Recognition of Ramps and Steps by People with Low Vision

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PURPOSE. Detection and recognition of ramps and steps are important for the safe mobility of people with low vision. Our primary goal was to assess the impact of viewing conditions and environmental factors on the recognition of these targets by people with low vision. A secondary goal was to determine if results from our previous studies of normally sighted subjects, wearing acuity-reducing goggles, would generalize to low vision.

METHODS. Sixteen subjects with heterogeneous forms of low vision participated—acuities from approximately 20/200 to 20/2000. They viewed a sidewalk interrupted by one of five targets: a single step up or down, a ramp up or down, or a flat continuation of the sidewalk. Subjects reported which of the five targets was shown, and percent correct was computed. The effects of viewing distance, target–background contrast, lighting arrangement, and subject locomotion were investigated. Performance was compared with a group of normally sighted subjects who viewed the targets through acuity-reducing goggles.

RESULTS. Recognition performance was significantly better at shorter distances and after locomotion (compared with purely stationary viewing). The effects of lighting arrangement and target–background contrast were weaker than hypothesized. Visibility of the targets varied, with the step up being more visible than the step down.

CONCLUSIONS. The empirical results provide insight into factors affecting the visibility of ramps and steps for people with low vision. The effects of distance, target type, and locomotion were qualitatively similar for low vision and normal vision with artificial acuity reduction. However, the effects of lighting arrangement and background contrast were only significant for subjects with normal vision. (*Invest Ophthalmol Vis Sci.* 2013; 54:288–294) DOI:10.1167/iovs.12-10461

Low vision is any visual impairment not correctable with glasses or contacts that affects everyday functioning. As of 2004, there were about 3.3 million Americans over the age of 40 years with impaired vision, with the number expected to increase to 5.7 million by 2020.[1] More than 90% of these individuals have functionally useful vision. Reduced mobility and associated social isolation and economic disadvantage are among the most debilitating consequences of low vision.

Visual impairment is a risk factor for both falls and fractures in the elderly.[2,3] Obstacles on the ground or discontinuities in the ground plane, such as steps, pose hazards for people with low vision. Most low-vision research on obstacle detection addresses the influence of three key measures of visual function—acuity, contrast sensitivity, and visual-field status—on avoiding contact with obstacles while moving through a cluttered space. Typically, results have shown that acuity level is not very important for navigating through a cluttered space, while contrast sensitivity is somewhat important, and the total extent of the visual field is of major importance.[4-6] However, safety depends critically on the ability to reliably identify potential hazards from a distance, placing greater reliance on acuity.[7] An interesting example is the detection of crossable gaps in traffic at intersections.[8,9]

Recognizing ground-plane irregularities, such as steps and ramps, is an important component of the visual accessibility of public spaces for people with low vision. Visual accessibility is the use of vision to travel efficiently and safely through an environment, to perceive the spatial layout of the environment, and to keep track of one's location and orientation. Many people with severe visual impairment deal effectively with obstacle avoidance using a white cane or guide dog. But the vast majority of people with milder forms of low vision rely on their residual vision. Orientation and mobility specialists have often noted the preference of people to rely on vision, sometimes to their detriment.[7]

Our previous work on subjects with normal vision wearing blur goggles to artificially reduce acuity has addressed the impact on visual accessibility of environmental factors likely to be important in real-world settings. These factors include target–background contrast and lighting arrangements, and also viewing conditions such as distance to target.[10,11] A major aim of the present study was to determine if these results generalize to people with low vision. A long-term goal of our research on visual accessibility is to provide a principled basis for guiding the design of safe environments for the mobility of people with low vision.

Legge and colleagues[10] investigated the effects of lighting arrangement, target geometry, and target–background contrast on the recognition of ramps and steps by subjects with normal vision wearing blur goggles that reduced acuity to 20/135 (mild blur) and 20/900 (severe blur). Subjects were tested in a windowless classroom (Fig. 1) on five targets: a step up, a step down, a ramp up, a ramp down, and a flat continuation of the sidewalk. Stationary subjects made target-recognition decisions from viewing distances ranging from 5 to 20 ft. Among the results of this study, they showed that a step up was more visible with blurry vision than a step down. The effects of target–background contrast were greater than the effects of lighting arrangement. Performance was similar at 5 and 10 ft, but accuracy decreased at 20 ft.

