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EFFECTS OF RETROREFLECTOR POSITIONING ON NIGHTTIME RECOGNITION OF PEDESTRIANS

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15. Abstract

This field study was designed to investigate potential effects of retroreflector positioning on recognition of nighttime pedestrians. The subject's task was to press a response button whenever he/she recognized a pedestrian on or alongside the road, while in a car with low-beam lamps on that was driven at a constant speed on a dark road. The recognition distances were determined by the elapsed time between when a subject started a timer and when the vehicle passed the pedestrian. Four retroreflector configurations were tested: (1) No retroreflectors, (2) Torso, (3) Wrists and ankles, and (4) Major joints. Each of these configurations was presented in connection with two walking directions: an approaching and a crossing pedestrian. The subjects did not know the location of targets in advance, and the order of the retroreflector configurations/walking directions was randomized so that the occurrence and type of the next target appeared unpredictable to the subjects.

The results showed that the mean recognition distance was 40 m when there were no retroreflectors, 96 m for torso reflectors, 156 m for wrist and ankle reflectors, and 169 m for major joints reflectors when a pedestrian was approaching the subject vehicle. When a pedestrian was crossing the road, the corresponding recognition distances were 35, 136, 241, and 249 m, respectively. Each retroreflector configuration yielded significantly longer recognition distances than the no-retroreflector configuration. More importantly, the retroreflective markings attached to the limbs led to significantly longer recognition distances than when the retroreflective markings were attached to the torso. Furthermore, the effect of walking direction and the interaction between retroreflector configuration and walking direction were significant, indicating that a pedestrian was more recognizable while crossing the road, except for configurations involving no retroreflective markings.

The main implication of this study is that retroreflective markings on the limbs, in comparison to those on the torso, significantly increase (by about 60 to 80%) the nighttime recognition distance of pedestrians.

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Retroreflector, pedestrian, nighttime, recognition, visibility, detection

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CONTENTS

INTRODUCTION

Reduced visibility is a major contributor to pedestrian accidents at night (Owens and Sivak, 1993). The visibility distance of dark-clad pedestrians is typically less than one-third the stopping distance at normal highway speed (e.g., Johansson and Rumar, 1968). Consequently, many pedestrian accidents that occur in nighttime are not accidents by normal definition (Rumar, 1976).

Many studies have shown that retroreflective markings increase the visibility distance of pedestrians at night (e.g., Rumar, 1976). Sufficient reflectivity, contrast, area, and durability of retroreflective markings have been considered the key variables affecting pedestrian visibility. While providing a substantial improvement in the distance at which a pedestrian is *detected*, good retroreflectors, as such, may not ensure that a driver *recognizes* the bright target as a person. However, the recognition might be important, because drivers may be more cautious when seeing a pedestrian on or alongside the road than when seeing some other objects.

Blomberg, Hale, and Preusser (1986) compared the detection and recognition distances of five different pedestrian targets in nighttime driving. They found that flashlights produced the longest detection distance (420 m), following by retroreflective markings called rings, i.e., retroreflective bands on the head, waist, wrists, and ankles (232 m), a jogging vest (227 m), dangle tags (162 m), and a baseline pedestrian with no retroreflectors (68 m). However, the mean distances for recognition were 96, 133, 98, 44, and 32 m, respectively. These results indicate that locations of retroreflective markings are likely to be important.

Owens, Antonoff, and Francis (1994) conducted two simulation experiments to evaluate potential benefits of different retroreflective markings for nighttime pedestrian visibility. Of particular interest in that study was the evaluation of the so-called *biological motion* or *biomotion* (Johansson, 1975). Specifically, the main question was whether the markings of all the major joints would create a biological motion phenomenon whereby the recognition of moving persons is improved in comparison to having retroreflectors on other locations of the body. Subjects viewed video recordings of a jogger wearing four different retroreflective markings, and their task was to respond as quickly as possible when seeing a jogger. The results showed that performance was better with markings of the limbs than of the torso. Furthermore, when a secondary task was included, Owens et al. concluded that performance was better for markings that incorporate biological motion than for a vest or for arbitrarily positioned stripes on the limbs.

