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Traffic Gap Detection for Pedestrians with Low Vision

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Abstract

Purpose—Pedestrians with low vision have identified crossing the street as a difficult task. With the increasing complexity of the crossing environment (actuated signals, roundabouts), the challenges are increasing. The purpose of this study was to evaluate the effect of two types of vision loss (central or peripheral) on the ability to detect gaps in traffic.

Methods—41 subjects participated with 14 being fully sighted, 10 having central vision loss from age-related macular degeneration (AMD), and 17 having peripheral vision loss from either retinitis pigmentosa (RP) or glaucoma (GL). Standing at entry and exit lanes of a roundabout, subjects depressed a hand held trigger to indicate when there was a sufficient gap in traffic to cross the street. A total of 12 two minute intervals were completed including four of those intervals with occluded hearing.

Results—No difference was found in the ability of the three subject groups to identify crossable or short gaps. There were significant differences in latency and safety margin. The AMD subjects did not perform as well as the fully sighted or the subjects with RP/GL. When hearing was occluded the two vision loss groups did not show a change in sensitivity but the fully sighted group did, being more sensitive when hearing was occluded.

Conclusions—The purpose of this study was to evaluate the effect of low vision on the ability to detect crossable gaps in traffic. The findings suggest that subjects with AMD have an increased risk because they show significant latency in their identification of gaps and this in turn results in a reduction of safety margin.

Keywords

orientation and mobility; low vision; pedestrian; street crossing; gap detection; time to contact

Crossing the street has been identified as a difficult task for people with low vision.[1] Obviously, one of the reasons for this is the loss of vision. Another reason is the increasing complexity of the streetscape and the demands that have been placed on pedestrians for making crossing decisions.[2] For example, intersections with traffic controls may have actuated pedestrian signals that prescribe the time for pedestrians to cross but also require the pedestrian to locate a pushbutton to activate the pedestrian signal. The introduction of right turn on red laws has also increased the attentional demand on pedestrians.

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Increasingly since the 1990s, traffic engineers in the United States have introduced a new type of intersection known as the modern roundabout whose main feature, from the point of view of the pedestrian, is the absence of a dedicated time to cross. The modern roundabout in the United States is characterized by traffic circulating counter clockwise on a circulating roadway of one or more lanes. Entering and exiting lanes are curved so that traffic is forced to slow down when negotiating the roundabout. Entering traffic must give way to traffic already circulating in the roundabout. At large roundabouts, streets joining the roundabout are split with lanes entering and lanes exiting the circulating roadway typically separated by a splitter island (whether physical or painted). According to traffic engineers the two major advantages of the modern roundabout are the significant reduction in traffic fatalities and the increase in the number of vehicles that can travel through the intersection in a given period of time in comparison with traffic lights.[3–7] Because there is no requirement for signalization, there is also a significant cost savings.

From the point of view of the pedestrian, there is no specified time that is allocated for the pedestrian to make a safe crossing at a roundabout. When a splitter island is present a pedestrian makes the decision to cross the one or two lanes entering the roundabout then makes another crossing decision for the one or two lanes exiting the roundabout. In practical terms this is similar to crossing at a one-way street. To make a safe crossing the pedestrian must identify a gap in traffic that is of sufficient duration for crossing the street or the driver of a vehicle must yield to the pedestrian. Geruschat and Hassan[8] evaluated the yielding behavior of drivers at two roundabouts finding that overall drivers yielded only 58% of the time. Even when presented with a long cane to symbolize blindness, the yielding rate for the outbound lane of a high speed roundabout was 37%. Ashmead, Guth, Wall, Long, and Ponchillia[9] found that pedestrians who were blind had difficulty in reliably detecting and making use of driver yields at a two lane urban roundabout. And, when pedestrians who were blind did make decisions to cross, 6% of their decisions resulted in the need for an intervention to prevent a vehicle-pedestrian crash. Drivers yielded frequently on entry lanes but rarely on exit lanes. If drivers will not reliably yield, then the pedestrian must identify a crossable gap in traffic.

Gap detection with blind pedestrians has been studied at both single lane and multiple lane roundabouts.10 The findings suggest that for single lane roundabouts, pedestrians who are blind or sighted can identify crossable gaps at similar rates whereas for large two lane roundabouts, the gap detection ability of the pedestrian who is blind is quite low compared with the pedestrian who is fully sighted.11 The most likely reason is because the pedestrian who is blind, utilizing auditory cues, cannot easily discriminate moving vehicles that are staying in the roundabout from vehicles that are exiting the roundabout. Essentially, the pedestrian who is blind waits for a gap of quiet whereas the sighted pedestrian can visually detect the intentions of the driver. With the gap detection ability of the two extremes, full vision and total blindness, being established, we proposed to study the gap detection ability of pedestrians with low vision, specifically those with central or peripheral loss of visual field to determine how vision loss type results in a decay of this skill. Low vision is more common than total blindness and with an aging population the percentage of the elderly with visual impairment is expected to increase 12, [13]. The combination of increasing complexity of the crossing environment with visual impairment may create challenges for the pedestrian with low vision. Because gap detection involves peripheral visual field (finding moving vehicles) and central vision (monitoring moving vehicles) we selected two groups of subjects with differing types of visual loss. We also decided to assess gap judgments at a large two-lane roundabout with a splitter island, given that our previous studies have demonstrated differences in performance between blind and fully sighted persons at these types of locations but not at single lane/low volume roundabouts.