In a subsequent study using similar methods, Bochsler et al.[11] asked whether two additional visual factors—surface texture and self-locomotion—would enhance the recognition
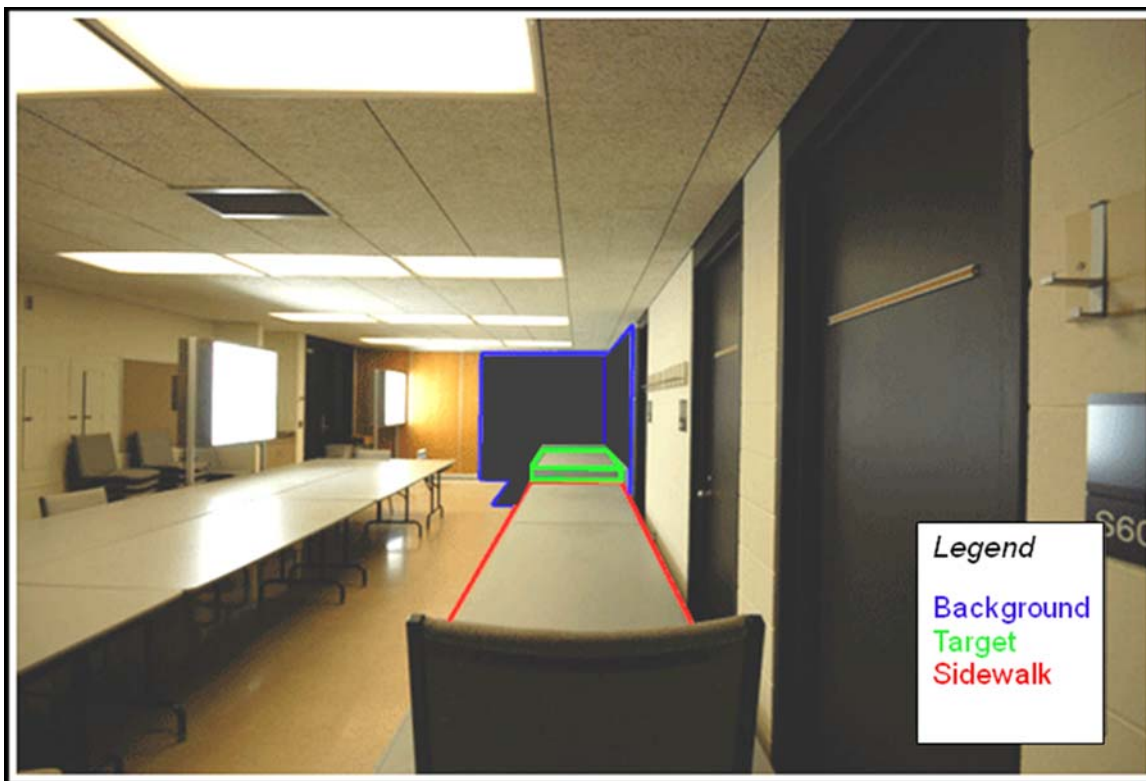
FIGURE 1. Photo of test space showing the black background, gray sidewalk, step up target, and three lighting conditions. Reprinted with permission from Legge GE, Yu D, Kallie CS, Bochsler TM, Gage R. Visual accessibility of ramps and steps. *J Vis.* 2010;10:1–19. Copyright 2010 ARVO.

of ramps and steps under low-acuity viewing. Contrary to expectation, a coarse texture pattern on the ground plane detracted from performance. As hypothesized, locomotion toward a step or ramp improved recognition compared with stationary viewing.

In the present study, we addressed two questions. First, how do these same factors affect the recognition of ramps and steps by people with low vision? Second, do results obtained with normally sighted subjects with artificial acuity reduction

generalize to low vision, thereby providing a useful surrogate for studying visual accessibility?