However, Owens, et al. (1994) indicated that the results from their laboratory study should be validated by carrying out field experiments. Such a validation is needed because, for example, video rendition of all retroreflective markings appeared somewhat unrealistic, and the magnitude of potential improvements in pedestrian recognition afforded by some locations of retroreflective markings should be determined. Consequently, the present study was designed to replicate the main features of the study of Owens et al. (1994) in a field study. However, there were two additional main differences between the study of Owens et al. and the present study. First, Owens et al. (1994) simulated four different environments (residential, dark, busy, and lighted road), while the present study was made in a predominantly dark-road environment. Second, pedestrians in the study of Owens et al. were always jogging toward the observer, while in the present study half of the encounters included a pedestrian crossing the road. The crossing condition was added to increase the validity of the study, because more than half of all pedestrian deaths and injuries occur when pedestrians cross or enter streets (National Safety Council, 1994).

METHOD

Tasks

Subjects performed a recognition task while seated in the front and rear passenger's seat of a car with low-beam lamps on that was driven on a dark road. Specifically, a subject's task was to press a response button whenever he/she recognized a pedestrian on or alongside the road ahead of the subject vehicle. This method of recording distances has been successfully used before (e.g., Shinar, 1984, 1985).

Retroreflectors

Four retroreflector configurations were tested:

(1) *No retroreflectors.*

(2) *Torso.* A vertically attached retroreflective stripe on both shoulders, each 1.3 cm wide, and one going around the body at midtorso (2.6 cm wide).

(3) *Wrists and ankles.* Six retroreflective stripes, each 2.6 cm wide. One was attached to each arm at the wrist, and two were attached to each leg at the ankle.

(4) *Major joints.* Eleven silver retroreflective stripes, each 1.0 cm wide. One retroreflective stripe surrounded the body at the hips, two were attached to each leg at the knee and ankle, and three were attached to each arm at the wrist, elbow, and vertically at the shoulder.

The clothing of the pedestrian was a black sweat suit with black socks and shoes. An attempt was made to equate the frontal areas (170 cm^2) and side areas (130 cm^2) of the retroreflective material of the different retroreflector configurations. Retroreflective material was silver 3M Scotchlite™ reflective fabric. Table 1 shows reflectivity values of the material.

Table 1
Reflectivity values of the retroreflective material.

Entrance angle (°)/Observation angle (°)	Reflectivity value cd/lx/m^2	
	Typical	Minimum
4.0/0.20	500	330
5.0/0.33	330	250

Test sites

Since other vehicles, either preceding or oncoming, would influence the visibility of the pedestrians, the study was conducted on rural roadway sections in north Ann Arbor with only sparse traffic. The route (see Figure 1) consisted of two-lane roads with no street lighting.