METHODS

Subjects

In all, 41 subjects participated in this study. Fourteen subjects (age *M*=68 *SD*=12.5) were fully sighted (FS), 10 subjects (age *M*=80 *SD*=8.3) had central loss of vision from age related macular degeneration (AMD), and 17 subjects (age *M*=56 *SD*=16.0) had peripheral loss of vision from either retinitis pigmentosa (RP) or glaucoma (GL).

Visual Function Measures

Measures of visual function were obtained on all subjects to characterize their visual status. Binocular visual acuity was tested with an ETDRS eye chart[14] transilluminated at 130 cd/m^2, and the number of letters correctly read[15] was converted to logMAR. Binocular peak contrast sensitivity was tested with the Pelli-Robson letter sensitivity test[16]. The test was administered at a viewing distance of 1 m with overhead illumination (approximately 85 cd/m^2). Contrast sensitivity was scored as the number of letters correctly read and converted to log contrast sensitivity. Visual fields were measured monocularly by kinetic perimetry with a Goldmann perimeter using the III/4e target (0.44° test spot at 320 cd/m^2) on a background luminance of 10 cd/m^2. Subjects were instructed to fixate on a central target located within the bowl of the Goldmann perimeter. The AMD subjects were encouraged to use eccentric fixation to maintain fixation during the visual field assessment.

Roundabout

Data were collected at a roundabout in the Baltimore, Maryland, metropolitan area known as the Towson Roundabout. This is an urban double-lane roundabout located in a busy shopping/business district along a commuter route. It has five legs with an oval shaped central island and a circulatory roadway with dimensions of 140 by 260 feet (42.6 by 79.2 m). Daily traffic volume, according to state traffic officials, was approximately 40,000 vehicles. Data were collected at painted crosswalks for the two-lane entry and exit lanes of York Road on the south side of the Towson roundabout. This same roundabout, but a different arterial, was used for data collection by Guth et al.[10]

Procedures

The research followed the tenets of the Declaration of Helsinki and was approved by the Johns Hopkins Medical Institutions Institutional Review Board. Written consent was obtained from all subjects prior to the initiation of data collection. The same procedures utilized in Guth et al [10] were introduced to enable comparisons across data sets. Subjects stood near the curb at the side of the street, where a pedestrian would stand if intending to cross the two lanes of the street in front of them. The subjects used a hand held push button to indicate when there was a gap of sufficient duration to make a crossing. The push button was connected to a portable computer that recorded the press/release time. Subjects were instructed to depress the push button when they believed they had enough time to cross the street prior to the next vehicle arriving at the crosswalk and to release the button when they decided they did not have enough time to cross prior to a vehicle arriving at the crosswalk. After releasing the button, they were to press it again whenever another crossing opportunity occurred. An experimenter stood about 2 m behind the participant and pressed a push button (connected to the same portable computer) whenever the front bumper of a vehicle arrived at the crosswalk, thus providing data about actual traffic gaps. Subjects were allowed to listen and look to determine whether oncoming traffic was too close or far enough away to afford them enough crossing time. Practice with the button pressing occurred at a mid-block crossing within walking distance of the Towson roundabout until the experimenter and the subject both agreed that the instructions were understood and could be implemented. To account for the effect of varying walking speeds[17], each subject crossed the street 2 times at the beginning of the experiment for the purpose of obtaining their crossing time and to give the subject the opportunity to experience the length of the crossing. Subject safety was supervised by the lead author.

The data collection consisted of 6 two-minute trials completed at the entry and exit for a total of 12 trials. The trials were counterbalanced across entry and exit. Within the 6 trials at the entry or exit lanes, 2 were randomly and sequentially selected for occluded hearing. In these 2 trials the subject wore EARsoft superfit earplugs. Tasco Golden Eagle full-spectrum attenuation 30 dB noise blocking ear muffs were worn over the earplugs. This combination did not result in fully occluded hearing but did offer a significant dampening of auditory input.

The instructions given to subjects were:

> You are to assume the same walking speed from your two practice crossings.
>
> Assume the driver will not yield to you.
>
> Squeeze the button when you can cross before a vehicle gets to the crosswalk.
>
> Release the button when you can longer begin and complete the crossing before a vehicle gets to the crosswalk.
>
> It is important that that you press the button when you **could** cross-- not when you **would** cross.