METHODS

Participants

Sixteen subjects (mean age = 49.19 years) with heterogeneous forms of low vision participated (see Table). All 16 participated in experiments

TABLE. Characteristics of 16 Visually Impaired Subjects

Subject	Sex	Age, y	Acuity (LogMAR Snellen)	Log Contrast Sensitivity	Field Loss	Diagnosis
a	M	50	1.28, 20/381	0.75	None	Congenital cataracts
b	F	61	1.54, 20/693	0.05	Peripheral	Optic neuritis, optic atrophy
c	M	42	1.46, 20/577	0.4	Peripheral	Glaucoma
d*	F	34	1.04, 20/219	0.8	None	Albinism
e	M	52	1.68, 20/957	0†	Peripheral	Optic nerve atrophy
f*	M	58	1.1, 20/252	1.65	Central	Stargardt disease
g	F	60	1.54, 20/693	0.15	Peripheral	Optic nerve atrophy
h*	F	32	1.2, 20/317	0.5	Peripheral	Retinopathy of prematurity
i	M	45	1.5, 20/632	0.25	Peripheral	Retinopathy of prematurity
j	M	63	2.18, 20/3000	0†	None	Secondary corneal scarring
k	F	19	1.70, 20/1000	0†	Central/Peripheral	Corneal failure
l	M	39	1.86, 20/1450	0.35	Peripheral	Glaucoma, cataracts
m	F	66	1.44, 20/551	0.15	Peripheral	Retinitis pigmentosa
n	F	64	1.18, 20/303	0.5	Central	Stargardt disease
o	M	50	1.04, 20/219	1	None	Sorsby disease
p	M	52	0.98, 20/191	1.05	Central	Fuch's dystrophy
	Mean	49.19	1.42, 20/526	0.58		

* Subject participated in experiments 1 and 2 only.
† At the testing distance of 1 m, these subjects were unable to read any letters on the Pelli-Robson chart.
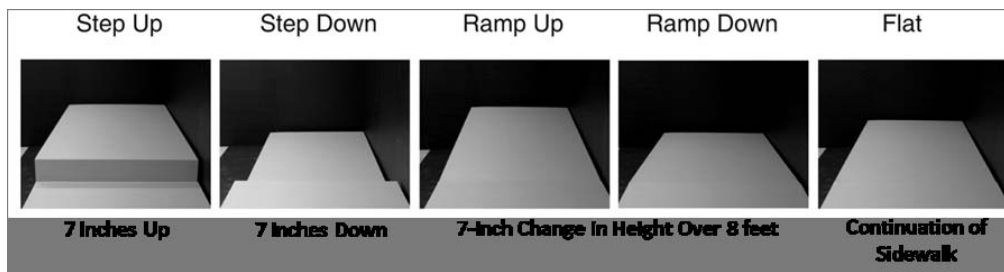
FIGURE 2. The five targets were step up, step down, ramp up, ramp down, and a flat continuation of the sidewalk. Reprinted with permission from Legge GE, Yu D, Kallie CS, Bochsler TM, Gage R. Visual accessibility of ramps and steps. *J Vis.* 2010;10:1–19. Copyright 2010 ARVO.

1 and 2, but only 13 in experiment 3. Selection criteria included subjects with moderate to severe low vision (logMAR acuity of approximately 1.0 or worse) to ensure that performance would not be at ceiling, and subjects who were expected to be nimble enough to step up onto our elevated sidewalk (16-inch step) and undertake the walking in our locomotion experiment; this concern led us to limit the age range of subjects to those in their 60s or younger. We note that our subject sample, while not representative of the overall population of people with low vision, does have the roughly inverse linear relationship between logMAR acuity and log contrast sensitivity typical of other samples of low-vision research subjects.[12] Each subject completed the experiment in one session lasting from 3 to 4 hours or in two sessions of about 2 hours each. The experimenter obtained informed consent in accordance with procedures approved by the University of Minnesota's institutional review board.