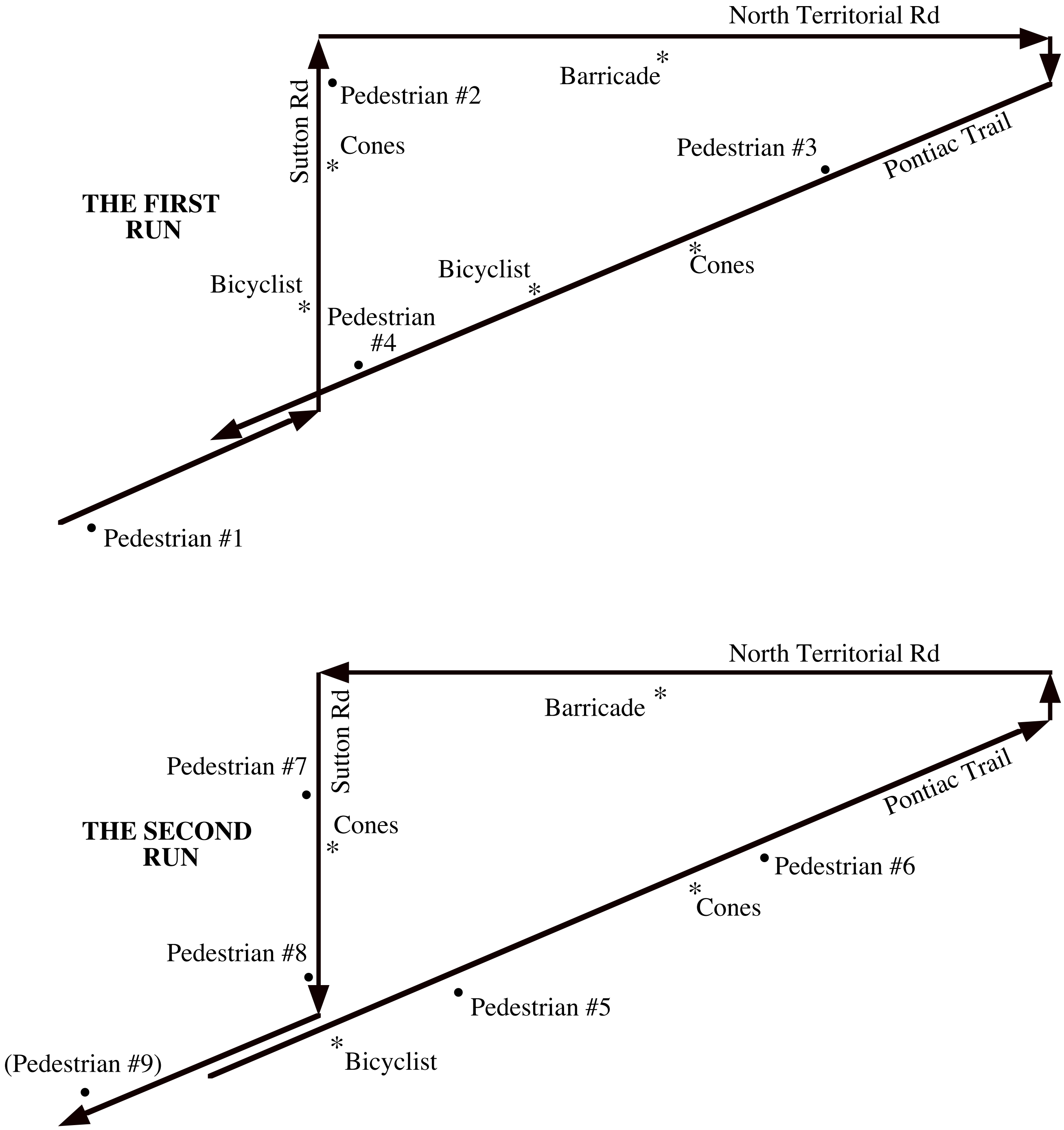

Figure 1. Schematic of the experimental route.

The surface of the road was asphalt (7.0 m wide) with edge lines on Pontiac Trial and North Territorial Road, but not on Sutton Road. The total length of the route was 40 km. Out of this length, 7 km at the beginning and 8 km at the end was for the drive to the experimental route.

Along the route, nine locations were chosen for the experimental sites where the subject vehicle encountered a pedestrian, one location being reserved for possible make up of a missed trial (see procedure). The minimum sight distance was 500 m at each location.

In addition to the pedestrian targets, the route included retroreflective traffic signs, roadside reflector posts, and other types of retroreflective markings. Furthermore, in order to increase distractors, the following clearly-visible retroreflective markings were deployed at the route: (1) four encounters with traffic cones with horizontally or vertically attached retroreflectors stripes, (2) three encounters with a bicycle driving either in the lane of oncoming traffic, in the lane of the subject vehicle, or turning left from the driveway into the lane of the subject vehicle, (3) two encounters with a barricade with horizontally or vertically attached retroreflector stripes.