When the subject was ready, each two minute trial always began on a non-crossable gap and by the word “Start” being stated to the subject. For the occluded – hearing condition, the trial began by the experimenter tapping the subject’s shoulder in addition to saying “Start”.

Definitions and Analysis

We defined each decision a subject made as “crossable” or “short” by comparing the length of each gap presented to each subject with the crossing time needed by that subject to cross the entry or exit lanes in front of them. Crossable or short gap decisions were based on the initial pressing of a button, that is, whether and at what point a subject identified a gap as crossable. A measure of when the subject let up on a button toward the end of a longer gap was also made and this is referred to in later analyses as “safety margin”. The unit of measure for decisions was the occurrence of a gap, be it long enough to cross in (crossable gap) or short. Across their trials, subjects were exposed to a median of 50 crossable gaps and 210 short gaps. The least number for any given subject was 17 crossable gaps and 113 short gaps. Across subjects’ 2 minute trials at the entry lanes, subjects encountered a median of 2.5 gaps long enough to afford a safe crossing and 16.5 short gaps. Across subjects’ 2 minute trials at the exit lanes, subjects encountered a median of 4 gaps long enough to afford a safe crossing and 17 short gaps.

Gap decisions were further separated into different categories according to signal detection theory. Good decisions are comprised of “true positive” responses (pressing the button early in a gap that was long enough to afford a crossing) and “true negative” responses (not pressing the button at any point during a gap too short to afford a crossing). Likewise, bad decisions are comprised of “false positives” (pressing the button during a short gap) and “false negatives” (not pressing the button during a gap that was long enough). Each of these categories reflects different aspects of the decision making of the subjects by which a high false positive rate indicates a subject making risky decisions by crossing in gaps that are not long enough (short gap) while a high false negative rate indicates a more cautious subject who is not identifying crossable gaps. Measures of sensitivity and specificity are also calculated from these categories. Sensitivity is given by true positive/(true positive + false negative) and specificity is given by true negative/(true negative + false positive).

In signal detection theory, an overall measure of a person's performance generally used is d'. Measures of d' for each subject were calculated using the true positive rates (i.e., hit rates) and false alarm rates according to the formula d' = z(true positive rate) − z(false alarm rate) where z indicates the transformation of the rates to a standard score. Due to the use of z scores, perfect hit rates and perfect false alarm rates required use of mathematical corrections. In cases where a true positive rate or hit rate of 1 was recorded, a correction was used of 1-1/(2*N) where N = the maximum number of hits. In cases where a false alarm rate of 0 was recorded, a correction was used of 1/(2*N) where N = the maximum number of false alarms.In the analysis of the latency data, the initial distribution of the latency data did not conform to assumptions of normality. A square root transformation was performed on the latency data for each group. After the transformation, data met normality assumptions for skewness (< 2 * sqrt(6/N)) and kurtosis (< 2 * sqrt(24/N)).

RESULTS

Characteristics of the subjects are provided in Table 1. Binocular visual acuity is reported as logMAR, binocular contrast sensitivity as logCS, and visual field as monocular extent from fixation (degrees). Time to cross is reported separately for entry and exit lanes of the roundabout. The numbers reported are the time in seconds that subjects required to cross those lanes. These crossing times were used to calculate safety margins for gap decisions.

An analysis of variance on the crossing times, using age as a covariate, indicated a significant difference across the subject groups for time to cross the entry lanes ($F(2,37) = 11.62$, $p < .001$) and time to cross the exit lanes ($F(2,37) = 13.23$, $p < .001$). Follow up comparisons indicated that when age is controlled for, the FS group was significantly faster than either of the other two groups when crossing the entry lanes (LSD mean difference FS versus AMD = −1.92, p<.001; LSD mean difference FS versus RP/GL = −2.05, p<.001) but the AMD group was not significantly different from the RP/GL group (LSD mean difference = .133, p=.83). For crossing the exit lanes, the same pattern of differences existed. The FS group was significantly faster than either of the other two groups when crossing the exit lanes (LSD mean difference FS versus AMD = −1.29, p=.003; LSD mean difference FS versus RP/GL = −1.75, p<.001) but the AMD group was not significantly different from the RP/GL group (LSD mean difference = .462, p=.33). Essentially, the presence of a visual impairment tended to make a person walk one to two seconds slower across entry or exit lanes, regardless of age.

There was a significant difference for age between the groups ($F(2,38)=10.6$, $p<.001$). A Scheffe test indicated that the fully sighted group did not differ from the other two groups with the difference being between the group with peripheral vision loss ($M = 56$) and central vision loss ($M = 80$). This was expected since most subjects experiencing a central loss of vision from AMD will tend to be older while subjects with retinitis pigmentosa (RP) and remaining functional vision tend to be middle aged.