The comparison group, from Legge et al., included 48 normally sighted young adults with a mean age of 22 years (see table 2 in Legge et al.[10] for further details). These subjects wore blurring goggles, made from Bangerder occlusion foils, which reduced effective acuity to 20/135 (mild blur) or 20/900 (severe blur).

Stimuli

A large, windowless, 33.25 by 18.58 ft (10.13 by 5.66 m) basement classroom was used as the test space for all experiments (Fig. 1). A uniform gray sidewalk (4 ft wide by 24.5 ft long; 1.3 m by 7.5 m) was constructed using hardboard deck portable stage risers. This sidewalk was elevated 16 inches (0.4 m) above the floor. Five possible targets were shown at a fixed location on the sidewalk's south end: a single step up or down (7-inch height), a ramp up or down (7-inch change of height over 8 ft), or flat (see Fig. 2).

A 4 by 8 ft, 2-inch-thick rectangular panel of expanded polystyrene (EPS), painted uniform gray, formed the target (see Fig. 1). Using motorized scissor jacks, the target panel was adjusted by raising or lowering one or both ends of the panel above or below the sidewalk. The visual background for the targets was formed by the classroom floor, far wall, and right-hand wall. The walls were paneled with rectangular sections of EPS, and the section of floor on the left of the target was covered with a wooden panel (painted to match the background). Overhead lighting, representative of typical ambient room lighting, was produced by four rows of three 2 by 4 ft luminaries. For more information about the test space and apparatus, please see Legge et al.[10]

Task and Procedure

Subjects participated in three experiments assessing the effects of target/background contrast and viewing distance (experiment 1), lighting arrangement (experiment 2), and locomotion (experiment 3). Prior to testing, the subjects were familiarized with the targets; they inspected the targets close up and were encouraged to feel the contours of the junction between target and sidewalk. During testing, subjects viewed the targets from three distances of 5, 10, and 20 ft.

During each trial, the subject reported which of the five targets was shown (five-alternative forced choice). Responses were used to calculate percent correct and to compose confusion matrices.

Subjects were instructed to turn their head to face the right-hand wall between trials, preventing them from viewing target setup. They were given a viewing time of 4 seconds. This time period was selected to provide subjects with sufficient time to turn to look at the target, but not excessive time for prolonged inspection. To mask auditory cues associated with changing the target configuration, subjects wore noise-reducing earmuffs and listened to auditory white noise.

In experiment 1, subjects viewed the gray targets against a gray (contrast = 0.25) or black (contrast = 0.82) background with standard overhead room lighting. It was hypothesized that subjects would have better recognition performance in the higher-contrast condition. For each of the contrast conditions, subjects viewed the targets from three distances (5, 10, and 20 ft), completing four trials per target (five targets) for a total of 60 trials. Trials were blocked by viewing distance. Based on the results of Legge et al.,[10] we hypothesized that the low-vision subjects in the present study would perform better at the shorter distances of 5 and 10 ft than at 20 ft and better with the high-contrast black background than the lower-contrast gray background.

In experiment 2, there were two different lighting arrangements (Fig. 1). A light box simulated a window to the near left (near window) or far left (far window) of the subject. Subjects completed 40 trials (2 windows × 5 targets × 4 trials per target) at a distance of 10 ft. Within each window lighting condition (near and far), the trials for the different targets were randomized. Performance for the two window lighting conditions was compared with the corresponding data for overhead lighting in experiment 1. Legge et al.[10] found that subjects with artificial acuity reduction performed better in the far-window condition, probably because this window condition enhanced contrast that highlighted the borders of the target panel. Accordingly, we hypothesized that low-vision subjects in the present study would perform better with far-window than near-window lighting.

