Biological Motion and Nighttime Pedestrian Conspicuity

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Two experiments were conducted in the laboratory to evaluate potential benefits of different retroreflective markings for nighttime pedestrian visibility. Video recordings of a jogger wearing four different markings were made from a vehicle in four different road environments. Subjects viewed composite tapes that included each of the 16 jogger marking/road environment combinations as well as travel with no targets. The task was to step on a pedal immediately upon seeing a jogger, which had no effect on the flow of the video playback. The time between depression of the pedal and the point of "impact" was the major dependent variable. Experiment 1 showed that performance was better for all retroreflective markings than for the dark control and that it was better with markings of the limbs than of the torso. Experiment 2, which included a secondary video tracking task, showed that performance was better for markings that incorporate biological motion than for a vest or arbitrarily positioned stripes on the limbs. Questionnaire data indicated that 85% of the subjects judged the biological motion markings to be "easiest to see." Also, subjects reported more conservative estimates of nighttime visibility and greater willingness to take personal precautions at night after participating in the experiment.

INTRODUCTION

Nighttime accidents pose one of the most difficult problems of traffic safety. Although the overall rate of traffic fatalities has declined consistently for decades, nighttime accidents continue to claim the majority of lives lost in traffic accidents every year. Corrected for mileage, nighttime fatality rates in the United States averaged 3.4 times higher than daytime rates over the past decade (Accident Facts, 1981–1990), and pedestrian accidents are among those overrepresented at night. According to statistics from the National Highway Traffic Safety Administration’s Fatal Accident Reporting System, more than 60% of all pedestrian fatalities occur at night. Most pedestrian deaths and injuries occur when the victim crosses or enters the street (Accident Facts, 1981–1990). The present study investigated a new approach to reduce such accidents that exploits dynamic visual information to increase pedestrian conspicuity.

Reduced visibility is a major contributor to

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pedestrian accidents at night, particularly in rural and suburban environments (Allen, 1970; Knoblauch, 1976; Roper and Howard, 1938; Rumar, 1966, 1976). The visibility distance of a dark-clad pedestrian in low-beam headlights is typically less than one-third the stopping sight distance at 55 miles/h (88.5 km/h) (Blomberg, Hale, and Preusser, 1986; Johansson and Rumar, 1968; Olson, 1987). For this reason, it should not be surprising that many drivers involved in nighttime pedestrian accidents claim to have heard the impact before they saw the pedestrian (Allen, 1970, p. 151).

Pedestrians are generally not aware of their hazardous situation, however. Studies by Hazlett and Allen (1968; Allen, Hazlett, Tacker, and Graham, 1969) and by Shinar (1984) found that most subjects, when posing as pedestrians, greatly overestimated their visibility to oncoming drivers. One explanation for this unrealistic assessment, which may contribute to greater risk taking, is that a pedestrian’s vision is usually adapted to lower levels of illumination than is a driver’s vision. Consequently, from the pedestrian’s viewpoint, headlight illumination seems more than adequate.

Pedestrians are not alone in misjudging the hazards of night driving—most drivers do not adjust their behavior to compensate for lower visibility at night. Traffic research indicates that nighttime speeds on suburban and rural roads are typically as high as daytime speeds (Herd, Agent, and Rizenbergs, 1980). This suggests that drivers do not appreciate their visual limitations and, therefore, are not prepared for emergency avoidance of unexpected pedestrians or other low-contrast obstacles. We have proposed that drivers’ overconfidence at night may be related to functionally selective visual degradation (Leibowitz and Owens, 1977; Leibowitz, Owens, and Post, 1982). Visual orientation and guidance functions are unaffected by reduced luminance, maintaining high levels of performance down to levels approaching the scotopic threshold (Leibowitz, Post, Brandt, and Dichgans, 1982; Leibowitz, Schupert-Rodemer, and Dichgans, 1979; Owens and Tyrrell, 1993). However, visual recognition functions such as acuity and contrast sensitivity deteriorate rapidly as luminance falls below daylight levels (Leibowitz and Owens, 1991; Owens, 1991). Drivers may fail to appreciate this selective degradation for two reasons: (1) visual guidance of steering—the primary task—remains effective, and (2) visual recognition of most important stimuli is enhanced by artificial lighting or reflectorization. This analysis underscores the importance of optimizing pedestrian conspicuity to compensate for drivers’ degraded recognition vision at night.

