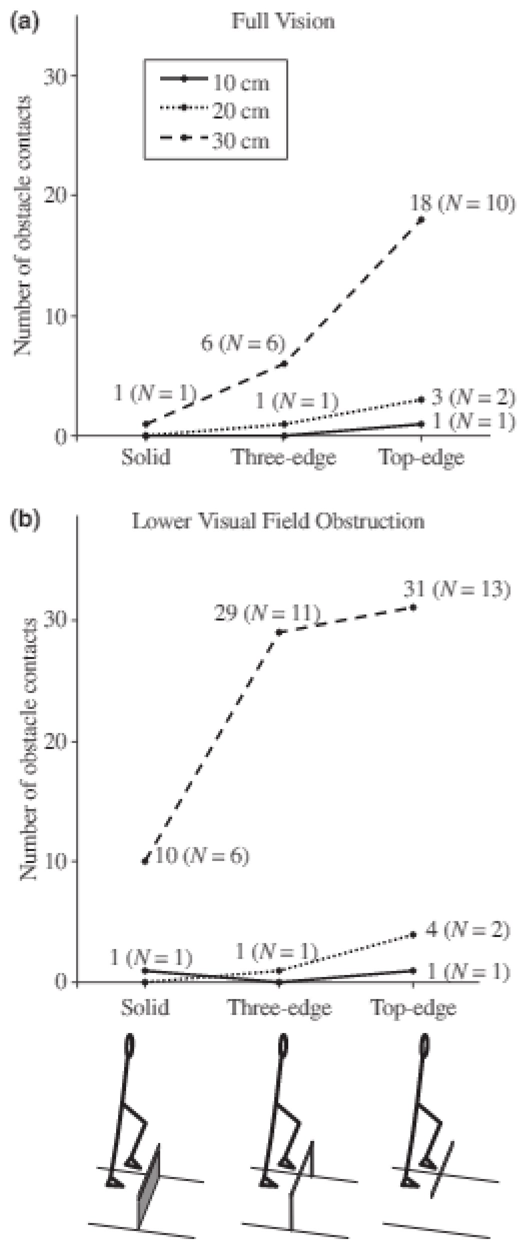

Figure 3. The number of obstacle contacts as a function of full vision (a) and obstructed vision (b). Both charts are expressed as a function of visible structure (*x*-axis) and obstacle height (10 cm = solid line, 20 cm = dotted line, 30 cm = dashed line). Numbers beside each data point indicate the total number of contacts for all subjects. Numbers in the brackets beside each data point indicate the number of subjects who contacted the obstacle. The stick figures at the bottom demonstrate the visible structure conditions. As no statistical differences between controls and construction workers were observed, results include both groups of subjects.

If the foot contacted the obstacle during the trial, the foot (lead or trail) which contacted the obstacle was recorded. Toe clearance was calculated as the vertical distance between toe diode and top of obstacle when the foot was over the obstacle. Horizontal distance was calculated as the horizontal distance between the toe diode and the obstacle at the foot placement before the obstacle. Both measures were recorded for the lead and trail limb. The variability of each measure was calculated as the standard deviation.

A repeated measures logistical regression was used to examine the odds ratio to determine if the obstacle contacts were related to visible structure, visual obstruction, obstacle height or work group. A four factor mixed within- and between-subject analysis of variance was used to determine if the variability measures were influenced by visible structure, visual obstruction, obstacle height (within-subject factors) or work group (between-subject factor). Duncan's multiple range *post hoc* analyses were used when appropriate. Significance was set at 0.05 level for all tests.

RESULTS

Risk of obstacle contact

One hundred and seven obstacle contacts were observed in 2736 trials (144 trials per subject), or 3.9% of all trials. Two of the 19 subjects did not make any contacts. Of the contacts, 91.6% were made with the trail limb. The logistic regression indicated that visible structure of the obstacle was significantly associated with risk of obstacle contact (Wald $\chi^2_2 = 16.97$, $p < 0.01$, *Figure 3*). Visual obstruction and obstacle height were also significantly associated with the risk of obstacle contact (Wald $\chi^2_1 = 9.97$, $p < 0.01$) and (Wald $\chi^2_2 = 15.58$, $p < 0.01$), respectively (*Figure 3*). Subject group was not associated with risk of obstacle contact (Wald $\chi^2_1 = 0.77$, $p = 0.38$).