Given that the three subject groups were chosen to reflect different visual abilities, significant differences in visual acuity, contrast sensitivity, and visual field size were expected. Analyses of covariance with age as a covariate were run to assess these differences. There were significant differences across the groups in terms of visual acuity ($F(2,37) = 16.44$, $p<.001$). Follow up comparisons showed that the fully sighted subjects had significantly better visual acuity ($M = −.08$) than either the group with central loss of visual field ($M = 0.80$) ($t(22) = 8.18$, $p<.001$) or the subjects with peripheral loss ($M = 0.41$) (t(29)

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= 3.77, *p*=.001) and that the two groups with vision loss were also significantly different from each other (*t*(25) = 2.24, *p* = .03). There were also significant differences across groups on contrast sensitivity (*F*(2,37) = 19.27, *p*<.001). Follow up comparisons showed that the fully sighted subjects had significantly better contrast sensitivity (*M* = 1.56) than those with AMD (*M* = 0.86) (*t*(22) = 5.36, *p*<.001) or those with peripheral field loss (*M* = 0.98) (*t*(29) = 5.73, *p*<.001) and that the two groups with vision loss were not significantly different from each other (*t*(25) = .79, *p* = .44). An analysis of covariance on field sizes, with age as a covariate, indicated significant differences across the groups (F(2,37)=24.49, p<.001). Follow up comparisons showed that the RP/GL group had significantly smaller fields (M=31.2) than either the AMD group (M=65.4) (*t*(25) = 4.97, *p*<.001) or the FS group (M=71.7) (*t*(29) = 6.91, *p*<.001).

Table 2 shows the rates of detection averaged across entry and exit lane and by visual condition group (AMD, GL/RP, FS).

An analysis of covariance, with age as a covariate, indicated that the three groups were not significantly different on the major measure of sensitivity, d' (F(2,37)=1.28, p=.29). The overall rate of missed crossing opportunities (false negatives) also did not show a significant difference across the groups (F(2,37)=2.79, p=.07). Groups averaged missing 16% to 38% of the potential crossing opportunities. A measure of risk is the rate at which subjects correctly did not cross during a short gap (true negative rate). Overall, groups did not differ on this measure (F(2,37)=.69, p=.51). All three groups had very high rates of correct rejection of short gaps, ranging from 93% to 97%.

When sensitivity was compared for entry and exit lanes for each group, all three groups were better at identifying crossable gaps on entry lanes than exit lanes (AMD: t(9)=5.01, p=.001; RP/GL: t(16)=3.94, p=.001; FS: t(13)=4.29, p=.001). All groups performed very well on entry and exit lanes by not signaling during short gaps as shown by true negative rates of 90% or higher. However, the FS and AMD groups were significantly better on entry lanes than exit lanes (FS: t(13)=2.22, p=.04; AMD: t(9)=3.00, p=.02). The RP/GL group performed equally well on entry and exit lanes (t(16)=.89, p=.39).

Reduced Hearing

Four of the 12 trials were completed with a significant reduction of auditory input. The purpose of this phase of the study was to isolate visual ability. Table 3 reports the average true positive, false positive, true negative, false negative, and d' measures for subjects, calculated separately for each subject for hearing occluded and non-occluded trials.

Paired samples t-tests showed that the groups with vision loss did not demonstrate significant differences in sensitivity, as measured by d', whether their hearing was occluded or not (AMD: t(9)=−.08, p=.94; RP/GL: t(16)=−1.83, p=.09) but the FS group was more sensitive when their hearing was not occluded (t(13)=−2.27, p=.04). All groups performed very well at not signaling during short gaps (true negative rate) when hearing was occluded or non-occluded with rates ranging from 93% to 97%. Occlusion also did not significantly impact the rate of missed crossing opportunities for any of the groups.

Latency

When subjects can quickly identify and act on a crossable gap, they are provided with a longer period of time for crossing the street. Latency was defined as the time between when a vehicle that preceded a crossable gap entered the crosswalk and a subject pressing the button. In simple terms this is defined as how quickly the subject identified a crossable gap. Table 4 shows the latency data for each subject group by entry and exit lane. Due to the presence of extreme scores in the data, medians are used to describe central tendency. The overall median latencies among groups were 1.6 for AMD, 1.5 for RP/GL, and 1.0 for FS.

Latency data were analyzed using a repeated measures ANCOVA with group (AMD, RP/GL, FS) as the between groups independent factor, lane (entry, exit) and hearing occlusion (occluded or not) as within subjects factors, and age as a covariate. Results showed a significant main effect of group ($F(2,36) = 46.65$, $p < .001$) with the fully sighted subjects identifying the gaps more quickly than the two low vision groups. There was also a significant main effect of occlusion ($F(1,36) = 8.17$, $p = .007$) and significant interaction effects of occlusion with group ($F(2,36) = 3.44$, $p = .04$), and age ($F(1,36) = 9.98$, $p = .003$). The significant interaction of occlusion with group is shown in Table 5 where it can be seen that AMD group was slightly faster at identifying crossable gaps with hearing, the RP/GL group was slightly faster with occlusion, and the FS group performed the same with and without hearing occlusion.