Numerous studies have shown that retroreflective markings on dangle tags, vests, and other garments greatly increase the visibility distance of pedestrians at night (Allen et al., 1969; Rumar, 1966, 1976; Shinar, 1985). Although these markings provide a dramatic improvement in the distance at which a pedestrian is detected, these devices are not as effective in ensuring that a motorist will recognize the luminous stimulus as a person. Blomberg et al. (1986) compared the visibility of five different pedestrian targets, including a baseline model who wore blue jeans and a white T-shirt and one wearing the same clothing plus two retroreflective dangle tags. They found that the dangle tags more than doubled the mean detection distance (from 68 m to 162 m) but increased mean recognition distance by only 37% (from 32 m to 44 m). It is worth noting that dangle tags are relatively uncommon in the United States. Shinar (1985) reported that these devices are effective only when the driver/subject has learned that they signify a pedestrian. Blomberg et al. found that a jogger’s vest, which is a familiar marking in the United States, increased recognition distance by a factor of three (to
98 m) over the baseline model. Interestingly, the most effective marking in their study, called “rings,” had no advantage of familiarity. Composed of six retroreflective bands—on the head, waist, wrists, and ankles—the rings configuration produced the longest recognition distance (133 m), more than four times farther than the baseline model. The mean distance for detection (232 m), however, was still 75% longer than that for recognition. These findings indicate that high reflectivity and contrast are not the only variables affecting pedestrian conspicuity; the dynamic characteristics of the markings are likely to be a key factor, as well.

Twenty years ago, Johansson (1973) reported a striking phenomenon that may help to explain and ameliorate this problem. Using films of models who had light points attached to their major joints (i.e., shoulders, hips, elbows, wrists, knees, and ankles), he showed that relative motions among the joints provide virtually immediate perception of the person in action. When the model is stationary, the light points appear meaningless, but when the model begins to move, the points appear as a consolidated whole—a person—in the act of walking, running, dancing, climbing, or whatever. Johansson called this phenomenon biological motion, and he described the dynamic visual information through a hierarchical vector analysis in which component pendular motions were nested within larger common motions of the entire configuration. Subsequent research has shown perception of biological motion to be extremely compelling. Biological motion can be recognized in exposures of only 100 to 200 ms (Johansson, 1975, 1985). It allows recognition of rather subtle characteristics, such as gender, as well as the person’s overt actions (Barclay, Cutting, and Kozlowski, 1978; Cutting and Kozlowski, 1977; Cutting, Proffitt, and Kozlowski, 1978; Kozlowski and Cutting, 1977, 1978; Runeson and Frykolm, 1981, 1983). It can also be perceived by human infants (Bertenthal, Proffitt, and Cutting, 1984; Fox and McDaniel, 1982); and even by cats (Blake, 1993). This research suggests that the superior performance resulting from the rings treatment used by Blomberg et al. (1986) may have derived from the kind of dynamic information contained in Johansson’s fuller array of light points. If so, markings of all the major joints, which would create the full biological motion phenomenon, may prove to be superior for safety because recognition of moving persons would be virtually simultaneous with first detection.

We now report two experiments that provide a preliminary test of this hypothesis. Both experiments used video sequences taken from a car at night to investigate the relative visibility of joggers wearing four different marking configurations. The jogger appeared at unpredictable locations in four different road environments, and the subjects’ task was to signal recognition as rapidly as possible by stepping on a pedal. In the second experiment, a video game was added as a secondary task, forcing subjects to divide their attention between tracking a video target and looking for pedestrians.

