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Safety on stairs: Influence of a tread edge highlighter and its position

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ABSTRACT

Background: Falls sustained when descending stairs are the leading cause of accidental death in older adults. Highly visible edge highlighters/friction strips (often set back from the tread edge) are sometimes used to improve stair safety, but there is no evidence for the usefulness of either.
Objective: To determine whether an edge highlighter and its location relative to the tread edge affect foot placement/clearance and accidental foot contacts when descending stairs.
Method: Sixteen older adults (mean ± 1 SD age; 71 ± 7 years) with normal vision (experiment 1) and eight young adults (mean ± 1 SD age; 24 ± 4 years) with visual impairment due to simulated age-related cataract (experiment 2) completed step descent trials during which a high contrast edge highlighter was either not present, placed flush with the tread edge, or set back from the edge by 10 mm or 30 mm. Foot placement/clearance and the number of accidental foot contacts were compared across conditions.
Results: In experiment 1, a highlighter set back by 30 mm led to a reduction in final foot placement ($p < 0.001$) and foot clearance ($p < 0.001$) compared to a highlighter placed flush with the tread edge, and the percentage of foot clearances that were less than 5 mm increased from 2% (abutting) to 17% (away30). In experiment 2, a highlighter placed flush with the tread edge led to a decrease in within-subject variability in final foot placement ($p = 0.004$) and horizontal foot clearance ($p = 0.022$), a decrease in descent duration ($p = 0.009$), and a decrease in the number of low clearances (<5 mm, from 8% to 0%) and the number of accidental foot contacts (15% to 3%) when compared to a tread edge with no highlighter present.
Conclusions: Changes to foot clearance parameters as a result of highlighter presence and position suggest that stairs with high-contrast edge highlighters positioned flush with the tread edge will improve safety on stairs, particularly for those with age-related visual impairment.

1. Introduction

Falls sustained on steps/stairs are the leading cause of accidental death in older adults (Startzell et al., 2000). Non-fatal injuries due to falling on steps (e.g. surface level change or kerb) or stairs are also highly prevalent in older adults, ranging from severe bruising to hip fractures (Gallagher and Scott, 1997; Templer, 1992). In the UK an estimated 11% of injuries sustained in home accidents in 2002 occurred due to a fall on steps/stairs (Department of Trade and Industry, 2002; Roys, 2001). Almost 1000 deaths occur each year in the UK as a consequence of older adults falling on steps or stairs in the home (Hill et al., 2000). Identifying ways to improve safety on stairs is thus a vital public health issue. Falls in older adults are three times more likely to occur during stair descent compared to stair ascent (Cohen et al., 1985; Tinetti et al., 1988), with a higher incidence occurring on either the top or bottom steps (Templer, 1992). Falls also frequently occur when transitioning from one level to another, such as descending a kerb (Gallagher and Scott, 1997). Reduced foot/heel clearances over the tread-edge, greater clearance variability and misjudgements in foot placement when descending steps or stairs are factors that are reported to increase falls risk (Hamel et al., 2005; Jackson and Cohen, 1995; Simoneau et al., 1991).

Vision is known to play a major role in successful stair negotiation (Startzell et al., 2000; Templer, 1992) and visual impairment becomes increasingly likely as people get older (Klaver et al., 1998). Locating the tread edge may be particularly problematic for older adults when the lighting levels are low and/or the step covering is patterned and/or if they are visually impaired (Buckley et al., 2005a,b, 2008; Hamel et al., 2005; Hill et al., 2000; Templer, 1992). To help counter the problems associated with poor vision, building regulations state that a visually contrasting permanent edge highlighter should be placed across the full width of each step-tread to help clearly delineate the tread edge from the rest of the tread (Archea et al., 1979). A tread edge highlighter can also be incorporated as part of the step 'nosing', and the British (building) standards (British Standards Institution, 2009) describe how the nosing should encompass both the front edge portion of a tread and top portion of the step riser. British and American building guidelines state that the width of the nosing on the tread should be between 50 and 65 mm (British Standards Institution, 2009) or no more than 38 mm (Architectural U, 2002) respectively. Slip-resistant

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strips (friction strips) are also commonly used on tread surfaces to help prevent slips and falls. However, there are no standards/guidelines regarding the location of slip-resistant strips, although by definition slip-resistant 'nosings' will be positioned at the tread edge. As slip resistant strips typically provide a visual cue regarding the position of the tread edge, they may be a source of visual ambiguity when positioned away from the tread edge (as is not uncommon on public stairs, Fig. 1a–b).

Previous research, looking at the effects of edge highlighters, has failed to determine any significant changes in stair descent stepping behaviour (Simoneau et al., 1991; Zietz et al., 2011). However, in both studies foot placement/clearance was only reported for the mid-stair portion of a five-step stairway, where trips/falls are least common (Templer, 1992), and where somatosensory information from negotiating the previous steps may have been used to judge riser height instead of relying on accurate visual information (Buckley et al., 2005a; Chapman et al., 2010).