Equipments

The subject vehicle was a 1993 Nissan Altima equipped with standard U.S. low beams (type HB2). The interior of the vehicle was dark during the experiment, and the windshield and headlamps were cleaned every night. The aiming of headlamps (measured with no passengers inside the vehicle) was in the normal range.

Experimenters inside and outside of the subject vehicle had a radio connection with each other by Citizens Band transceivers. In addition, a yellow flashing lamp was placed on the roof of the vehicle. The purpose of this lamp was to facilitate identification of the subject car by the experimental pedestrians.

A timer was connected to each subject's response button. Response times were recorded to the nearest hundredth of a second.

Subjects

Thirty-two paid subjects participated in the study. Sixteen subjects were between the ages 20 and 28 (with a mean of 23) and sixteen were between the ages 60 and 77 (with a mean of 67). There were 8 females and 8 males in each age group. All subjects were licensed drivers.

Design

There were eight trials for each subject that included two trials each for every retroreflector configuration. During four trials the pedestrian approached the test vehicle on the right-hand edge of the roadway (as seen from the subject vehicle), and during the other four trials the pedestrian crossed the road back and forth. The subjects did not know in advance the location of pedestrians, and the order of the retroreflector configurations/walking directions was randomized. Consequently, the occurrence and type of the next target appeared unpredictable to the subjects. In addition, the order of the configuration-by-direction combinations and seating locations (front versus rear) was balanced across subjects within each age-by-sex subject group.

Procedure

The subjects were run in pairs. One subject was seated in the right front seat and one in the left rear seat. The latter subject leaned towards the center seat, so that he/she also had an unobscured view to the road through the windshield. They were told that this study investigated how well drivers can see pedestrians at night. Particularly, the subjects were instructed to press a hand-held response button whenever they saw a pedestrian on or alongside the road ahead of the test vehicle. Furthermore, they were told not to respond to anything else (bicyclists, debris, etc.) on the road. No mention was made of the retroreflective markings.

While the subjects were driven to the experimental route, they practiced starting the timer in response to various targets. During the experiment, the subjects held the silent response buttons so that neither subject was influenced by the other's responses.

Five experimenters carried out the study. The first and second experimenters acted as pedestrians, and the third one as a bicyclist. The fourth experimenter drove the subject vehicle. The fifth experimenter, sitting in the right rear seat of the subject vehicle, provided the subjects with instructions, stopped the timers when the vehicle passed pedestrians, recorded the response times, and provided information about the location of the subject vehicle to experimenters outside of the vehicle by the transceiver (by naming each major intersection when it was passed). In addition, the experimental pedestrians informed this experimenter each time they expected that a next trial would not be possible because of other traffic.

The subject vehicle was driven at a constant speed of 50 km/h (31 mph), except for North Territorial Road (that included no experimental pedestrians). There the speed was 56 km/h (35 mph) because of generally higher speeds on this section. In order to estimate whether the actual speed during trials was influenced by a driving style and a potentially biased speedometer, five test runs with a timer were made in a section of 500 m. The results of the tests revealed that the mean speed was 49.5 km/h (30.9 mph, 13.8 m/s), with a standard deviation of 0.28 km/h. Correspondingly, the mean walking speed of the experimental pedestrians was 1.4 m/s, with a standard deviation of 0.05 m/s.

The experiment was conducted in May, only on nights without active precipitation or water on the road surface. The vehicle was driven in the middle of the right lane. The experiment began at least 50 minutes after sunset and it lasted approximately 45 minutes. The locations of the experimental pedestrians were free of lighting from buildings. No other traffic was present while the test vehicle was approaching the pedestrians. If it was expected that other traffic would be present, the experiment was temporarily halted and data collection resumed only when the roadway was free of traffic. In addition, the subject vehicle pulled over when other cars reached it and let them pass. Also, in order not to reveal to subjects the reason for stops (to wait until the location of the pedestrian was free of other traffic), additional transceiver contacts and subsequent pullovers were made, and codes were used in transceiver communication.