Safety Margin

We also compared the safety margin responses for the three groups. Safety margin was defined as the time from when a subject released the button, indicating that they would no longer cross, until the next vehicle arrives. By definition, a safety margin could not be calculated unless a decision to cross had been made in a given gap. In practical terms, this measure addresses whether the subject was in the street when the next vehicle arrives. For each button release, the safety margin was calculated by taking the time from the button release to the arrival of the next vehicle and subtracting the crossing time needed by that subject to cross at their individual crossing speed. For example, consider the situation where a subject requires 6 seconds to cross the street and the gap is 9 seconds. If the subject pressed the button as soon as the gap began and released the button 3 seconds later (indicating they could no longer initiate and complete a crossing prior to the arrival of the next vehicle, then the safety margin would be $9 - 6 - 3 = 0$ seconds. In this example the subject would be completing the crossing just as the next vehicle arrived at the crosswalk. If the safety margin was negative, then the next vehicle would have arrived while the pedestrian was in the crosswalk. In this example, if the same pedestrian (6 seconds needed to cross the street) released the button 5 seconds into the 9 second gap, the safety margin would be $9 - 6 - 5 = -2$ seconds. The pedestrian would have been 2 seconds away from completing the crossing when the vehicle arrived at the crosswalk, possibly requiring evasive action by the pedestrian or driver.

Table 6 presents the safety margins for each subject group for entry and exit lanes. Three safety margins were calculated using different crossing times. From left to right in the table, the safety margins reflect those calculated using each subject’s actual crossing time, followed by safety margins calculated using the value that had been used by traffic engineers when accounting for pedestrians (4 feet/second), followed by those calculated using the recently adopted assumed walking speed of 3.5 feet/second. Due to extreme scores in the data, medians were used to better demonstrate central tendency.

Negative safety margins represent crossing decisions where the subject would have still been willing to initiate a crossing when there was no longer sufficient time to afford a complete crossing. The fact that median values for safety margin with the three walking speeds were between −3 and −7 seconds for all three groups for both entry and exit lanes shows a general inability to gauge the time left until the next approaching vehicle will arrive at the crosswalk. An alternative explanation is that subjects were expecting that if they began to cross, the approaching vehicle, if given enough warning, would slow and/or stop.

Since the distribution of safety margin data did not conform to assumptions of normality, a square root transformation was performed on the data for each group individually. After the transformation, data met normality assumptions for skewness (< 2 * sqrt(6/N)) and kurtosis (< 2 * sqrt(24/N)). Safety margin data were analyzed using a repeated measures ANCOVA with group (AMD, RP/GL, FS) as the between groups independent factor, lane (entry, exit) and hearing occlusion (occluded or not) as within subjects factors, and age as a covariate. This analysis was performed with safety margins calculated using individual subjects' crossing times, an assumption of 4 ft/sec and an assumption of 3.5 ft/sec. At all three walking speed calculations, the AMD group showed lower safety margins (e.g., riskier decisions). Using actual crossing speed safety margins, the main effect of group was $F(2,36) = 576.31$, $p < 001$, for the 4 ft/s assumption, the main effect of group was $F(2,36) = 628.49$, $p < .001$, and for the 3.5 ft/s assumption, the main effect of group was $F(2.36) = 609.03$, $p < .001$. No other main effects or interaction effects were significant at the .05 alpha level. For 4 ft/s, the overall median safety margins for the groups were: AMD = −3.8, RP/GL = −2.9, FS = −3.1. For 3.5 ft/s, the overall median safety margins for the groups are: AMD = −4.6, RP/GL = −3.8, FS = −4.0. These findings demonstrate that whatever walking speed is used to characterize subjects' performance of the crossing task, the AMD group consistently made riskier crossing decisions than the RP/GL or FS groups. It is important to note that all three groups tended to have negative safety margins, placing them in the street when the vehicle passed. However, the AMD group was 2 to 4 seconds worse than the other two groups, meaning they would still be completing their crossing at a greater distance from the curb, increasing their risk.