The aims of this study were to determine: i) whether the presence and location of a step-edge highlighter affected foot placement/clearance and the number of accidental foot contacts during descent of a flight of stairs (experiment 1 – habitual vision) and ii) whether the effects would change for those with poor/impaired vision (experiment 2 – cataract simulation).

We chose not to use older participants with age-related visual impairment in experiment 2 for the following reasons: 1) Pilot work indicated that manipulating the position of a step-edge highlighter had a significant and profound effect on stair descent safety, which we thought would make risk of tripping and falling in elderly individuals too great. If we had used elderly participants we would have had to use a safety harness system, but this would have led to an unnatural and/or very cautious stair descent approach. 2) Previous research has indicated that stepping parameters in both young and older adults are affected by blurred vision (due to simulated cataract), but that the effects are similar for both age groups (Heasley et al., 2005). Thus the use of younger participants with visual impairment due to a cataract simulation (Elliott et al., 1996; Heasley et al., 2004, 2005) allowed us to satisfactory meet the study's aims as the effects of blurring vision in young adults were expected to provide data that is representative of how older adults with simulated cataract would have performed.

2. Materials and methods

2.1. Participants

The average (±1 SD) characteristics of participants for each experiment are presented in Table 1. The tenets of the Declaration of Helsinki were observed and the experiments gained institutional ethical approval. Participants with a history of musculoskeletal or neurological impairment, cardiovascular disorders, vestibular disturbances, a history of falling or significant eye disease as determined by clinical examination were excluded from taking part. All participants recruited for Experiment 1 had normal vision for their age, with binocular visual acuity better than 0.1 logMAR. Participants in experiment 2 wore cataract simulation goggles (Vistech, Stereo Optical Co., Chicago, Illinois) (Elliott et al., 1996; Heasley et al., 2004, 2005) throughout the entire session, which reduced contrast sensitivity (Pelli-Robson chart) to approximately 0.75 log units. This is a level of vision that would be described as visual disability (Leat et al., 1999), which is most common in the elderly population (Elliott et al., 1997). All participants provided written informed consent to take part in the study.

2.2. Stair design and apparatus

The stairs used were custom built for the purpose of conducting research within the gait lab environment. Consisting of three steps, the stairs were 1000 mm wide with the top step consisting of a landing area measuring 1500 mm long (Fig. 2a). Each tread/going measured 285 mm and the step risers ranged between 167 and 175 mm. The step treads and risers were painted a uniform grey colour. A handrail was positioned on the right side of the stairs (as viewed during descent), and crash mats were positioned on the left side for safety.

During the experiments a research team member was positioned close to the stairs to aid participants if they lost balance or stumbled during the trial (this did not occur across any of the trials and none of the participants used the handrail at any time).

2.3. Tread edge highlighter

For each experiment, repeated trials were undertaken of four experimental tread edge highlighter conditions: 1) no edge highlighter on the tread (plain); 2) a high-contrast black strip 55 mm wide placed flush with the leading edge of the tread (abutting); 3) a high-contrast black strip 55 mm wide placed 10 mm from the leading edge of the tread (away10); and 4) a high-contrast black strip 55 mm wide placed 30 mm from the leading edge of the tread (away30). In both experiments the edge highlighter was present across the top, middle and bottom step edges. The width of the black strip adhered to British (building) standards (British Standards Institution, 2009). The Weber contrast of the strip against the grey tread background was 95% and the laboratory was lit to an ambient illuminance of 400 lx.

Fig. 1. a) The separation (~30 mm) between the slip resistant strip and physical tread edge is noticeable when viewing the public stairs from close up, but from the perspective of the stair user (b) it is difficult to clearly delineate the tread edge from the tread surface on the step below.

Table 1
The characteristics of participants taking part in each experiment (mean ± 1 SD).

	Experiment 1	Experiment 2
Number of participants	16 (8 female)	8 (3 female)
Age (years)	71.1 ± 7.4	24.0 ± 4.3
Height (m)	1.69 ± 0.12	1.73 ± 0.10
Mass (kg)	77.33 ± 18.98	72.06 ± 16.67
Binocular VA (logMAR)	−0.02 ± 0.06	0.16 ± 0.16[a]
Contrast sensitivity (logCS)	1.84 ± 0.14	0.76 ± 0.02[a]

[a] Participants in experiment 2 wore the cataract simulation goggles during the assessment of binocular visual acuity and contrast sensitivity.

2.4. General protocol

In experiment 1 (habitual vision) and experiment 2 (cataract simulation) participants completed 3 and 5 trials of each highlighter condition respectively. Three trials were used in experiment 1 to avoid fatigue in the older participants. Highlighter conditions were presented in a randomised order. Participants started from a standing position approximately two and a half walking steps away from the edge of the top step and completed each trial using a 'step-over-step' gait (i.e. alternative limb lead on each step). The same self-selected leading limb was used to begin each trial and participants were instructed to use their vision throughout the trial to help negotiate the stairs. Several strategies were used to attempt to counter the use of somatosensory information about step height and position gained when completing the preceding trials. These included 1) varying the starting location by ±50 mm (in randomised order) (Chapman et al., 2010), 2) participants stepping on to custom built 'stepping stones' (square wooden blocks) to return to the top of the stairs (the heights of the stepping stones were varied between trials), and 3) using "dummy trials" after every third trial in which the riser height and/or tread depth were altered by 10 or 20 mm (Chapman et al., 2010; Johnson et al., 2008). Data were not collected during the dummy trials and participants were advised at regular intervals during the protocol that the height/tread depth and appearance of the steps may vary between trials.