In spite of all preparations for other traffic, some trials were missed because of unexpected vehicles. If only one trial was missed, it was repeated at the end of the experiment at the ninth location (7.8% of the final data). However, if more than one trial was missed, the data for all trials were excluded.

Sixteen subjects responded only to the pedestrians. The other sixteen subjects responded to a bicyclist, as well. Twelve of them responded to the first bicyclist. In those twelve cases, the experimenter reminded subjects not to respond to anything other than pedestrians. This feedback was given in order to decrease the subject's tendency to respond to each moving target that would have increased error variance and obscured differences between retroreflector configurations.

RESULTS

An analysis of variance (4 x 2 x 2 x 2 ANOVA) was performed on recognition distances that were derived from measured response times, mean driving speed, and mean walking speed. The analysis incorporated two within-subject variables (retroreflector configuration and walking direction) and two between-subject variables (age and sex). The statistically significant main effects were as follows: (1) *Retroreflector configuration,* $F(3,84) = 124.9$, $p = 0.001$[1] , with the shortest recognition distances for pedestrians with no retroreflectors, followed by torso, wrists and ankles, and major joints; (2) *Walking direction,* $F(1,28) = 51.5$, $p = 0.001$, with longer recognition distances for crossing than approaching pedestrians, and (3) *Age,* $F(1,28) = 10.5$, $p = 0.003$, with longer recognition distances for younger subjects (161 m) than older subjects (119 m). The effect of sex was not significant.

The effect of retroreflector configuration by walking direction is shown in Figure 2. The significant interaction between those variables ($F(3,84) = 9.00$, $p = 0.002$) indicates that the effect of walking direction was not the same for the different retroreflector configurations. Specifically, when retroreflective markings were attached to pedestrians, the crossing condition yielded 42% to 53% longer recognition distances than the approaching condition. In contrast, when a pedestrian had no retroreflectors, the recognition distance in the crossing condition was 13% shorter than in the approaching condition.