**EXPERIMENT 1**

**Method**

**Subjects.** Thirty-two undergraduates (17 women and 15 men) served as subjects in order to receive credit for a course in introductory psychology. Each was tested individually after granting informed consent. Three were subsequently excluded from analysis because they failed to comply with instructions (see Results).

**Task.** Each subject was tested with one of four video sequences created from tapes recorded in four road environments. The task was to step on a “brake” pedal whenever a pedestrian came into view. A jogger, clothed
in varying attire, appeared unpredictably along the right shoulder of the road 16 times during the 33-min test sequence. The jogger was always jogging slowly toward the observer and thus was seen from the front. This viewpoint was selected because it is both realistic and conservative, given that it probably provides the minimal perceptual advantage of biological motion. A side view, which reveals sweeping pendular motions of the limbs, generally yields a more effective impression of biological motion.

Stimuli and apparatus. Original tapes were recorded at night with a CCD video camcorder (Zenith VM6200, 15-lux sensitivity) from the front passenger seat of a 1983 Mazda GLC. The car was driven at 40 km/h, (25 miles/h), and low-beam headlights were used throughout. Five passes were recorded in each of the following road environments. Dark: a narrow, two-lane asphalt road through dark farmland. Residential: a two-lane asphalt street through a residential neighborhood, with no overhead luminaires but occasional off-street lighting at private residences. Busy: a three-lane asphalt commercial artery near Lancaster, Pennsylvania, with irregular street lighting and a wide array of visually “noisy” light sources from businesses neighboring the road. Lighted: a wide, two-lane asphalt circumferential access road surrounding a large shopping mall, with luminaires positioned at regular intervals.

Passage through each environment was taped five times—once with no jogger and four times with a jogger appearing once in each of the following markings. Dark Control: a navy blue sweat suit. Vest: the same dark sweat suit with addition of a jogger’s vest made of yellow fluorescent material with a diagonal retroreflective stripe on both front and back, each 5.2 cm wide and 36 cm long. Stripes: the dark sweat suit with 5 silver retroreflective stripes, each 2.6 cm wide. One surrounded the body at midtorso; two surrounded the upper arms, midway between shoulder and elbow; and two surrounded the lower legs, midway between knee and ankle. Biomotion: the dark sweat suit with 11 silver retroreflective stripes, each 1.5 cm wide. One surrounded the body at the level of 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) shoulder.

Using a JVC video editing system (Model RM-86U), four test tapes were created by re-recording the 20 original episodes onto standard VHS tapes in counterbalanced orders (Appendix A), which were determined as follows: The 16 jogger segments were divided into four groups, in which a random order of the four road environments was replicated. Across the four repetitions of road environments, the order of jogger markings was varied according to a Latin square, such that each marking appeared once in each ordinal position. This basic order for Tape A was then reversed to create the order for Tape B. The same strategy, using a different replicated sequence of the road environments, was used to generate the orders for Tapes C and D. For all test tapes, eight “blank” segments (depicting travel through the same four road environments but with no jogger) were inserted at randomly selected points among the 16 segments that included a jogger. The order and location of these blank segments were identical for all tapes. No gaps were introduced among the 24 spliced segments. A 1000-Hz signal, to be used for timing purposes, was dubbed onto the audio track at the last frame in which the jogger appeared in each of the 16 stimulus segments of each tape. Test Tapes A through D were assigned to the subjects in order of appearance.

Test tapes were presented silently on a 68.6-cm (27-in., diagonal-measure) color video monitor and viewed at a distance of 57.4 cm, which provided angular visual
dimensions matching the original environments. Subjects responded by means of a spring-loaded pedal. Closure of this switch started a hardware clock (John Bell) in an Apple II+ microcomputer. The clock was stopped by the 1000-Hz signal from the audio track of the tape. The time that elapsed between the subject’s response and the last video frame containing the jogger was then stored as the time before impact. Responses during blank segments were recorded as false alarms.