Whole-body kinematic data were captured at 100 Hz using a 10-camera motion capture system (Vicon MX, Oxford Metrics, UK). Participants were asked to wear sensible/comfortable flat shoes and clothing, and used their habitual vision correction throughout each trial. Note that participants in experiment 2 wore the cataract simulation glasses over the top of any corrective lenses. Reflective markers (14 mm diameter) were placed directly onto the skin, clothing, or shoes in accordance with the lower body and thorax segments that are defined in Vicon's 'plug-in-gait' full-body marker set (Gutierrez et al., 2003). Additional markers were placed on the left and right greater trochanter, second metatarsal head and distal phalange of the second toe, and a cluster of four markers were placed on the sacrum. Markers were also placed on each tread edge in order to determine its location within the lab coordinate system. Virtual markers were created at the shoe's heel and toe inferior tips (heel and toe tip), by constructing their positions relative to the heel and toe markers respectively (Graci et al., 2009).

2.5. Data analysis

Marker trajectories were labelled in Vicon Nexus (Vicon, Oxford Metrics, UK) and the resultant C3D files uploaded to Visual 3D (C-Motion, USA) for further analysis. Existing stair descent marker-based event detection algorithms were used to determine instants of touch-down and foot-off in each trial (Foster et al., 2014). The following dependent variables were then determined in Visual 3D:

Penultimate foot placement: the horizontal distance between the leading-limb shoe tip and edge of the top stair when the foot was motionless on the landing (Fig. 2a–b).
Final foot placement: the horizontal distance between the trailing-limb shoe tip and edge of the top stair when the foot was motionless on the landing (Fig. 2a–b). Negative foot placement values indicated that the shoe tip was behind the edge of the top stair.
Middle step foot placement: the horizontal distance between the leading-limb shoe tip and edge of the middle step (Fig. 2a). A positive value indicated that the shoe tip was beyond the edge of the step.
Horizontal and vertical foot clearance (FC): the respective horizontal and vertical distance between the leading-limb heel and edge of the top/middle step as the leading-limb passed over (swing phase) the edge of the step (Fig. 2a) (Buckley et al., 2011).
Descent duration: from the instant of leading-limb foot-off prior to stepping over the top step to the instant of leading-limb touch-down on the ground (Buckley et al., 2013).
Heel scuff: the number of instances where a participant's heel caught the tread edge/going or riser (accidental foot contact). Each heel scuff was only recorded if agreed upon by the two experimenters present.
Horizontal foot clearance <5 mm: the number of instances where horizontal FC fell below 5 mm. Such clearance levels have been associated with greater risk of catching the heel on the tread edge/going, especially on flights of stairs where riser height varies between one riser and another (Hamel et al., 2005).

As stride length during the stair-to-floor transition is significantly increased when compared to mid-stair descent (Lee and Chou, 2007), indicating that gait/stepping behaviour is significantly different when stepping onto the ground compared to that on the stairs, the effects of

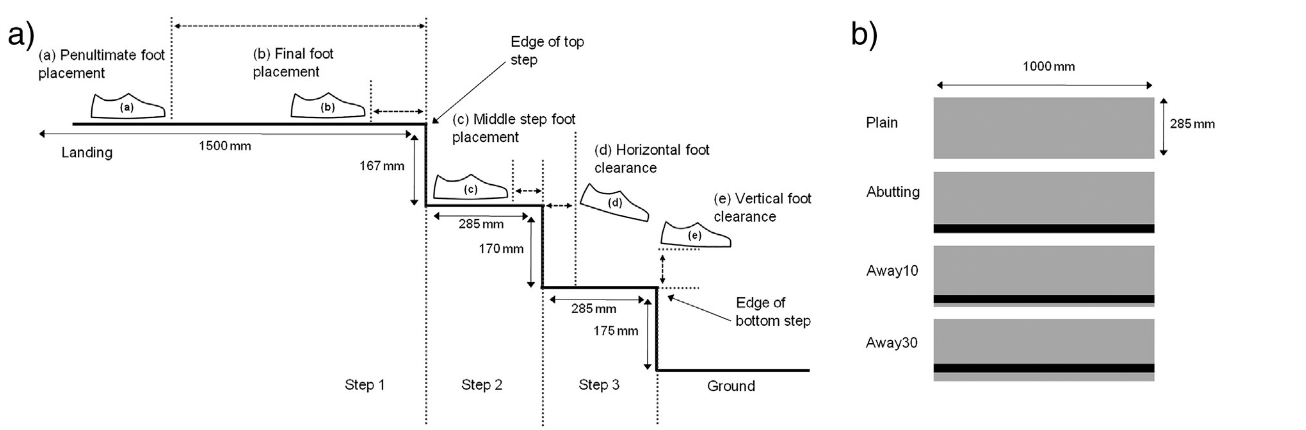

Fig. 2. a) Schematic of the stairs and how foot placement and clearance parameters (a–e) were determined. b) The four stair edge highlighter conditions used for each experiment: plain, abutting, away10, and away30.

tread edge highlighter condition were only considered on/over the top and middle step.

