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# Estimating Time-to-Collision with Retinitis Pigmentosa

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***Abstract:*** This article reports on the ability of observers who are sighted and those with low vision to make time-to-collision (TTC) estimations using video. The TTC estimations made by the observers with low vision were comparable to those made by the sighted observers, and both groups made underestimation errors that were similar to those that were previously reported in the literature.

For the pedestrian who is visually impaired (that is, is blind or has low vision), walking--which is fundamental to independent mobility, both for travel and for access to public transportation, is a precarious activity. Accounting for a third of all trips in the United Kingdom and approximately 80% of all journeys of less than a mile, walking is a significant mode of transportation for visually impaired people (Royal National Institute of the Blind, RNIB, 2002). The gauntlet of obstacles that these pedestrians face includes poorly maintained pavements, illegally parked vehicles, street signs, garbage cans, advertisement boards, and other pedestrians. Unexpected contact with obstacles is the most significant issue for independent travel by pedestrians who are visually impaired (North, 2000). The dangers and risks of contact with obstacles are exacerbated when they are coupled with inadequate street lighting (RNIB, 2002) and objects with poor contrast (McNamara & Banim, 1996). Gallon, Fowkes, and Edwards (1995) surveyed 300 people with visual impairments and reported that all had experienced accidents and more than half had sustained injuries while walking.

Both dog guides, which are trained to avoid obstacles, and long canes can be used to aid mobility and prevent contact with some obstacles. They are useful devices for the prevention of contact with stationary objects, but are limited in scope. For example, people who use dog guides reported that their dogs did not locate high obstructions (North, 2000), and the long cane is unable to detect an overhanging object if the object's lowest surface is higher than 27 inches from the ground (Americans with Disabilities Act Accessibility Guidelines, 1991) and has a limited range of approximately 1 meter (about 3 feet) from the user. Although a long cane may locate a stationary object (such as a street sign, café chair, or wall), enabling the pedestrian to avoid contact with that object, what happens when an object is moving? Perhaps the most significant limitation of the long cane is that it is unable to provide information about moving objects.

Walking along a street requires the avoidance of both stationary objects and those that are moving: other pedestrians, including those in wheelchairs; animals; and baby carriages or strollers. The pedestrian must locate, identify, and judge the time-to-collision (TTC) with obstacles to avoid them. *TTC* is defined as the time taken for an observer who is moving at a constant speed to reach a specified obstacle in his or her path or the time for a moving object to reach the observer (Schiff, 1965; Schiff & Detwiler, 1979).

The indirect method of estimating TTC suggests that both the distance to an object and the speed at which the individual (or object) is moving are calculated independently (by the individual), and TTC is given as the ratio of distance to the object divided by the speed at which the object is moving. The direct method, known as *tau*, suggests that TTC information is derived through the changing optic array in the eye of the observer. TTC is derived from the relative rate of increase in the separation of an image at any two points on the surface of the target object; since no cognitive process is required to interpret this information, it is considered to be direct (Gibson, 1966, 1979; Lee, 1979). In the direct method. TTC is given by

$$\mathrm{TTC} = \frac{\theta_1}{(\theta_2 - \theta_1)/(t_2 - t_1)},$$

where $\theta_1$ and $\theta_2$ refer to the angular separation of any two image points at times $t_1$ and $t_2$ .

The ability of people who are sighted to estimate TTC using both direct and indirect theoretical methods has been documented extensively (Dunkeld & Bower, 1980; Gray & Regan, 1999; McLeod & Ross, 1983; Tresilian, 1999). Furthermore, although sighted people are able to make TTC judgments, their estimations are consistently made with errors. Schiff and Detwiler (1979) presented dynamic film images to sighted observers from various starting points and velocities and found that the observers made underestimation errors of between 34% and 40%. Gray and Regan (1999) suggested that underestimation errors of 30% could not be tolerated in practical settings. Although underestimation errors err on the side of caution, they could be dangerous, since if a TTC estimation is made too early, the observer is vulnerable to other approaching objects and any change in velocity of the initial object (Gray & Thornton, 2001). The ability of observers with low vision to make similar judgments has been less well documented.

Previous research has concentrated on monocular viewers with noncongenital low vision and their ability to use binocular depth-cue retinal disparity (Steeves, Gray, Steinbach, & Regan, 2000), rather than those with ocular disorders, such as retinitis pigmentosa (RP). RP describes the retinal appearance that is observed in a number of hereditary and progressive degenerations of the retina, in which disorders to retinal neural cells (primarily, although not exclusively, rods) and a disturbance to the retinal pigment epithelium are observed. In all cases of RP, the ability to respond to light is affected, and the narrowing of the visual field and nyctalopia (night blindness) are common characteristics, although nyctalopia can take up to 30 years before it becomes severely debilitating (Tielsch, 2000). There are a reported 1.5 million cases of RP worldwide, with the disorder affecting 1 in 4,000 individuals (Wellspring Clinic, 2003). The constriction of the visual field that is seen in RP may adversely affect an individual's ability to make accurate TTC judgments. Groeger and Brown (1988) reported that when the visual field of sighted participants was narrowed from 40 degrees to 10 degrees, the participants' accuracy of underestimation increased. In addition, binocular viewing yielded more accurate TTC estimates than did monocular viewing.