**Procedure.** Subjects were tested individually in a laboratory room approximately 3 m wide and 4 m long. Subjects were seated the appropriate distance from the video monitor and instructed to keep their backs pressed firmly against the chair. A footrest with the response pedal was then positioned at a comfortable distance on the floor.

Subjects were told that they would be viewing a 33-min videotape of nighttime driving recorded from a moving car. A jogger would appear occasionally along the right side of the road ahead. They were instructed to step on the brake pedal immediately upon seeing the jogger, regardless of whether the jogger appeared to obstruct the path ahead. Subjects were told that the “brake” response would have no effect on the apparent speed of travel, and it was stressed that they should hold the pedal in the depressed position until the jogger disappeared from view as this was necessary for the computer program to function properly. The subjects were warned that the videotape might seem somewhat tiresome, but they were asked nevertheless to maintain constant attention. As added encouragement, they were told that “false alarms” would be recorded, and if there was evidence of inattention, the entire procedure would have to be repeated. This provision was not exercised for any of the subjects.

After any questions were answered, the subject was asked to sign an informed consent form and was told the experimenter would return following the 33-min videotape. The experimenter then started the computer program and video player, extinguished the room lights, and left the subject to complete the task alone and with no distractions. Following the task, the subject was debriefed.

**Results**

Recognition performance was defined operationally as the time before impact. Misses were recorded as zero time before impact, and the number of false alarms was counted. Three subjects generated unusually high numbers of false alarms: they hit the brake 12 to 22 times ($M = 15.67, SD = 5.51$) when there was no jogger in view. The other 29 subjects generated 1 to 8 false alarms ($M = 5.21, SD = 4.45$). It appears that the three outlying subjects set their response criterion so low that they were not performing the intended task. They responded to irrelevant stimuli nearly as much as, or more than, they did to joggers. Because this strategy could increase error variance and obscure differences between conditions, these outliers were excluded from further analysis.

A technical problem with one of the videotapes resulted in failure to record some responses for the residential/biomotion condition, so all data for the residential condition were discarded. Also, for eight subjects in the dark/vest condition and one subject in the busy/biomotion condition, false alarms that closely preceded a target could not be distinguished from hits or misses. These ambiguous responses were treated as missing data and replaced with mean times before impact in subsequent analyses.

For the remaining three road environments, the overall mean time before impact was 3.11 s ($SD = 2.30$). Recognition performance for each of the retroreflective markings is illustrated in Figure 1, where longer times before impact indicate earlier
recognition. Mean data, averaged across all road environments, are illustrated in Panel A; data for the remaining three road environments are presented separately in Panels B, C, and D. The mean times before impact, averaged across markings, for each road environment, were: dark, $M = 2.67$ s ($SD = 2.46$); busy, $M = 2.74$ s ($SD = 2.00$); and lighted, $M = 3.70$ s ($SD = 2.22$).

An ANOVA confirmed significant main effects for both road environment, $F(2, 56) = 16.39$, $p < 0.0001$, $MS_e = 3.39$, and jogger markings, $F(3, 84) = 96.19$, $p < 0.0001$, $MS_e = 2.56$, and a significant interaction between road and markings, $F(6, 168) = 15.18$, $p < 0.0001$, $MS_e = 1.78$. We have adopted the convention proposed by Lehman (1991, p. 363) for reporting ANOVA results because it provides sufficient information to reconstruct the complete ANOVA summary table.

Post hoc Tukey tests (alpha = 0.01) of the main effect of markings revealed that (1) the three retroreflective treatments yielded significantly longer times before impact than did the dark control condition and (2) the bio-motion and stripes markings resulted in similar times before impact, which were significantly longer than were those with the vest.