2.6. Statistical analysis

Foot placement and clearance parameters were analysed using 2-way repeated measure analysis of variance (ANOVA, StatSoft, Statistica, USA) with edge highlighter (plain, abutting, away10, away30) and repetition (3 and 5 trials respectively) as repeated factors or 3-way repeated measure ANOVA with step (top/middle step) as an additional repeated factor. All interactions between step number, edge highlighter and repetition were found to be of no consequence and thus are not reported. Post-hoc analyses were performed using Tukey's HSD test and the alpha-level of significance was set at $p = 0.05$. Given the explorative nature of the study (i.e. to determine the effects of the presence and location of a step-edge highlighter on foot placement/clearance parameters during stair descent), we believed that adjusting the alpha level ($p < 0.05$) was not warranted (Perneger, 1998).

3. Results

The mean (±1 SD) and within-subject variability (the standard deviation across the three repetitions in experiment 1 and five repetitions in experiment 2) for kinematic and temporal measures in each edge highlighter condition for experiment 1 (habitual vision) and experiment 2 (cataract simulation), are presented in Tables 2 and 3.

3.1. Main effect of edge highlighter

3.1.1. Experiment 1 (habitual vision)

Highlighter condition had no significant main effect on penultimate foot placement ($p = 0.71$), but had a significant main effect on final foot placement ($p < 0.001$). Final foot placement for away10 and away30 was significantly further from the tread edge than for abutting ($p = 0.005$ and $p < 0.001$ respectively) or plain ($p = 0.003$ and $p < 0.001$ respectively). Highlighter condition had a significant main effect on middle step foot placement ($p < 0.001$), with away10 and away30 being significantly further from the tread edge than for abutting ($p < 0.001$ and $p < 0.001$ respectively) or plain ($p = 0.029$ and $p < 0.001$ respectively).

Highlighter condition had a significant main effect on horizontal FC and vertical FC over the top step edge ($p < 0.001$ and $p < 0.001$ respectively). Horizontal FC and vertical FC for away30 were significantly closer to the tread edge than during plain ($p < 0.001$ and $p = 0.001$ respectively), abutting ($p < 0.001$ and $p = 0.001$ respectively) or away10 ($p = 0.002$ and $p < 0.001$ respectively, Table 2). There were no main effects of highlighter condition on the horizontal or vertical FC over the middle step edge (Table 2).

Highlighter condition had no significant main effect on descent duration ($p = 0.37$).

There were no significant differences in within-subject variability between highlighter conditions in any of the outcome parameters analysed (penultimate and final foot placement, horizontal or vertical FC over the top and middle step edge, and descent duration).

3.1.2. Experiment 2 (cataract simulation)

Highlighter condition had no significant main effect on penultimate foot placement ($p = 0.60$), but there was a significant main effect on final foot placement ($p = 0.004$, Table 3). Final foot placement was significantly further from the tread edge for plain in comparison to abutting ($p = 0.004$) or away10 ($p = 0.019$). There was a significant increase in final foot placement within-subject variability in the plain condition, compared to away30 ($p = 0.038$). There was a significant main effect of highlighter condition on middle step foot placement ($p = 0.049$), but post-hoc analysis indicated that there were no significant differences between highlighter conditions. Middle step foot placement within-subject variability was reduced for the abutting condition, compared to away10 ($p = 0.039$) or plain ($p = 0.035$, Table 3).

Highlighter condition had a significant main effect on horizontal and vertical FC over the top step edge ($p = 0.002$ and $p = 0.019$ respectively). Both horizontal and vertical FC were significantly closer to the edge in away30 compared to abutting ($p = 0.001$ and $p = 0.026$ respectively). There was a significant increase in horizontal FC within-subject variability in the plain condition compared to abutting ($p = 0.022$), away10 ($p = 0.024$) or away30 ($p = 0.003$). Highlighter condition had no significant main effect on horizontal FC over the middle step edge ($p = 0.06$), but there was a significant main effect on vertical FC ($p = 0.009$, Table 2); vertical FC was significantly closer to the edge in away30 compared to plain ($p = 0.005$).

Highlighter condition had a significant main effect on descent duration ($p = 0.001$); duration was significantly longer for the plain condition compared to abutting ($p = 0.009$), away10 ($p = 0.036$) or away30 ($p = 0.001$). Descent duration within-subject variability was significantly increased in the plain condition compared to away30 ($p = 0.006$).

3.2. Main effect of repetition

Stair descent duration was significantly reduced in the last compared to the first trial in both experiments. For example, in experiment 1, trial 1 descent duration (2.10 ± 0.39 s) was significantly longer than trial 3 (2.01 ± 0.39 s, $p = 0.019$). Final foot placement and middle step foot placement were closer to the tread edge in the last compared with the first trial ($p < 0.05$) in both experiments.