DISCUSSION

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The purpose of this study was to determine the effect of central or peripheral vision loss on the ability to detect crossable gaps in traffic at a modern roundabout. Before discussing the differences that were described in the results, there was one anticipated finding that did not occur. Since totally blind pedestrians identify only 20% of all crossable gaps compared with the fully sighted,[10] we expected our partially sighted subjects to have a higher percent of identified crossable gaps than the blind but less than the fully sighted. This did not occur. The true positive rate (correct identification of a crossable gap) was higher for the AMD group than for either the RP/GL or FS groups (which were equitable) (Table 2). This is supported by analysis of d', a measure of sensitivity that incorporates the true positive rate. There was no difference between groups across entry or exit lanes for true negative rates (not crossing during a short gap) but all groups showed entry/exit differences for true positive rate (more crossable gaps correctly identified on entry lanes), false positive rate (more crossing during short gaps on exit lanes for RP/GL and FS) and false negative rates (more missed crossable gaps on exit lanes for all three groups). The most likely explanation for these findings is the challenge of making decisions about the exit lane compared to the entry lane. The exit lane was more difficult because vehicles could stay in the roundabout or exit, requiring the subjects to scan a much wider area and to make quick decisions about the intention of the driver. By comparison every vehicle approaching the entry had to enter the roundabout, eliminating the need to interpret driver behavior. This challenge was self – reported by blind and sighted subjects in the study by Guth el al.[10] Our results affirm that exit lane decisions are more difficult than entry lane decisions. The data show that the AMD group was different from the other two groups on the exit lane with about half the misses of crossable gaps shown by the other two groups and twice the false positives but since these two measures contribute to the measure of d', the groups are actually not significantly different on their sensitivity.

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Humans integrate sensory information in many activities of daily life. Because of this we sought to isolate visual information by reducing auditory input. Our methodological concern was that pedestrians with low vision may rely more on their hearing, masking the effects of vision loss. We did not find a difference between groups with the effect of reduced auditory information being the same across the three subject groups. The only group that showed a difference in sensitivity between having their hearing occluded or not was the FS group which was significantly more sensitive without occlusion. The topic of the integration of hearing and vision will benefit from further research.

While the three groups performed similarly in terms of gap detection the effect of low vision is clearly found in the measures of latency and safety margin with the AMD and RP/GL subjects having significantly longer latency compared to the fully sighted and the AMD subjects having significantly larger negative safety margin compared to the RP/GL and fully sighted subjects. What these findings tell us from a functional perspective is that the subjects with low vision are capable of identifying crossable gaps as well as the fully sighted, but they require more time to make the identification. Recognizing there is no prescribed time that has been set aside for the pedestrian to cross at a roundabout, the requirement to monitor a constantly changing pattern of traffic gaps places a burden on the pedestrian, and as our findings show, a potentially heavy burden on the pedestrian with low vision. Pedestrians with low vision self report that crossing the street is one of the most difficult tasks[18] even though many continue to make independent crossings. The slowness to respond offers less of a cushion for error and they may be aware of their increased risk.

The findings of Geruschat and Hassan[8] that drivers do not yield consistently when presented with the long cane (52% yields without the cane, 63% with the cane; a statistically non-significant difference) raises another concern. The profession of orientation and mobility (O&M) teaches that the long cane is a useful tool for identifying the pedestrian as blind or visually impaired and that the presence of the cane can affect the behavior of the driver, specifically to increase the willingness of drivers to yield as the pedestrian initiates a street crossing. It seems to be questionable whether the long cane can actually be a useful tool for increasing driver yield and pedestrian safety.

Assumptions about walking speed have a major impact on the design of intersections and the safety of the pedestrian. Many traffic engineering applications have traditionally used a walking speed of 4 feet (1.2 m) per second (although this has recently been updated to 3.5 feet (1.1m) per second. The AMD and RP/GL subjects walked slower than 4 feet per second with the fully sighted subjects walking slightly faster than 4 feet per second. On average, subjects with AMD would be in the street 1.85 seconds and subjects with RP/GL would be 0.14 seconds longer than the traffic engineers assume while the fully sighted pedestrians would be out of the street 0.30 seconds longer than the traffic engineers would predict. Thus while the previous industry standard of 4 ft/sec (1.2 m/sec) may be useful for estimating walking speeds of pedestrians without a disability, this assumption of walking speed is not supported by our data. Since our AMD group was also the oldest on average, and we know that older pedestrians walk slower than younger pedestrians[15] and the population in the United States is aging, this raises questions as to whether a further reduction in assumed walking speed might make the built environment more hospitable to older pedestrians, especially those with disabilities. Our data support the recent move on the part of the traffic engineering community to adopting a standard of a 3.5 ft/sec (1.1 m/sec) crossing speed. The new standard of 3.5 ft/sec (1.1 m) would better fit our RP/GL subjects yet still not quite match the slowness demonstrated by our AMD group.

We also calculated safety margins for our subjects using the 4 and 3.5 feet per second walking speed assumptions (see Table 6). The calculated medians demonstrate that when using the industry standard, the AMD group was making riskier judgments than the other two groups. What this translates to is that the AMD group often made crossing decisions that would have put them in the street with 5 to 7 seconds left in their crossing when the next vehicle passed whereas the other groups were less risky, being left with only about 3 seconds left in their crossings. It is important to note that all three groups had an overall negative safety margin and that this put the average pedestrian almost a full lane of traffic away from completing their crossing.