Previous research has focused on the ability of binocular and monocular observers to make estimations on TTC and has largely ignored the abilities of observers with low vision who have disorders, such as RP. This research trend is interesting, since people with low vision retain residual vision and may use this remaining vision (in addition to mobility and travel devices) to avoid obstacles. Because "safe" travel relies partly on the ability to identify what an object is and where it is located within the environment (Armstrong, 1977; Petrie & Johnson, 1995), it seems plausible to assume that people with low vision may be able to make TTC estimations to avoid contact with moving objects.

## Method

### Participants

Ten adults with RP were recruited from the United Bristol

Healthcare Trust, Bristol Eye Hospital. These participants were patients who attended the hospital for low vision care and were available during the course of the study. The mean age of the participants was 66.6 years (range 46-78 years). The participants with low vision were required to meet the following criteria: They were registered as blind (although not congenitally blind) and retained some residual vision. The severity of their visual field losses was not recorded. Although the absence of data on the participants' visual status limits the extrapolation of the results, the limited causal descriptions of field loss that were provided at the time of the study for some participants and not for others would be insufficient to report. Unfortunately, more accurate data could not be collected post hoc because a policy to protect the patients' privacy prevented further contact with participants.

Ten sighted, age-matched participants were recruited from a research database at the University of Bristol. The mean age of these participants was 67 years (range 46-82). The sighted participants had corrected visual acuities of 6/6 (20/20). All the participants were paid for their participation in the experiment, which lasted approximately 45 minutes. They all gave informed consent prior to taking part.

## Structure of the study

The participants watched a video of an electric scooter (traveling at a constant velocity of 6.20 feet per second). Either the scooter was filmed as traveling toward the participant (object movement) or the camera was mounted on the scooter to provide a view as if the participant was traveling. In both instances, the scooter traveled along a 36.29-foot route, where four road-traffic cones (18 inches high and 11 inches wide) were placed at 4.53-, 21.13-, and 31.69-foot intervals and at 36.29 feet (see Figure 1).

A Canon digital video camera with the first zoom setting selected was used to capture the video. The zoom setting was selected to ensure that magnification was constant with the linear perspective in the real scene.

The participants (seated 16 inches away from the screen to ensure the constancy of linearity) watched the video on a NEC (Intel Pentium III) desktop computer running at 800Mhz with 256MB random access memory (RAM) and a 19-inch (18-inch maximum viewable area) CRT color monitor. The participants were instructed that they would see either an electric scooter moving toward them (object movement) or a moving image as if they were sitting on a moving object that was traveling toward a traffic cone (observer movement). The noise of the scooter was omitted from the video because it could have acted as a potential cue to the scooter's current position. During the video presentation, the participants were informed that the screen on the monitor would go blank (occlusion event) and were asked at this point to imagine that the object was continuing to move or that they were still moving toward the cone. When the participants believed that the scooter had reached them or that they had reached the cone, they were told to press the left mouse button (recording their TTC estimation). They were instructed to press the right mouse button to begin the next trial.

Judgments were made at each of three distances (4.53 feet, 21.13 feet, and 31.69 feet), but the participants were not told at which distance the occlusion event occurred. Each participant completed 18 trials, since each of the three distances was presented in random order three times for both the object's and the observer's movement.

## Results

### Object-moving condition

Table 1 shows the means and standard deviations for the participants in the object-moving condition. The means indicate that all the participants underestimated TTC at 21.13 feet and 31.69 feet, but the participants with low vision overestimated TTC at 4.53 feet. At the other distances, the sighted participants made more accurate TTC estimations, although these estimations were still made with underestimation error. The means suggest, however, that the participants with RP were able to make TTC estimations on moving objects that were comparable to those of the sighted participants.

A three-factor split-plot analysis of variance (SPANOVA) was adopted to further investigate the results. The between-participant factors were vision group (sighted or low vision) and estimation (actual and estimated TTC). The within-participant factor was distance (4.53 feet, 21.13 feet, and 31.69 feet). There was a significant difference between distance, $F(2, 72) = 980.21$, $p < .05$, suggesting that all the participants made significantly different TTC estimations at each distance. A significant interaction between distance and vision group was observed, $F(2, 72) = 8.41$, $p < .05$.