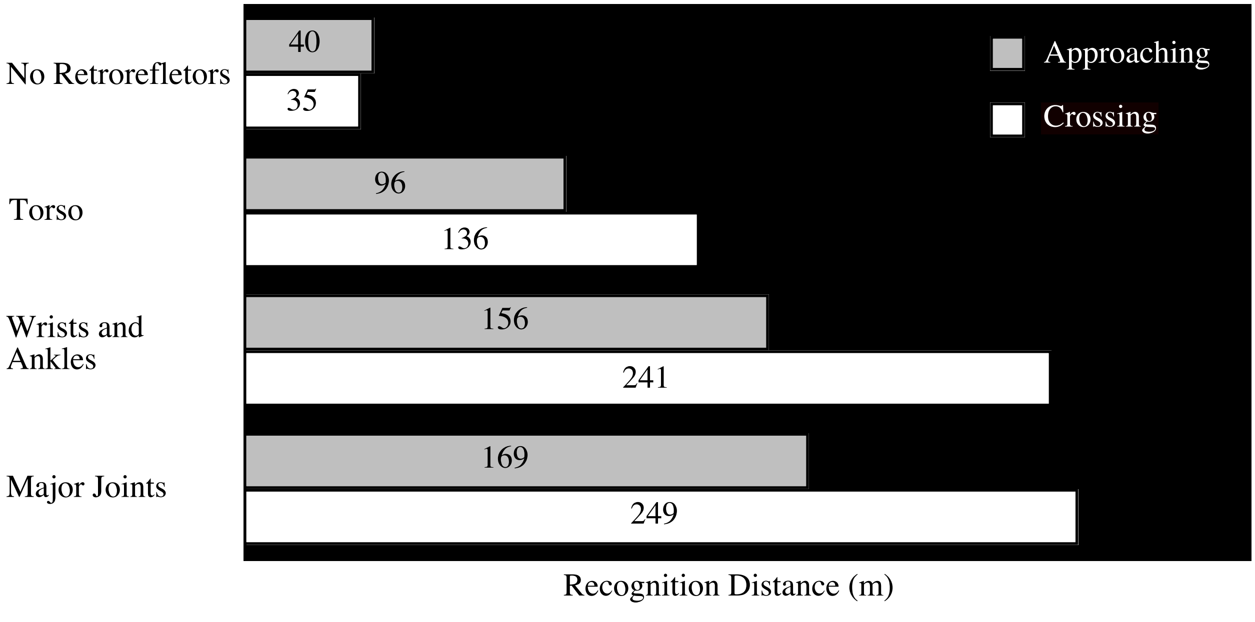

Figure 2. Mean recognition distances for four different retroreflective markings.

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[1] For main effects and interactions involving repeated measures, the levels reported for p are based on the Greenhouse-Geisser correction (see Keppel, 1982).

Post hoc Tukey tests ($\alpha = 0.05$) of the interaction between retroreflector configuration and walking direction showed that each difference in both walking directions is statistically significant, except for the differences between the wrists and ankles versus the major joints.

The interaction between age and retroreflector configuration (Figure 3) was significant ($F(3,84) = 3.35$, $p = 0.03$), indicating that the effect of retroreflector configuration was different in the two age groups. Figure 3 shows that older subjects needed shorter distances for recognition in each configuration, but the difference between the recognition distances of the older and younger subjects was longest for the wrists and ankles, followed by the major joints, torso, and no retroreflectors. Post hoc Tukey tests ($\alpha = 0.05$) of the interaction between retroreflector configuration and age showed that recognition distances of different age groups were statistically significant for the wrists and ankles and the major joints (but not for the torso or no retroreflectors).

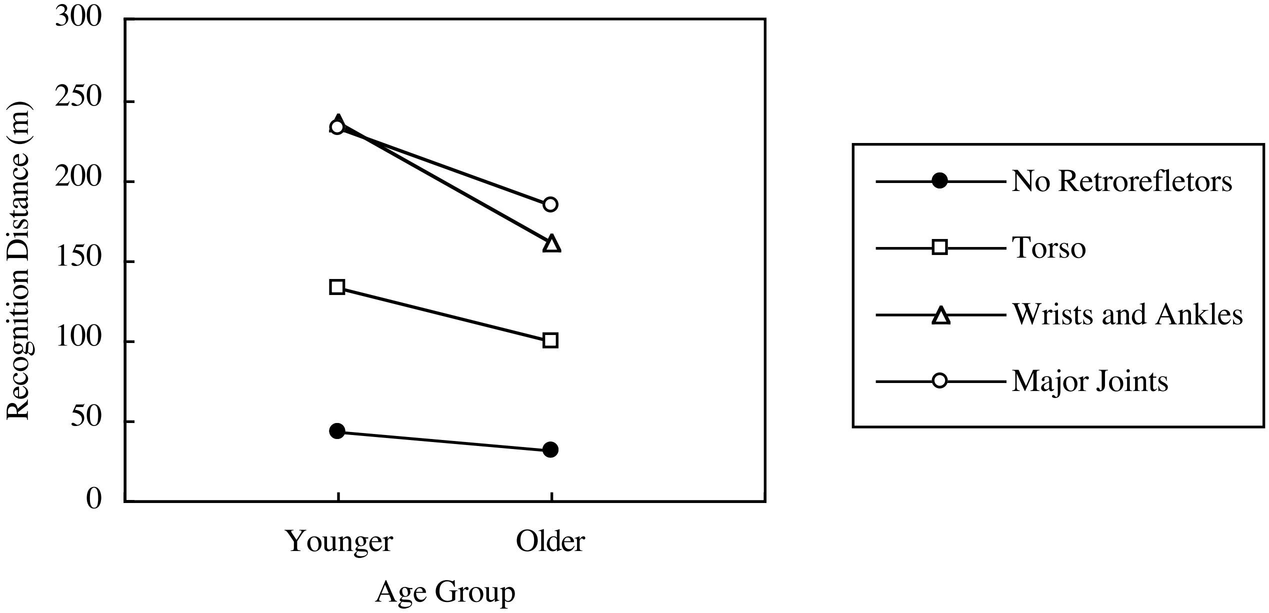

Figure 3. Mean recognition distance for different retroreflector markings by age group.