3.3. Heel scuff and horizontal foot clearance <5 mm

The percentages of the total number of trials that resulted in a heel scuff or where horizontal FC fell below 5 mm for both experiments are shown in Table 4. The percentage of trials in which horizontal FC fell below 5 mm was highest for the away30 highlighter.

Table 2
The effect of each edge highlighter condition on stair descent parameters for older adults under habitual vision (experiment 1).

	Metric and temporal means (±1 SD)			
	Plain	Abutting	Away10	Away30
Penultimate foot placement (mm)	−467 ± 73	−465 ± 62	−468 ± 69	−474 ± 69
Final foot placement (mm)	−23 ± 43	−24 ± 46	−41 ± 44	−46 ± 43
Middle step: foot placement (mm)	0 ± 29	4 ± 29	−8 ± 27	−13 ± 26
Top step: horizontal FC (mm)	46 ± 18	47 ± 14	42 ± 15	32 ± 19
Middle step: horizontal FC (mm)	41 ± 17	39 ± 16	39 ± 14	35 ± 17
Top step: vertical FC (mm)	25 ± 12	25 ± 11	25 ± 13	19 ± 15
Middle step: vertical FC (mm)	30 ± 20	30 ± 16	29 ± 20	24 ± 17
Descent duration (s)	2.05 ± 0.37	2.06 ± 0.37	2.11 ± 0.37	2.08 ± 0.41

There were no significant differences in any within-subject variable measures for experiment 1.

Table 3
The effect of each edge highlighter condition on stair descent parameters for young adults with simulated impaired vision typically seen in the elderly (experiment 2).

	Metric and temporal means (±1 SD)				Within-subject variability means (±1 SD)			
	Plain	Abutting	Away10	Away30	Plain	Abutting	Away10	Away30
Penultimate foot placement (mm)	−476 ± 71	−475 ± 45	−486 ± 52	−473 ± 59	47 ± 20	57 ± 27	55 ± 19	52 ± 29
Final foot placement (mm)	−55 ± 35	−15 ± 36	−22 ± 50	−30 ± 51	37 ± 24	30 ± 17	25 ± 9	20 ± 8
Middle step: foot placement (mm)	31 ± 21	47 ± 17	29 ± 27	31 ± 19	20 ± 7	12 ± 3	20 ± 7	18 ± 8
Top step: horizontal FC (mm)	47 ± 16	58 ± 17	48 ± 13	38 ± 18	28 ± 14	17 ± 7	17 ± 7	14 ± 4
Middle step: horizontal FC (mm)	58 ± 20	52 ± 19	51 ± 21	47 ± 25	15 ± 9	13 ± 6	12 ± 3	13 ± 9
Top step: vertical FC (mm)	29 ± 18	33 ± 17	32 ± 19	23 ± 19	12 ± 3	8 ± 3	11 ± 6	10 ± 4
Middle step: vertical FC (mm)	49 ± 27	44 ± 25	43 ± 31	37 ± 30	13 ± 6	11 ± 4	10 ± 3	11 ± 8
Descent duration (s)	2.63 ± 0.98	2.18 ± 0.79	2.26 ± 0.79	2.04 ± 0.64	0.40 ± 0.36	0.32 ± 0.35	0.29 ± 0.33	0.20 ± 0.25

3.4. Supplementary results

A third experiment determined whether the presence of an edge highlighter and its positioning affected foot placement and clearance parameters in older adults when descending a surface level change (see Supplemental material, Table S1). Highlighter condition had a significant effect on final foot placement, horizontal and vertical FC ($p < 0.001$). Final foot placement was significantly further from the tread edge for away10 and away30 in comparison to plain and abutting ($p \leq 0.025$). Horizontal and vertical foot clearances for away30 were significantly closer to the tread edge than plain, abutting or away10 ($p < 0.001$). However, the percentage of the total number of trials that resulted in a heel scuff or where horizontal FC fell below 5 mm was minimal (2%, see Supplementary material, Table S2).

4. Discussion

The results indicate that the presence of a tread edge highlighter can significantly influence foot placement and FC during stair descent, and importantly that the location of the highlighter relative to the edge of the tread impacts upon the risk of tripping in older adults with habitual visual correction and more so in adults with a simulated cataract. Findings suggest that having a high-contrast tread edge highlighter present on steps and stairs and positioned flush with the edge of the tread should improve stairs safety in older people.

All stepping characteristics in experiment 1 (habitual vision) were unaffected by the presence of an edge highlighter that was placed flush with the leading edge of the tread in comparison to when there was no highlighter present, a finding that is consistent with previous research (Simoneau et al., 1991; Zietz et al., 2011). The older adults who took part in the present study had very good binocular visual acuity (0.10 to −0.18 logMAR; Snellen 6/4 to 6/7.5) suggesting that they would have been able to delineate the edge of the treads when there was no edge highlighter present.

Table 4
The percentage of trials in experiments 1 and 2 where the heel caught the stair tread edge or riser, and horizontal foot clearance was less than 5 mm.