A significant main effect of estimation, $F(1, 36) = 25.87$, $p < .05$, suggests that the estimations made by all the participants were significantly different from the actual TTC and thus that the participants underestimated TTC. That vision group was not significant, $F(1, 36) = 2.67$, $p > .05$, suggests that the sighted participants and the participants with low vision did not make TTC estimations that were significantly different from each other.

### Observer-movement condition

The results for the observer-movement condition are presented in Table 2. The means suggest that the sighted participants and the participants with low vision generally underestimated TTC, although at the 4.53-foot distance, those with low vision again overestimated the TTC. At the far distance (31.69 feet), the mean TTC estimate by the participants with low vision was less underestimated than that of the sighted participants, although this difference is unlikely to be significant. The results suggest that all the participants were able to make TTC judgments.

A three-factor SPANOVA was used to investigate the results of the observer-movement condition. The between- and within-participant factors remained the same as in the object movement condition. There was a significant difference between distance, $F(2, 72) = 1128.18$, $p < .05$, suggesting that all the participants made significantly different TTC estimations at each of the distances.

A significant main effect of estimation, $F(1, 36) = 23.91$, $p < .05$, suggests that estimations made by all the participants were significantly different from the actual TTC, and hence that the participants again underestimated TTC. Similar to the object movement condition, vision group was not significant, $F(1, 36) = 0.40$, $p > .05$, suggesting that the sighted participants and the participants with low vision did not make TTC estimations that were significantly different from each other.

## Discussion

The results suggest that observers with RP are able to make TTC estimations that are comparable to those made by sighted observers. Furthermore, the underestimation errors that were observed (29-30%) are consistent with the underestimation errors that have been reported in the literature (25-40%) (Cavallo & Laurent, 1988; Gray & Regan, 1999; Schiff & Detwiler, 1979). Groeger and Brown (1988) suggested that when the visual field was narrowed from 40 degrees to 10 degrees in sighted observers, the level of TTC accuracy decreased. The results of this study suggest that the accuracy of TTC by observers with low vision who had RP, and therefore a reduction in their visual field, was not significantly decreased compared to that of the sighted observers. However, since the extent of the visual field was not measured, the reduction in the visual field of RP observers may not have equaled or exceeded 10 degrees.

Although estimations were based on video information, not on an encounter in the "physical environment," previous studies (Jones, 2004; Schiff & Detwiler, 1979) have suggested that sighted observers make similar judgments in either condition. The results of this study suggest that both sighted observers and observers with low vision are able to make TTC judgments on the basis of video information. Because the color, texture, and luminance of video images can be altered, the effect that such changes have on TTC judgments could be investigated in future work. Increasing the contrast of video images, for example, may increase the accuracy of TTC judgments in observers with RP. Furthermore, the use of a video presentation as an alternative to field testing should be tested in further studies. In addition, the object that was used in the study (an electric mobility scooter) provided a degree of ecological validity, since it is the type of moving obstacle that pedestrians may face when navigating a street environment.

The results of the study are limited, however, and the results should not be extrapolated from the relatively small number of observers with RP. Future studies should investigate the ability of other observers with low vision to judge TTC and whether the ability to judge TTC and the accuracy of judgments are affected by different disorders and the extent of the disorders. The results provide initial and indicative empirical data that observers with low vision are able to use their residual vision when judging TTC with moving objects and may use their residual vision when walking. Since a long cane cannot provide detailed information about moving obstacles, it would appear reasonable to assume that pedestrians with low vision may use their remaining vision (in addition to their existing mobility device and other environmental cues) to help prevent contact with obstacles.

The results did not indicate whether both groups of participants used the indirect method of TTC, relying on encoding distance information (Ross, Dickinson, & Jupp, 1970) or tau (Schiff & Detwiler, 1979). Instead, the study focused on addressing the ability of observers with low vision and RP to make TTC estimations, rather than the way in which those estimations were made. Future work could investigate the way in which observers with low vision make their judgments and if it differs from the way in which sighted observers do so. To investigate the indirect method, observers with low vision could be asked to estimate the distance of the approaching object at the point of occlusion and correlate this distance with TTC estimations. Positive correlations would suggest that distance could be encoded by observers with low vision. Although such a correlation would not necessarily show that distance was being used to help make a TTC judgment, it would show that distance could be estimated.

In conclusion, the results of this study confirm those of previous research (Dunkeld & Bower, 1980; Gray & Regan, 1999; McLeod & Ross, 1983; Tresilian, 1999), suggesting that observers with low vision are able to make TTC judgments. They also clearly demonstrated that observers with RP are able to make similar judgments and that these judgments are comparable to those of sighted observers. Underestimation errors were predominately made by the participants, and this finding was consistent with previous research (Gray & Regan, 1999). Furthermore, the results demonstrated that TTC judgments can be made on the basis of video information.

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