Ideally there is an interaction between the pedestrian and the driver of a moving vehicle that increases the safety of the pedestrian. The calculations describe the location of the pedestrian in the crosswalk but they do not account for the interaction of the driver and the pedestrian. For example, the presence of a pedestrian who is halfway across the street may increase the yielding behavior of the driver or their presence may get the driver to slow when they are three-quarters of the way across the street. Another issue that has not been explored is why all three groups had negative safety margins. It may be that the task of releasing the button to represent the last moment when a crossing could safety be initiated was a difficult task. It may also be that the roadway was wide enough and the volume of traffic high enough that subjects found it difficult to process the information in a timely way.

The instructions may have had an effect on the button pressing behavior of the subjects. During pilot testing we learned that some subjects pressed the button when they **would** cross, not when they **could** cross. The implication of “would or could” is important because we did not evaluate what they would do in a crossing situation. We were interested in learning of their ability to make the crossing discrimination: what they could do. Since the purpose of our study was to learn about gap detection ability not actual crossing behavior, we emphasized the words “could and would” during the practice session as well as during the review of the directions throughout the experiment. We do not know how their button pressing behavior relates to their actual crossing decisions. This is an issue for further research.

Limitations

The AMD subjects were significantly older than the RP/GL subjects. This is primarily due to the nature of the timing of the presence of the disease with AMD occurring in the elderly and RP presenting in young adults. The results showing differences between the AMD and RP/GL groups may also have been affected by age. The fact that the AMD group had an average age of 80.1 years, the RP/GL group had an average age of 55.9 years, and the FS group had an average age of 68.0 years may have affected the results. One could envision two groups of fully sighted subjects with mean ages of 80 and 56 having differences on a task which involves perceptual judgments and safety when crossing the street.

CONCLUSIONS

As the population ages there is an increase in the percent of elderly people with low vision. The complexity of the environment (absence of prescribed time to cross the street) that is experienced by the pedestrian, combined with low vision, increases the difficulty of travel. This study evaluated the ability of pedestrians with two categories of low vision to judge gaps in traffic. The reduction of visual acuity or peripheral visual field presents different problems when completing the task of crossing the street. The findings demonstrate that while the subjects with low vision can accurately identify gaps, there is a significant delay (latency) and a significant increase in time in the street (safety margin) for subjects with central vision loss. These findings suggest that crossing the street may not be as safe an experience for pedestrians with loss of central vision.

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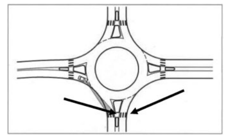

Figure 1.
Arrows indicate location where data were collected. The vehicle on the left side represents the movement of a vehicle exiting the roundabout.

Table 1

Characteristics of subjects.

ID	Age (years)	Crossing time (sec)		Visual acuity (logMAR)	Contrast sensitivity (log CS)	Average visual field (degrees radius)
		Entry	Exit	OU	OU	Monocular extent from fixation
Central vision loss						
AMD1	88	12.7	7.3	1.16	0.95	72.8
AMD2	89	14.4	10.2	1.14	0.15	71.5
AMD3	81	11.3	7.8	0.32	0.75	68.9
AMD4	77	11.3	7.8	1.22	0.05	59.8
AMD5	87	11.3	7.8	0.06	1.20	68.9
AMD6	74	10.9	8.3	0.72	1.20	61.9
AMD7	85	10.9	7.1	0.72	1.00	52.8
AMD8	62	10.3	6.2	0.72	1.40	79.5
AMD9	83	10.1	7.2	1.08	1.05	62.7
AMD10	75	8.6	6.6	0.84	0.85	61.6
Peripheral vision loss						
GL1	48	8.5	5.4	1.40	0.75	16.8
GL2	40	8.7	6.5	−0.10	1.15	46.9
GL3	28	8.8	6.1	0.82	0.85	47.3
GL4	89	14.3	10.3	0.64	0.70	61.8
GL5	59	9.5	6.8	1.52	0.70	37.1
GL6	84	13.0	9.6	0.28	0.65	52.8
GL7	56	8.3	6.2	0.24	0.70	55.9
GL8	45	8.9	6.7	0.08	1.05	31.2
GL9	74	10.3	8.3	0.10	0.65	38.2
RP1	44	9.2	5.9	0.18	1.35	9.2
RP2	57	7.9	5.3	−0.06	1.50	12.7
RP3	47	8.1	5.2	0.68	0.85	10.5
RP4	42	8.0	6.2	0.38	0.95	67.0