	Heel scuff	
	Experiment 1 (%)	Experiment 2 (%)
Plain	0	15
Abutting	0	3
Away10	0	5
Away30	2	10
	Horizontal foot clearance <5 mm	
	Experiment 1 (%)	Experiment 2 (%)
Plain	8	8
Abutting	2	0
Away10	2	3
Away30	17	10

The middle and top stair edge are both included in the analysis.

For young adults with simulated cataract, within-subject variability for both final foot placement and horizontal FC over the top step was increased when there was no edge highlighter present compared to when a highlighter was present (regardless of its positioning). The increase in within-subject variability, coupled with an increase in the time it took participants to negotiate the stairs, suggests that there was uncertainty in determining the exact location of the top/first step edge when there was no edge highlighter present. Moreover the increased percentage of trials in which participants caught the heel (scuffed) on the edge of the tread/riser (15% of trials) or the horizontal FC fell below 5 mm (8%), indicates that there was also an increased fall risk when no highlighter was present (though no actual falls resulted). These results are comparable with previous research which found that minimum FC within-subject variability increased when older adults were uncertain about the location of the tread edge under poor lighting conditions (Hamel et al., 2005).

For older adults with habitual visual correction (experiment 1) final foot placement, middle step foot placement, horizontal FC and vertical FC were significantly reduced when the highlighter was set back from the leading edge of the treads by 30 mm (away30) in comparison to a plain tread, or when the edge highlighter was placed abutting the leading edge. Final and middle step foot placements were also significantly reduced (further from the tread edge) when the highlighter was set back by 10 mm (away10) compared to plain and abutting. Notably, horizontal FC fell below 5 mm for 17% of trials when presented with the away30 highlighter, suggesting that there was also a greater fall risk associated with negotiating a step when the definition of the edge of the tread was misleading or disrupted. When the older participants negotiated the single surface level change (see Supplemental material, Table S1), foot placement and FC parameters altered in a similar manner to that seen on the stairs for each highlighter condition, which suggests that the presence and position of tread edge highlighters are as important to safety when negotiating a single surface level change, such as door steps or kerbs, as they are for safety on stairs. However, the magnitude of both parameters was much greater than on the stairs and posed less risk to the participants catching their heel on the edge of the tread, as evidenced by the low percentage of heel scuffs and horizontal FCs which fell below 5 mm (see Supplemental material, Table S2).

The positioning of the tread edge highlighter relative to the edge of the step was also seen to alter participant stepping characteristics in young participants with simulated cataract (experiment 2). Horizontal FC over the top step was significantly reduced when the highlighter was 30 mm set back (away30, 38 ± 18 mm) compared to abutting (58 ± 17 mm), a reduction of 20 mm. This would have put participants at an increased risk of catching the heel on the edge of the tread, and this is emphasised by the high percentage of trials where scuffs occurred (10%) or where horizontal FC fell below 5 mm (10%) for the away30 highlighter. These findings replicate similar patterns to those evidenced in older adults under habitual vision conditions (experiment 1), suggesting that the presence and positioning of an edge highlighter are important factors to consider for stair design and improving safety on stairs.

Previous studies have reported that foot placement and FC when crossing obstacles or descending a kerb is determined/planned using visual information acquired during the approach to an obstacle or kerb edge (Buckley et al., 2011; Patla and Vickers, 1997; Timmis and Buckley, 2012). The results from the present study indicate that the visual information provided on the tread (highlighter condition) also determines foot placement and FC during the approach to the stair. As the gap between the leading edge of the step and the highlighter's leading edge increased, final foot placement was placed further from the edge of the tread. The results suggest that when presented with a highlighter set back by 10 mm (away10), final foot placement was reduced by a similar extent to the change in highlighter location (i.e. ~10 mm, Table 4). However, when presented with a highlighter set back by 30 mm, foot placement was reduced (compared to a tread with no highlighter) by only approximately 15–20 mm. As a consequence of foot placement being further from the edge of the tread, horizontal FC was significantly closer to it, thus reducing stair safety. It is therefore assumed that a greater distance between the highlighter and the leading edge of the tread increases the risk of a trip incident occurring on stairs or when stepping down from a kerb.

Importantly, the findings of the present study suggest that in high-risk older adults with visual disability, a high contrast edge-highlighter placed flush with the tread edge (abutting) rather than being placed back from the tread edge, could reduce the risk of a trip incident occurring. Many elderly individuals wear multifocal spectacles for activities of daily living such as gait and stair negotiation. Multifocal spectacles induce blur in the lower visual field beyond the reading distance of about 40 cm, and the accompanying impairment in contrast sensitivity and depth perception can decrease the accuracy of determining step edge position (Johnson et al., 2007, 2008; Lord et al., 2002; Timmis et al., 2010). The findings of the present study thus suggest that tread edge highlighters could also improve stair safety for such individuals.