Gait kinematics: effect of visible structure

Only main effects were observed for visible structure manipulations (*Table 1*), so they are considered separately. The main effect of visible structure was significant for lead toe clearance variability ($F_{2,4} = 4.26$, $p = 0.015$, *Figure 4a*) and trail toe clearance variability ($F_{2,4} = 5.16$, $p = 0.006$, *Figure 4b*). Lead toe clearance variability was greater for the top-edge obstacle compared to the three-edge or solid obstacles; trail toe clearance variability was greater for the top-edge obstacle vs the solid obstacle. Lead horizontal distance variability was not modified by obstacle type ($F_{2,4} = 0.13$, $p = 0.88$, *Figure 4c*), and trail horizontal distance variability showed a trend as a function of obstacle type ($F_{2,4} = 2.72$, $p = 0.067$, *Figure 4d*). Larger toe trajectories were expected for the top-edge obstacle; but no significant differences in toe clearance and horizontal distance were observed as a function of visible structure (*Table 1*). The data were examined for trends; the solid obstacle had the largest lead toe clearance (23.9 vs 22.5 vs 23.3 cm for the solid, three-edge outline and top-edge obstacles, respectively), the largest trail toe clearance (22.9 vs 21.3 vs 22.8 cm for the solid, three-edge outline and top-edge obstacles, respectively), and the largest trail horizontal distance (24.4 vs 22.9 vs 23.3 cm for the solid, three-edge outline and top-edge obstacles, respectively).

Table 1. Significance values for main effects and interactions

	G	VS	G*VS	V	V*G	V*VS	V*VS*G
Lead TC	0.055	0.290	0.860	0.455	0.960	0.897	0.980
Trail TC	0.138	0.441	0.921	0.405	0.507	0.989	0.980
Lead HD	0.247	0.865	0.978	0.928	0.725	0.902	0.949
Trail HD	0.276	0.405	0.884	0.800	0.580	0.994	0.927
Var Lead TC	**0.016**	**0.015**	0.970	0.428	0.864	0.671	0.490
Var Trail TC	**<0.001**	**0.006**	0.783	0.151	0.172	0.752	0.206
Var Lead HD	0.335	0.878	0.919	0.789	0.606	0.592	0.599
Var Trail HD	0.187	0.067	0.249	0.780	0.840	0.256	0.665

	OH	OH*G	OH*VS	OH*VS*G	OH*V	OH*V*G	OH*V*VS	OH*V*VS*G
Lead TC	**<0.001**	0.250	0.918	0.999	0.562	0.937	0.999	0.999
Trail TC	0.133	**0.048**	0.955	0.993	0.640	0.913	0.998	0.996
Lead HD	0.639	0.932	0.947	0.949	0.970	0.908	0.994	0.981
Trail HD	0.578	0.638	0.893	0.982	0.860	0.969	0.997	0.994
Var Lead TC	0.762	0.795	0.202	0.831	0.714	0.796	0.861	0.754
Var Trail TC	**0.031**	0.216	0.438	0.961	0.831	**0.042**	0.392	0.985
Var Lead HD	0.957	0.962	0.858	0.579	0.805	0.541	0.913	0.925
Var Trail HD	0.857	0.974	0.932	0.614	0.761	0.708	0.972	0.732

TC, toe clearance; HD, horizontal distance; Var, variability; G, group (controls or construction workers); V, visual manipulation (full vision or lower visual field obstruction); VS, visible structure condition (full, three-edge or top-edge) and OH, obstacle height (10, 20 or 30 cm).
Statistically significant effects at the $p < 0.05$ level are bolded.