None of the other interactions was statistically significant. Furthermore, additional analyses of variance were performed to test the effects of seating position (front versus rear) and false alarms (a response to the bicyclist) on recognition distances. Neither of these effects was significant.

DISCUSSION

This field study was designed to investigate the effects of retroreflector positioning on recognition of nighttime pedestrians. Specifically, the subject's task was to press a response button whenever he/she recognized a pedestrian on or alongside the road, while seated in a car with low-beam lamps on that was driven at a constant speed on a dark road. Four retroreflector configurations were tested: (1) No retroreflectors, (2) Torso, (3) Wrists and ankles, and (4) Major joints. Each of these configurations was presented for approaching and crossing pedestrians.

The main finding of this study is that retroreflective markings attached to the limbs (i.e., the wrists-and-ankles configuration, as well as the major-joints configuration) lead to significantly longer recognition distances than when the markings are attached to the torso. This was the case whether a pedestrian was approaching the vehicle (156 to 169 m versus 96 m) or a pedestrian was crossing the road (241 to 249 m versus 136 m). The results confirmed the main results of Owens et al. (1994), and the results are in agreement with the results of Blomberg et al. (1986). Consequently, the main implication of this study is that retroreflective markings on the limbs, in comparison to those on the torso, increase significantly (by about 60 to 80%) the recognition distance of nighttime pedestrians.

Each retroreflector configuration yielded significantly longer recognition distances than the no-retroreflector configuration. This effect might have been slightly smaller if pedestrians had worn light-colored clothing (see Blomberg et al., 1986). However, it is assumed that the color of clothing had only a minor or no effect on differences in recognition distances produced by different retroreflective configurations.

The effect of walking direction indicates that pedestrians with retroreflective markings are more visible when they are crossing the road. This result is important because, as noted earlier, most pedestrian accidents occur when pedestrians cross or enter the road. On the other hand, this result is not surprising, because the movement of the retroreflective markings is more substantial and, therefore, they are more visible. However, when pedestrians had no retroreflective markings, the recognition distance was shorter for the crossing than for the approaching condition. This finding is in agreement with a well-known fact that headlamps illuminate the right lane further ahead than the left lane (Sivak, Flannagan, and Sato, 1994). Consequently, the recognition distance for a dark-clad pedestrian is longer on the right side than on the left side of the road (e.g., Schmidt-Clausen, 1988). In the present experiment, crossing pedestrians were in the left lane about 50% of the time while approaching pedestrians were always in the right lane.

The older subjects needed shorter distances to recognize a pedestrian. This difference may be partly caused by the decreased visual acuity of older people (visual functions of the subjects were not examined), as well as to their slower information processing. In addition, we may assume that older subjects preferred to get more information to decide whether or not a given target is a pedestrian. This assumption is supported by the significant interaction between age and retroreflector configuration, along with a (nonsignificant) trend of the older subjects (but not the younger ones) needing shorter distances for recognition of the wrists and ankles than for the major joints (Figure 3). The magnitude of this difference was even larger when pedestrians were approaching the vehicle, which is a more demanding condition because of less movement, than when they were crossing the road (not shown above). However, these trends should be interpreted cautiously, because the differences were not statistically significant.