In experiment 3, recognition performance for a stationary condition and a walking condition were compared. In the stationary condition, subjects made their recognition decisions while standing 10 ft from the target. In the walking condition, subjects started at 20 ft. They walked toward the targets along the sidewalk, stopping at the designated viewing distance of 10 ft to make their recognition decisions. Weight-bearing railings were added to both sides of the sidewalk to enhance safety and to guide the subjects. The goal of this experiment was to determine if locomotion facilitated the recognition of ramps and steps. Walking and stationary trials were randomly interleaved, with four trials per target in each condition, for a total of 40 trials. Bochsler et al.[11] used the same paradigm to measure the influence of locomotion on the performance of normal subjects with acuity-reducing goggles. They addressed the difference in time per trial for walking and stationary trials and concluded that it was unlikely to influence the results.
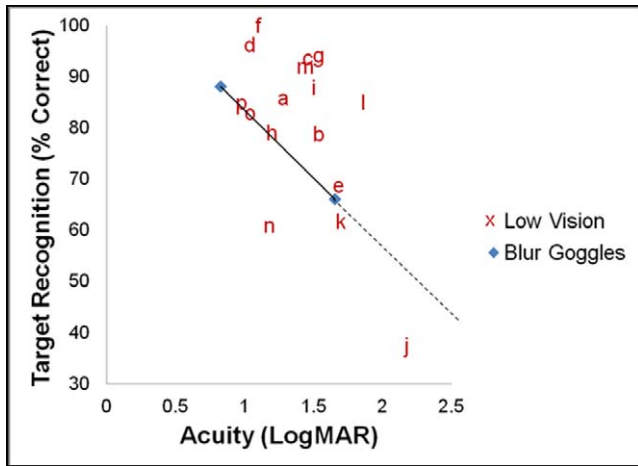
Figure 3. Relationship between acuity and target recognition performance. Low-vision data are compared with data from normally sighted subjects wearing acuity-reducing goggles. Letter symbols for the low-vision subjects correspond to the entries in the Table. The dashed line represents extrapolation of the straight-line fit to the data for the normally sighted subjects.

Results

Experiment 1: Effects of Visual Acuity, Background Contrast, and Target Type

Figure 3 shows the overall recognition accuracy for the sixteen low-vision subjects in experiment 1. The values are based on data combined across distance and background conditions and are plotted as a function of acuity. The individual letter symbols correspond to the subject designators in the Table. For comparison, mean performance levels for normally sighted subjects wearing acuity-reducing goggles for the same conditions are replotted as blue symbols (from Legge et al.[10]). As expected, low-vision performance tended to decrease with lower acuity (larger logMAR values). Most of the low-vision data points lie above the line depicting the performance of the goggle-wearing normal subjects. A t-test on the difference scores between the low-vision points (red) and the blur-goggles line showed that low-vision subjects significantly outperformed estimated levels of the normally sighted goggle
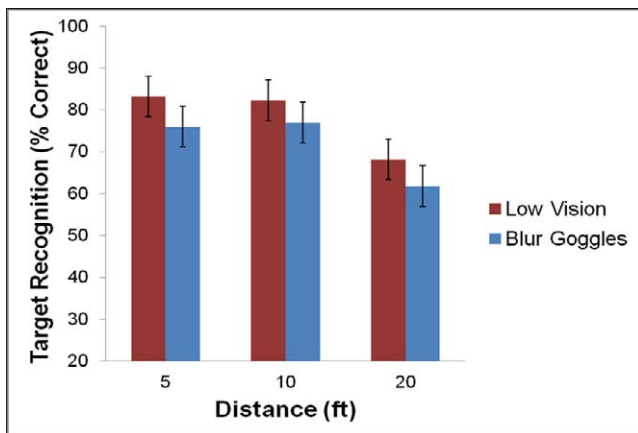

Figure 4. Mean performance at three distances (5, 10, and 20 ft). Low-vision data are compared with data from normally sighted subjects wearing acuity-reducing goggles (combined across blur conditions). Goggle data are replotted from Legge et al.[10] Error bars represent ±1 SE.