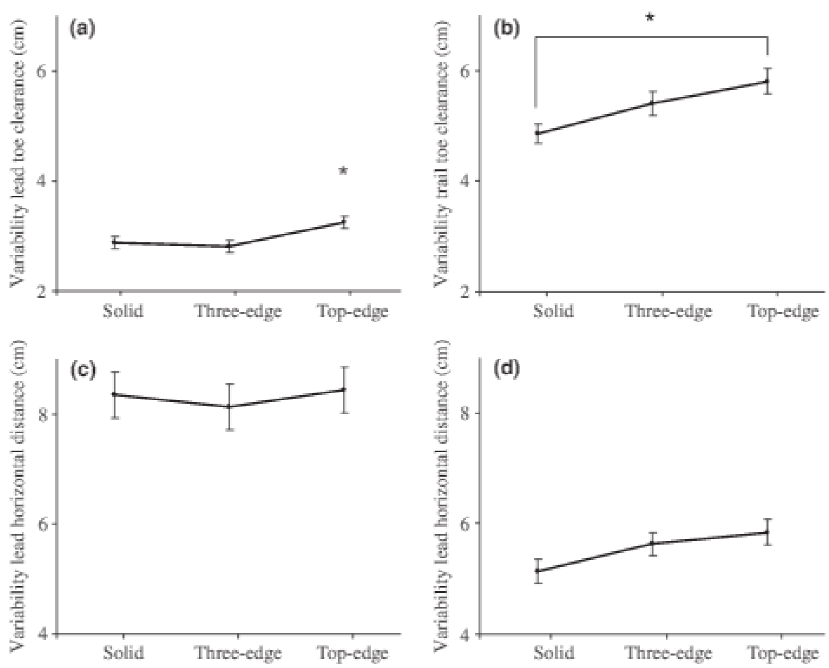

Figure 4. Variability of lead toe clearance (a), variability of trail toe clearance (b), variability of lead horizontal distance (c) and variability of trail horizontal distance (d). Error bars represent standard error. Asterisks (*) indicate significantly different values. As no significant interactions were observed as a function of visible structure conditions and subject groups, results include both controls and construction workers.

Gait kinematics: effect of obstacle height, vision obstruction and work group

Lead toe clearance was modified as a function of obstacle height ($F_{2,4} = 17.67$, $p < 0.001$, *Table 1*). *Post hoc* analyses revealed that all lead toe clearances were significantly different from each other [10 cm: 25.9 (SD 7.0) cm; 20 cm: 22.9 (SD 6.1) cm and 30 cm: 20.9 (SD 5.5) cm]. The main effect of group was significant for lead toe clearance variability, ($F_{1,4}$ = 5.91, p = 0.016, *Table 1*), control subjects had more lead toe clearance variability [3.1 (SD 1.2) cm vs 2.8 (SD 1.2) cm].

An interaction effect (obstacle height by work group) was observed for trail toe clearance ($F_{2,4}$ = 3.07, p = 0.048, *Figure 5a*). *Post hoc* analyses revealed that trail toe clearance for workers was not affected by the obstacle height, but controls demonstrated significantly higher toe clearance for the 10 cm obstacle (24% higher when compared to the average of the 20 and 30 cm obstacles, *Figure 5a*). Main effects were observed for work group and obstacle height for trail toe clearance variability ($F_{1,4}$ = 12.77, p < 0.001 and $F_{2,4}$ = 3.52, p = 0.031, respectively; *Table 1*). *Post hoc*analyses revealed that control subjects had higher trail toe clearance variability [5.8 (SD 2.1) vs 4.9 (SD 2.4) cm] and the 10 cm obstacle had lower trail toe clearance variability than the 30 cm obstacle [4.9 (SD 2.2) vs 5.4 (SD 2.1) vs 5.7 (SD 2.5) cm for 10, 20 and 30 cm obstacles, respectively]. The interpretation of these main effects is mediated by the presence of an interaction, obstacle height by vision by work group ($F_{2,4}$ = 3.21, p = 0.042, *Figure 5b*). *Post hoc* analyses revealed that trail toe clearance variability was not modified as a function of obstacle height for controls under either visual condition. Trail toe clearance variability increased with obstacle height for construction workers only when the lower visual field was obstructed.