While the risk of accidental foot contacts and number of low FCs increased when the tread edge highlighters were positioned away from the tread edge in both young and older adults, foot-overhang (when the most anterior portion of the foot is placed beyond the tread edge) on the middle step decreased. Although there are no formal reports on the amount of foot-overhang required to experience a loss of balance, slip or fall whilst descending a step or stairs, it is estimated that stair users are at an increased risk when 50%–60% of the shoe plantar surface (British Standards Institution, 2009) (i.e. phalanges and metatarsal–phalangeal joints) is over-hanging the tread edge. In the present study, the largest foot-overhang occurred in the abutting edge highlighter condition. In young and older adults overhang was on average just 17% and 2% of the shoe plantar surface respectively (based on average shoe lengths of 280 mm and 270 mm respectively), with variability margins (upper 95% confidence interval) less than 29% and 23% respectively. These results suggest that there was minimal risk associated with foot-overhang when the edge highlighter was abutting the tread edge.

The present study was limited by the number of steps ($n = 3$) on the stairs which may not be representative of all real-world stair negotiation activities. Furthermore, the small number of trials ($n = 3$) used to provide a measure of variability in experiment 1 (where no statistical differences in variability were found) may not have been sufficient and it may have been preferable to have used older participants in experiment 2 (cataract simulation). The rationale for these decisions has been provided in the earlier sections of the report. Although the highlighted limitations may be confounding factors and/or may mean the findings presented are not generalizable to the wider elderly population, we can hypothesise from these results that an edge highlighter placed flush with the tread edge of a step might reduce tripping risk and thus trip-related fall injuries on stairs. Further research, involving a large number of older adults perhaps in a real-world setting, on stairs with a greater number of steps, is required to confirm this hypothesis.

5. Conclusion

In summary, findings of the present study indicate that for older people with visual impairment for whom tread edges are difficult to see, the provision of an edge highlighter, particularly on the top step, may increase the precision of heel clearance over the tread edge and potentially reduce the number of heel scuffs and low clearances (less than 5 mm) when descending stairs. Findings also indicate that the positioning of the highlighter is also important; when the tread edge highlighter was set back from the leading edge of the step/walkway by 10–30 mm, foot clearances reduced and the number of accidental foot contacts increased. These findings suggest that having high-contrast tread edge highlighters present on steps and stairs and positioned flush with the edge of the tread or as near to this as possible should improve stairs safety in older people. Ultimately, further research is required to monitor whether less falls occur based on the recommendation of positioning an edge highlighter flush with the tread edge. However, the findings from the present study suggest that consideration of the relative positioning of step edge highlighters should be given for changing current building regulation specifications.

Conflict of interest statement

The authors have no conflicts of interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.exger.2014.04.009.

References

Archea, J., Collins, B.L., Stahl, F.I., 1979. Guidelines for stair safety: the Bureau.
British Standards Institution, 2009. Code of practice for the design of buildings and their approaches to meet the needs of disabled people. BSI (BS 8300:2009).
Buckley, J.G., Heasley, K., Scally, A., Elliott, D.B., 2005a. The effects of blurring vision on medio-lateral balance during stepping up or down to a new level in the elderly. Gait Posture 22 (2), 146–153.
Buckley, J.G., Heasley, K.J., Twigg, P., Elliott, D.B., 2005b. The effects of blurred vision on the mechanics of landing during stepping down by the elderly. Gait Posture 21 (1), 65–71.
Buckley, J.G., MacLellan, M.J., Tucker, M.W., Scally, A.J., Bennett, S.J., 2008. Visual guidance of landing behaviour when stepping down to a new level. Exp. Brain Res. 184 (2), 223–232.
Buckley, J.G., Timmis, M.A., Scally, A.J., Elliott, D.B., 2011. When is visual information used to control locomotion when descending a kerb? PLoS One 6 (4), e19079.
Buckley, J.G., Cooper, G., Maganaris, C.N., Reeves, N.D., 2013. Is stair descent in the elderly associated with periods of high centre of mass downward accelerations? Exp. Gerontol. 48, 283–289.
Chapman, G.J., Vale, A., Buckley, J., Scally, A.J., Elliott, D.B., 2010. Adaptive gait changes in long-term wearers of contact lens monovision correction. Ophthalmic Physiol. Opt. 30 (3), 281–288.
Cohen, H.H., Templer, J., Archea, J., 1985. An analysis of occupational stair accident patterns. J. Saf. Res. 16 (4), 171–181.
Department of Trade and Industry, 2002. Home and leisure accident surveillance system: 24th report. Department of Trade and Industry.
Elliott, D.B., Bullimore, M.A., Patla, A.E., Whitaker, D., 1996. Effect of a cataract simulation on clinical and real world vision. Br. J. Ophthalmol. 80 (9), 799–804.
Elliott, D.B., Trukolo-Ilic, M., Strong, J.G., Pace, R., Plotkin, A., Bevers, P., 1997. Demographic characteristics of the vision-disabled elderly. Invest. Ophthalmol. Vis. Sci. 38 (12), 2566–2575.

Foster, R.J., De Asha, A.R., Reeves, N.D., Maganaris, C.N., Buckley, J.G., 2014. Stair-specific algorithms for identification of touch-down and foot-off when descending or ascending a non-instrumented staircase. Gait Posture 39, 816–821.