The main results did not support an advantage of markings in the major joints over the wrists and ankles. However, the available data are inconclusive about the differential effect of the biomotion/major joints configuration and other configurations on the limbs on recognition distance. This is the case because of (1) the above-mentioned interaction between age and retroreflector configuration, and (2) the findings of Owens et al. (1994) indicating a marginal advantage of the biomotion over the arbitrarily positioned stripes on the limbs in an experiment with higher task demands (i.e., in the experiment involving a tracking task). Given that the subjects did not drive in the present study (i.e., low task demands), one could assume that the major joints would have led to somewhat shorter distances if subjects did drive. Consequently, there is room for further studies addressing this issue, although the difference between the biomotion/major joints configuration and other configurations on the limbs, if it exists, may not be substantial.

On the other hand, retroreflectors on the wrists and ankles are more practical than on the major joints. Specifically, clothes may be cheaper and more convenient to manufacture when the number of retroreflective marking is smaller. In addition, temporary stripes that are frequently used in Scandinavia, for example, are relatively convenient to attach to wrists and ankles, but not to all major joints.

It is noteworthy that each retroreflector configuration/walking direction combination met a frequently mentioned criterion distance of 100 m (e.g., Rumar, 1976) that should be required considering the normal nighttime driving speeds on the roads, i.e., 55 mph in the U.S., or 80 to 100 km/h in Europe. However, it is assumed that the subjects were relatively alerted, because they were instructed to search for pedestrians. Also, the radio communication between the experimenters (while giving no specific information) might indicate to subjects that the next pedestrian will appear in the following one or two kilometres. More generally, this study focused on effects of retroreflector positioning on *human performance* of alerted subjects, but did not examine *safety effects* of retroreflector positioning. The causation of accidents in general, and of nighttime pedestrian accidents in particular, is complex, and there are many factors that increase risks to pedestrians at night (see e.g., Reinhardt-Rutland, 1986). Risk-increasing factors include the following: (1) drivers in real traffic may not respond appropriately, although they recognize a pedestrian with retroreflective markings (Lehtimäki, 1971; Summala, 1980); (2) young drivers, who have higher accident risks on average, are overrepresentated in nighttime traffic (Massie and Campbell, 1993); (3) drivers overestimate their ability to detect obstacles on the road because of functionally selective visual degradation, i.e., when luminance falls below daylight levels, visual recognition functions, such as acuity and contrast sensitivity, deteriorate rapidly, but orientation and guidance functions are unaffected (Owens, Francis, and Leibowitz, 1989); (4) night myopia, i.e., many people tend to become near-sighted in dim illumination (Owens, Leibowitz, Norman, 1976); (5) pedestrians overestimate their visibility (Shinar, 1984); and (6) it is assumed that the proportion of drunk road users is generally higher at night than during the day. Consequently, no prediction of the magnitude of potential accident reduction for a given retroreflector configuration can be made on the basis of the present findings. However, it is reasonable to assume that a longer recognition distance would lead to a safer encounter between a vehicle and a pedestrian.

Based on results of Shinar (1985), we may assume that after the first trial or two, subjects in the present study (as well as in studies with a similar design of repeated measures) began partially to search for moving retroreflective markings instead of pedestrians. In order to reduce this effect, the subjects in the present study met a bicyclist three times. However, one could assume that, in comparison to real driving, the overall results may overemphasize situations in which drivers expect to encounter pedestrians with retroreflective markings. Consequently, the information concerning the effects of retroreflector positioning on recognition distances while encountering a pedestrian for the first time during a given trip would be of great interest, and especially in the U.S. where drivers almost never expect to encounter pedestrians with retroreflectors. Therefore, further research should address this question. Another interesting possibility for further studies would be to investigate potential effects of experience with retroreflectors on recognition of nighttime pedestrians, the hypothesis being that the performance of experienced subjects would be less dependant on the type of the retroreflector. Finally, possible effects of different retroreflector configurations on unalerted driver behavior should be measured in future studies, because the extended recognition distance is only a prerequisite for enhancement of pedestrian safety. If a pedestrian with given retroreflective markings increases safety margins in terms of reduced vehicle speeds or increased vehicle lateral movements, and this has no harmful side effects, then it is reasonable to assume that road safety will be improved.

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