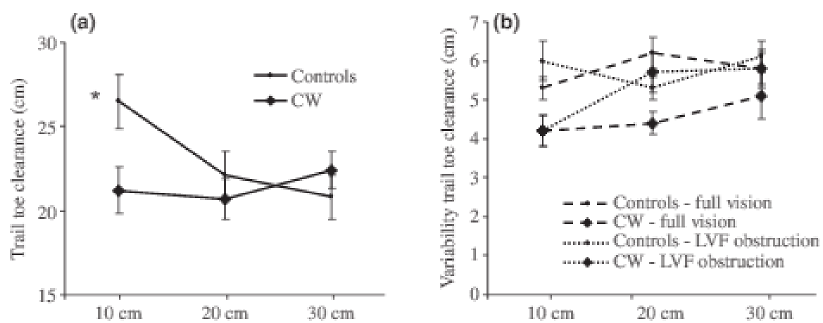

Figure 5. Trail toe clearance as a function of work experience and obstacle height (a), and variability of trail toe clearance as a function of work experience, visual condition and obstacle height (b). Asterisk in (a) indicates significantly different values; see text in Results for description of significantly different values for (b). CW, construction worker; LVF, lower visual field.

DISCUSSION

The results of this study indicate that locomotor behaviour was influenced by the visible structure of the obstacle, lower visual field obstruction, obstacle height and work experience. Increased risk of obstacle contact and increased gait variability support the idea that during obstacle avoidance, the sensory-to-motor transformation was compromised by reduced visible structure of the obstacle. In addition, construction workers appear to have a more accurate sensory-to-motor transformation – suggesting that they are better able to attend to visual cues.

Reduced visible structure compromised the ability to clear obstacles, as reflected in both risk of obstacle contact and gait variability. Contact with the obstacle occurred more frequently when only the top edge was visible, consistent with the idea that obstacle position and height are underspecified in the top-edge condition. It is reasonable to argue that the side edges allow the obstacle to be described in a reference system fixed to the ground, so that the position and height of the obstacle can be specified more accurately. The trend of increased foot placement variability ($p = 0.067$, *Figure 4d*) may reflect uncertainty regarding obstacle position when only the top edge was visible. Increased foot placement variability would result in some trials with the foot too close to the obstacle, leading to increased risk of obstacle contact.[27] Increased trail toe clearance variability (*Figure 4b*) may reflect either uncertainty of obstacle height, or may be a consequence of a shift in the trail toe trajectory due to more variable foot placement. However, lead toe clearance variability was higher without a concurrent increase in lead foot placement variability; therefore, the increased lead toe clearance variability reflects uncertainty of obstacle height. In summary, decreased visibility of the side edges interfered with the visual-to-motor transformation used to control the lead and trail limbs during obstacle approach and crossing.

No difference in variability was observed for the three-edge outline and solid obstacles, which reinforces the idea that more accurate position and height information was available when the obstacle was specified in a ground reference system. However, a greater number of contacts were observed for the three-edge outline vs solid obstacle, consistent with the idea proposed in the introduction that the planar surface of the solid obstacle may provide more information regarding obstacle position and/or height. However, this conclusion is tempered by the fact that the solid obstacle had a substantially larger amount of glow-in-the-dark tape, which could also have influenced risk of contact in at least two other manners. First, the larger amount of tape may have increased the brightness and visibility of the solid obstacle, thereby reducing the risk of contact. Second, the larger amount of tape may have made the solid obstacle appear larger. The latter interpretation is supported by larger toe clearances and trail horizontal distance for the solid obstacle, although the increases were not statistically significant. We explored this further in a subsequent study and found that the solid obstacle was judged as taller than the three-edge outline obstacle, and higher toe clearances were observed during the first five obstacle crossing trials.[18]Similarly, higher toe clearances were observed when stepping onto steps perceived to be larger,[22]and stepping over fragile obstacles.[28] Therefore, the decreased number of contacts observed for the solid obstacle vs the three-edge outline obstacle is confounded by the effect of the solid obstacle on height judgment and subsequent change in toe clearance.[18]