Figure 5. Confusion matrices showing the percentage of responses for each of the five target types. Diagonal values represent correct recognition performance and off-diagonal values represent confusions. (A) Values for subjects with normal vision wearing blur goggles (table 3 from Legge et al.[10]) and are based on 18 trials per target across 48 subjects (864 trials per target). (B) Values for the low vision subjects in this study, based on 14 trials per target across 16 subjects (224 trials per target).

wearers, $P < 0.05$. Subjects j and n were exceptions to the general finding that low-vision subjects outperformed the subjects with normal vision. J's acuity lay outside the range of the goggle measurements. After j and n were removed from the analysis, low-vision observers significantly outperformed subjects with normal vision wearing goggles by an even greater margin.

We conducted a repeated-measures analysis of variance (ANOVA) on the arcsine-transformed accuracy data, with three within-subjects factors—viewing distance (5, 10, or 20 ft), target type (step up, step down, ramp up, ramp down, and flat), and target–background contrast (low or high). The analysis revealed significant main effects of viewing distance ($F_{1,15} = 8.36$, $P < 0.01$) and target type ($F_{1,15} = 19.96$, $P < 0.0001$), but not target–background contrast. There was no interaction between viewing distance and target type. T-tests, with a Bonferroni correction for multiple comparisons, were used in post hoc testing.

Figure 4 shows that both low-vision subjects and those with normal vision wearing blur goggles performed better at the shorter distances (5 and 10 ft) than the longest distance (20 ft; $P < 0.01$). Both normal and low-vision subjects showed no significant difference in performance between 5 and 10 ft.

Figure 5 shows confusion matrices for subjects with normal vision wearing blur goggles (top matrix) and for the low-vision subjects in this study (bottom matrix). The pattern of results is similar in the two matrices. The diagonals of the matrices, shown in bold, represent correct responses. The order of target performance, from best to worst, was the same for the low-vision group and those wearing the blur goggles: step up, step down, ramp up, flat, and ramp down (Pearson correlation of 0.88 for the on-diagonal elements). A step up was more recognizable than a step down for both groups ($P < 0.01$), perhaps because of the high contrast between the top of the step and the riser. See table 1 in Legge et al.[10] for detailed contrast measurements on all five targets.
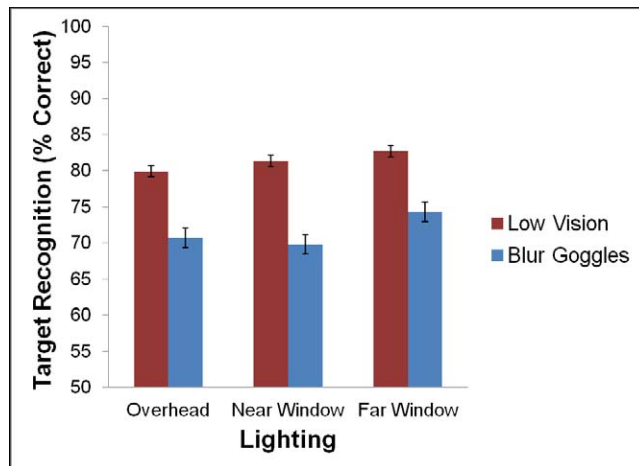
FIGURE 6.   Performance for the three lighting arrangements (overhead, near window, and far window). Low-vision data are compared with data from normally sighted subjects wearing acuity-reducing goggles (combined across blur conditions). Goggle data are replotted from Legge et al.[10] Error bars represent ±1 SE.
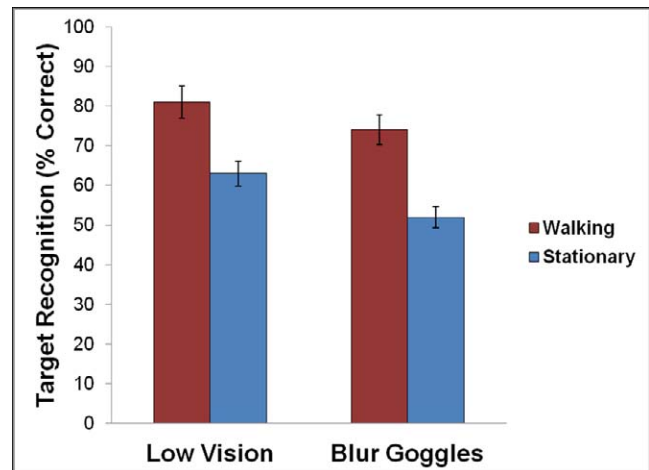

FIGURE 7.   Performance in walking and stationary trials. Subjects with low vision are compared to those with normal vision wearing blur goggles in Bochsler et al.[11] Error bars represent ±1 SE.