Gallagher, E., Scott, V., 1997. The STEPS Project: participatory action research to reduce falls in public places among seniors and persons with disabilities. Can. J. Public Health 88 (2), 129.

Graci, V., Elliott, D.B., Buckley, J.G., 2009. Peripheral visual cues affect minimum-foot-clearance during overground locomotion. Gait Posture 30 (3), 370–374.

Gutierrez, E.M., Bartonek, Å., Haglund-Åkerlind, Y., Saraste, H., 2003. Centre of mass motion during gait in persons with myelomeningocele. Gait Posture 18 (2), 37–46.

Hamel, K.A., Okita, N., Higginson, J.S., Cavanagh, P.R., 2005. Foot clearance during stair descent: effects of age and illumination. Gait Posture 21 (2), 135–140.

Heasley, K., Buckley, J.G., Scally, A., Twigg, P., Elliott, D.B., 2004. Stepping up to a new level: effects of blurring vision in the elderly. Invest. Ophthalmol. Vis. Sci. 45 (7), 2122–2128.

Heasley, K., Buckley, J.G., Scally, A., Twigg, P., Elliott, D.B., 2005. Falls in older people: effects of age and blurring vision on the dynamics of stepping. Invest. Ophthalmol. Vis. Sci. 46 (10), 3584–3588.

Hill, L., Haslam, R., Howarth, P.A., Brooke-Wavell, K.S., Sloane, J.E., 2000. Safety of older people on stairs: behavioural factors.

Jackson, P.L., Cohen, H.H., 1995. An in-depth investigation of 40 stairway accidents and the stair safety literature. J. Saf. Res. 26 (3), 151–159.

Johnson, L., Buckley, J.G., Scally, A.J., Elliott, D.B., 2007. Multifocal spectacles increase variability in toe clearance and risk of tripping in the elderly. Invest. Ophthalmol. Vis. Sci. 48 (4), 1466–1471.

Johnson, L., Buckley, J.G., Harley, C., Elliott, D.B., 2008. Use of single-vision eyeglasses improves stepping precision and safety when elderly habitual multifocal wearers negotiate a raised surface. J. Am. Geriatr. Soc. 56 (1), 178–180.

Klaver, C.C., Wolfs, R.C., Vingerling, J.R., Hofman, A., de Jong, P.T., 1998. Age-specific prevalence and causes of blindness and visual impairment in an older population: the Rotterdam Study. Arch. Ophthalmol. 116 (5), 653.

Leat, S.J., Legge, G.E., Bullimore, M.A., 1999. What is low vision? A re-evaluation of definitions. Optom. Vis. Sci. 76 (4), 198–211.

Lee, H.-J., Chou, L.-S., 2007. Balance control during stair negotiation in older adults. J. Biomech. 40 (11), 2530–2536.

Lord, S.R., Dayhew, J., Howland, A., 2002. Multifocal glasses impair edge-contrast sensitivity and depth perception and increase the risk of falls in older people. J. Am. Geriatr. Soc. 50 (11), 1760–1766.

Patla, A.E., Vickers, J.N., 1997. Where and when do we look as we approach and step over an obstacle in the travel path? Neuroreport 8 (17), 3661–3665.

Perneger, T.V., 1998. What's wrong with Bonferroni adjustments. BMJ 316 (7139), 1236.

Roys, M.S., 2001. Serious stair injuries can be prevented by improved stair design. Appl. Ergon. 32 (2), 135–139.

Simoneau, G.G., Cavanagh, P.R., Ulbrecht, J.S., Leibowitz, H.W., Tyrrell, R.A., 1991. The influence of visual factors on fall-related kinematic variables during stair descent by older women. J. Gerontol. 46 (6), M188–M195.

Startzell, J.K., Owens, D.A., Mulfinger, L.M., Cavanagh, P.R., 2000. Stair negotiation in older people: a review. J. Am. Geriatr. Soc. 48 (5), 567–580.

Templer, J., 1992. The staircase—studies of hazards, falls, and safer design. MIT Press, Cambridge.

Timmis, M.A., Buckley, J.G., 2012. Obstacle crossing during locomotion: visual exproprioceptive information is used in an online mode to update foot placement before the obstacle but not swing trajectory over it. Gait Posture 36 (1), 160–162.

Timmis, M.A., Johnson, L., Elliott, D.B., Buckley, J.G., 2010. Use of single-vision distance spectacles improves landing control during step descent in well-adapted multifocal lens-wearers. Invest. Ophthalmol. Vis. Sci. 51 (8), 3903–3908.

Tinetti, M.E., Speechley, M., Ginter, S.F., 1988. Risk factors for falls among elderly persons living in the community. N. Engl. J. Med. 319 (26), 1701–1707.

U.S Architectural and Transportation Barriers Compliance Board, 2002. Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities (Washington, DC).

Zietz, D., Johannsen, L., Hollands, M., 2011. Stepping characteristics and centre of mass control during stair descent: effects of age, fall risk and visual factors. Gait Posture 34 (2), 279–284.