Lower visual field obstruction due to the goggles also increased the risk of obstacle contact, but did not modify any other gait parameters. Previous research with similar goggles has demonstrated a robust change in crossing behaviour in normal lighting (increased toe clearance and horizontal distance).[15,24,29,30] Since similar changes were not observed in this study, it is likely that the lower limb was not as visible due to the low lighting, which compromised the foot-to-obstacle exproprioceptive information. Despite the lack of change in gait parameters, the higher risk of obstacle contact with obstructed lower visual field (*Figure 3a vs b*) adds to the growing literature that on-line exproprioceptive information plays an essential role in guiding locomotion.[31]

The height of the obstacle also influenced the ability to safely cross the obstacle, with the largest number of contacts observed for the 30 cm obstacle. The requirement for appropriate trail foot placement is greater for the 30 cm obstacle, as foot placement closer to the obstacle requires a more vertical trajectory to clear the larger obstacle.[27] Also, trail toe clearance variability was higher for the 30 cm than the 10 cm obstacle for the construction workers (*Figure 5b*), without associated changes in foot placement variability, which can be interpreted as greater certainty regarding obstacle height for the smaller obstacle. Changes in variability as a function of height were observed only in the construction workers, and are consistent with the idea that workers have a more accurate sensory-to-motor transformation (discussed further in the next paragraph). Note that it does appear important to modify the obstacle heights in order to examine obstacle contacts, as in a similar study in low light with a single obstacle height (30 cm), only one obstacle contact was observed.[18]

The interpretation that construction workers were more accurate in their sensory-to-motor transformation was supported by three main findings. First, construction workers scaled trail toe trajectories to obstacle height, while the controls overcompensated for the 10 cm obstacle by 24% (*Figure 5a*). Second, construction workers had lower lead toe clearance variability. Third, construction workers had lower trail toe clearance variability than controls for the 10 cm obstacle, and variability increased as a function of both lower visual field obstruction and obstacle height for the workers only (*Figure 5b*). These behaviours are consistent with the idea that workers were able to obtain visual information to control the toe trajectory more accurately than controls. The observation that toe clearance values were not different between general construction workers vs controls stands in contrast to a previous study. A higher toe clearance was observed for a specific group of construction workers – roofers – when stepping up onto a platform.[26] The difference may be due to a number of factors. First, the higher toe clearance of the roofers was coupled with higher toe clearance variability, so the roofers apparently compensated for higher variability with higher clearances. Second, the risk of balance loss was lower in the present study. The solid wood platform in the roofer study would arrest the limb if contacted, while the obstacles in this study collapsed when contacted. Third, the low lighting levels may have resulted in a different behaviour than observed under more typical lighting situations. Finally, while both groups of construction workers work in cluttered environments, roofers work on sloped surfaces with a higher consequence following balance loss; these differences may result in different strategies to avoid loss of balance. Further research is needed to fully address the issue of work experience and risk of tripping.

The reduced risk of obstacle contact due to increased visible structure of an obstacle can be applied to help prevent falls in older adults. Obstacles in the community should be modified, if possible, to increase visible structure. For example, curbs should be painted a high contrast colour so the curb-pavement interface is easily discernible. Also, eye care providers should consider that the effect of visible structure may be compounded by the deleterious effect of multifocal lenses on the ability to avoid obstacles.[32,33] When visible structure is reduced, multifocal lenses may further distort obstacle height and/or position information. It should be pointed out that the observations on the effect of visible structure were made on healthy younger males, yet older women are most likely to suffer injury from falls.[34] Future research should confirm the effect of visible structure in older adults and in both sexes. An important limitation in the application of the study findings is the low lighting level; low lighting was essential to ensure that participants would not take advantage of any small clue provided by the fishing line to simplify their task.[35] However, the low lighting may have affected the results in several ways, such as unfamiliarity with the task in low light and reduced visibility of the lower limbs. Further research should confirm these observations under more typical lighting.

In conclusion, decreased gait variability in construction workers is consistent with the idea that workers were more accurate in the sensory-to-motor transformation to control the lead and trail limb during obstacle crossing. The most compelling observation was that decreased visible structure of an obstacle increased both gait variability and risk of obstacle contact.

ACKNOWLEDGEMENTS

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