Similarities exist between the off-diagonal cells of the matrices as well. For both low-vision (LV) and goggle-wearing normal vision (NV) groups, the highest percentage of off-diagonal cells occurred when the subject viewed the ramp down target and confused it for flat (NV = 22.6%, LV = 17.6%), or viewed the ramp up target and confused it for flat (NV = 22.7%, LV = 13.8%). The most evident departure in the pattern of responses between normal and low vision occurred for the step down target; normally sighted subjects often responded with flat when presented with step down (13.2%), while subjects with low vision only did so rarely (2.4%).

Experiment 2: Effect of Lighting Arrangement

We conducted a repeated-measures ANOVA on the arcsine transformed accuracy data, with lighting condition (overhead, near window, or far window) as the within-subjects factor (Fig. 6). Like the subjects with normal vision wearing blur goggles, subjects with low vision performed better with far-window lighting than with overhead or near-window lighting. However, this difference was only significant for the subjects with normal vision wearing blur goggles ($P < 0.05$).

Experiment 3: Effect of Locomotion

A paired samples t-test comparing performance in walking and stationary conditions showed that low-vision subjects recognized ramps and steps significantly more accurately in locomotion trials (81% correct) than in stationary trials (68% correct), $P < 0.01$ (Fig. 7). Similarly, goggle-wearing subjects with normal vision performed better after walking (74%) than in the stationary condition (52%).[11]

The order of target performance from best to worst was similar for the stationary and walking conditions (Fig. 8). In both conditions, low-vision and normally sighted subjects performed best on the same three targets, in the following order: step up, step down, ramp up. In the description of results for experiment 1, we pointed out that the difference in visibility for the five targets showed this same ordering for the low-vision subjects and the goggle-wearing normal subjects (diagonals of Figs. 5A and 5B).

In summary, locomotion and viewing distance strongly influence performance, while background contrast and lighting

arrangement have weaker effects. Subjects with low vision outperformed subjects with normal vision wearing blur goggles.

DISCUSSION AND CONCLUSIONS

In this study, low-vision subjects outperformed normally sighted subjects who wore acuity-reducing goggles. People with low vision may recognize objects better because they have more experience functioning visually under low-resolution conditions. But we cannot exclude the possibility that the poorer performance of the normal subjects is related to the optical properties of the goggles.

Experiment 1 revealed that performance declined with increasing viewing distance and acuity, as hypothesized. In Legge et al.,[10] we pointed out that some of the cues useful for recognizing ramps and steps (such as the L-junction in the edge contour of step down) are likely to place demands on acuity and would exhibit the dependencies on distance and acuity we observed (see Legge et al.[10] for a more detailed description of cues).

Surprisingly, target–background contrast did not significantly influence the performance of these low-vision subjects. Although some of the subjects had very low contrast sensitivity (Table), most of them may have had sufficient contrast sensitivity to detect the targets, even in the low-contrast condition. Another study from our lab, Kallie et al.,[13] tested recognition performance with blurry vision for other high-visibility targets (cylinders and boxes). Consistent with the present study, the higher-contrast target under most conditions (cylinder) was more salient with low-acuity vision than the lower contrast target (box).

The effect of lighting arrangement was weaker than expected. Experiment 2 showed that subjects with low vision performed best with far-window lighting, but this effect was only significant for normally sighted subjects wearing blur goggles. Perhaps this null result is due to the narrow range of lighting conditions tested here, compared to the wide variety present in the real world. Consistent with the present study, Kallie et al.[13] found no effect of lighting arrangement on convex object detection.