ID	Age (years)	Crossing time (sec)		Visual acuity (logMAR)	Contrast sensitivity (log CS)	Average visual field (degrees radius)
		Entry	Exit	OU	OU	Monocular extent from fixation
RP5	56	10.2	7.3	0.12	1.55	6.5
RP6	55	9.5	7.0	0.36	0.50	5.0
RP7	71	7.0	4.8	0.14	1.35	13.9
RP8	56	7.6	4.8	0.12	1.40	10.2
				Fully Sighted		
FS1	83	9.1	6.2	0	1.35	67.8
FS2	54	7.4	5.0	−0.08	1.45	77.3
FS3	66	7.8	5.0	−0.08	1.45	59.9
FS4	77	8.9	5.7	−0.16	1.40	61.9
FS5	86	10.9	7.0	0.24	1.35	71.5
FS6	69	8.5	5.6	0	1.50	76.7
FS7	48	4.2	3.8	−0.20	1.90	77.6
FS8	55	7.7	5.5	−0.18	1.90	74.2
FS9	76	9.4	5.8	−0.16	1.65	76.8
FS10	77	7.9	6.1	−0.02	1.45	71.7
FS11	75	8.8	5.9	−0.14	1.65	75.1
FS12	77	8.5	6.4	0	1.50	64.6
FS13	53	7.7	5.1	−0.20	1.65	74.6
FS14	56	8.6	5.3	−0.16	1.60	75.5

AMD=adult macular degeneration, GL=glaucoma, RP=retinitis pigmentosa, FS=fully sighted

Table 2

Detection measures.

Vision Status	Lane	Average hit rate (sensitivity)	Average true negative rate (specificity)	Average false positive rate (false alarms)	Average false negative rate (misses)	Average d'
AMD						
	Entry	.89	.96	.04	.10	3.16
	Exit	.79	.90	.10	.18	2.37
	Total	.84	.93	.07	.16	2.67
RP/GL						
	Entry	.75	.98	.02	.25	2.85
	Exit	.55	.97	.04	.45	2.39
	Total	.62	.97	.03	.38	2.57
FS						
	Entry	.74	.97	.03	.26	2.87
	Exit	.63	.94	.06	.37	2.24
	Total	.66	.95	.05	.34	2.49

Table 3

Rates of detection with reduced hearing.

Vision Status	Hearing Condition	Average hit rate (sensitivity)	Average true negative rate (specificity)	Average false positive rate (false alarms)	Average false negative rate (misses)	Average d'
			AMD			
	Occluded	.82	.93	.08	.15	2.64
	Non-occluded	.83	.93	.07	.16	2.65
Total		.84	.93	.07	.16	2.67
			RP/GL			
	Occluded	.60	.97	.04	.40	2.38
	Non-occluded	.63	.97	.03	.37	2.59
Total		.62	.97	.03	.38	2.57
			FS			
	Occluded	.67	.94	.07	.34	2.32
	Non-occluded	.64	.96	.04	.33	2.53
Total		.66	.95	.05	.34	2.49

Table 4

Latency by group for entry and exit.

Vision Status	Lane	Median latency (seconds)	Range
AMD	Entry	1.3	−4.9 to 12.6
	Exit	1.6	−0.8 to 11.5
RP/GL	Entry	1.4	−1.8 to 14.1
	Exit	1.7	−0.4 to 18.4
FS	Entry	0.8	−4.9 to 8.8
	Exit	1.1	−1.0 to 11.1

Table 5

Median latency with and without reduced hearing.

Vision Status	Hearing state	Median latency (seconds)	Range
AMD	Hearing	1.3	−0.8 to 12.6
	Occluded	1.6	−4.9 to 11.4
RP/GL	Hearing	1.7	−0.6 to 17.3
	Occluded	1.5	−1.8 to 18.4
FS	Hearing	1.0	−1.0 to 8.8
	Occluded	1.0	−4.9 to 11.1

Table 6

Safety margins.

Vision Status	Lane	Median safety margin	Range	Median safety margin	Range	Median safety margin	Range
		Individual crossing speeds		**4 ft/s**		**3.5 ft/s**	
AMD	Entry	−7.2	−18.5 to 15.7	−5.0	−16.2 to 18	−6.3	−17.5 to 16.7
	Exit	−5.25	−19.0 to 2.7	−3.35	−18.2 to 4.9	−4.1	−18.9 to 4.1
RP/GL	Entry	−3.25	−39.3 to 16.8	−3.4	−40.0 to 15.9	−4.7	−41.6 to 14.6
	Exit	−3.4	−8.5 to 10.0	−3.1	−8.3 to 9.5	−3.8	−9.1 to 8.8
FS	Entry	−3.1	−22.0 to 8.1	−3.9	−21.9 to 8.5	−5.2	−23.2 to 7.3
	Exit	−3.2	−10.3 to 17.6	−3.3	−9.8 to 17.4	−4.0	−10.6 to 16.7