In experiment 3, we learned that locomotion through an environment may enhance the visibility of obstacles for people with low vision. In particular, walking provided a strong advantage for step down, the most dangerous target to miss!
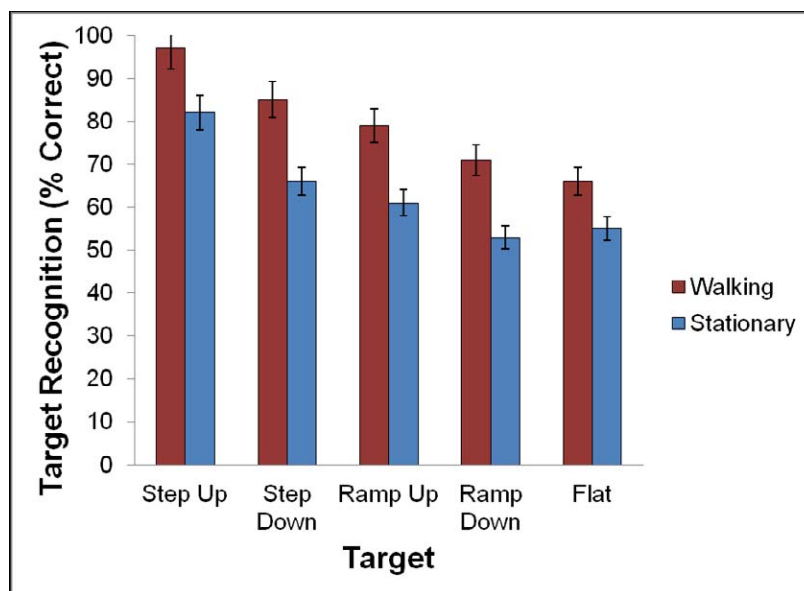
Figure 8. Target performance in walking trials compared to stationary trials. Error bars represent ±1 SE.

Eighty-five percent of low-vision subjects successfully identified step down after walking, while only 66% did so with stationary viewing.

Why does locomotion enhance recognition of steps and ramps for people with low vision? Three possible cues from motion include motion parallax, accretion and deletion of surface features, and enhanced retinal image motion. Motion parallax is known to improve depth discrimination in low vision and for normal vision under conditions of blur or low contrast.[14] Accretion and deletion of surface features as the viewpoint changes between a nearer surface and a more distant partially overlapping surface may also provide useful information.[15] Locomotion may produce greater retinal image motion of informative image contours, enhancing their visibility. This might be especially significant for people with very low acuity because it is well known that contrast sensitivity for patterns composed of low spatial frequencies is enhanced by abrupt temporal onsets or offsets.[16] See Bochsler et al.[11] for a more detailed description of motion cues.

The qualitative effects of viewing distance, target type, and locomotion were similar for the low-vision subjects and subjects with normal vision wearing blur goggles. Although low-vision subjects did not exhibit the significant effects of target–background contrast and lighting arrangement found with the normally sighted subjects, these effects were relatively weak for both groups. Together, these findings suggest that subjects with normal vision wearing blur goggles can provide a convenient test bed for studying visual accessibility. However, caution should be exercised in generalizing results from goggle-wearers to low vision, and ideally, goggle studies should be replicated with low-vision subjects.

While we expect the qualitative features of our results to generalize beyond our specific sample of subjects and testing conditions, we mention two caveats. First, our sample of low-vision subjects was unrepresentative in focusing on moderate and severe low vision, and on subjects in their 60s or younger. A broader sampling of low-vision subjects might conceivably yield some differences in performance. Second, our subjects knew that one of the five targets was present in each trial and where to look for it. In a more natural context, low-vision pedestrians traveling in unfamiliar locations do not necessarily know when and where obstacles will appear in their path. Such uncertainties pose challenges for mobility not present in our study.

Even so, these results provide evidence that people with low vision may perform better on obstacle recognition tasks when actively walking through an environment, rather than passively viewing obstacles from a sitting or standing position. Researchers in visual accessibility may want to design active tasks for low-vision subjects for the most ecologically relevant results. We suspect that orientation and mobility instructors who work with low-vision clients already incorporate visual-cue selection during active mobility into their training protocols.

Acknowledgments

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