Simple main effects analyses of markings were significant for all road environments:

![Graphs showing mean times before impact for four retroreflective markings in Experiment 1. Panel A presents data averaged across three road environments. Panels B–D illustrate the mean data separately for each road environment. Error bars represent ±1 standard error.](image-url)
dark, $F(3,84) = 32.31, p < 0.0001, MS_e = 2.96$; busy, $F(3,84) = 45.38, p < 0.0001, MS_e = 1.60$; and lighted, $F(3,84) = 84.09, p < 0.0001, MS_e = 1.51$. Post hoc Tukey tests (alpha = 0.01) revealed the following: (1) In the dark road environment, times before impact for the biomotion and stripes markings did not differ but were significantly longer than those for the vest and dark control markings, which also did not differ from each other. (2) In the busy road environment, performance with the biomotion markings was significantly better than that for the vest ($p < 0.05$), whereas there was no significant difference in performance between the stripes and biomotion markings, nor between the stripes and vest; performance for all retroreflective markings was significantly better than that for the dark control. (3) In the lighted road environment, performance for the stripes, which did not differ from that of the vest markings, was significantly better than that for the biomotion markings. The vest markings also elicited better performance than did the biomotion markings ($p < 0.05$), and again, performance for all retroreflective markings was better than that for the dark control condition.

Discussion

The major finding of Experiment 1 is that the biomotion and stripes markings, which both included retroreflective material on the limbs, elicited responses that were significantly earlier than those obtained with a retroreflective vest. Not surprisingly, performance for all retroreflective markings was superior to that of the dark control. The special advantage predicted for biological motion was obtained in the busy road environment, in which performance for the biomotion markings was significantly better than for the vest, whereas that for the vest and stripes did not differ. Contrary to this result, performance in the lighted road environment (in which reflective markings might be expected to have the least effect) was best for the stripes and the vest.

These findings generally support the prediction that recognition performance is enhanced by dynamic visual information provided by markings of the limbs, at least when subjects are forewarned that pedestrians/joggers will appear fairly frequently. It is possible that the present test encountered a "ceiling effect" and that the potential advantages of biological motion would be more apparent under more challenging conditions. For example, drivers might recognize a person sooner in the biomotion than in the stripes configuration if the appearance of the pedestrian/jogger were more surprising or if the concurrent task of driving were more demanding of attention. To investigate this latter possibility, Experiment 2 tested recognition performance under conditions of divided attention.

EXPERIMENT 2

In order to make the laboratory simulation more similar to actual two-way driving, we replicated the procedure used in Experiment 1 with the addition of a secondary task, a video game called NightDriver (Atari). Also, the defective videotape was repaired so that we could assess performance for the residential road environment. In addition, before and after the last video test, subjects responded to brief questionnaires, which were designed to assess their personal precautions when walking or jogging at night, their impressions of the general visibility of pedestrians at night, and their preferences among the three retroreflective marking configurations used in the video simulation.

Method

Subjects. Twenty undergraduates (8 women and 12 men) served as paid participants.
Four were subsequently excluded from analysis because they failed to comply with instructions (see Results).

**Stimuli and apparatus.** We used the same apparatus and videotapes as in Experiment 1 except that the faulty tape had been repaired. In addition, a 22.9-cm (9-in., diagonal-measure) black-and-white monitor (Concord MR-700) was mounted in front and above the large color monitor, with its screen facing downward. A glass beam splitter, tilted 45 deg about the horizontal axis, superimposed the smaller screen near the center of the larger video display. Thus the image of the NightDriver video game was combined with the prerecorded night road environments in a position near the middle of the road scene, adjacent to but not obstructing the area where joggers would appear.

**Procedure.** Subjects followed the same procedure and were given the same instructions used in Experiment 1, with the addition of the following secondary task. Before beginning the test procedure, each subject played three practice rounds of the video game, which involved a two-dimensional tracking task controlled with a joystick. After the third practice run, the computer program and test tapes were started, and the subject commenced the primary task while continuing the video game. The experimenter remained in the room to reset the video game as necessary throughout the 33-min test period. As in Experiment 1, the time before impact of each correct braking response, as well as the number of false alarm responses, was recorded automatically. Subjects were encouraged to maintain constant attention to the primary task of detecting pedestrians while also trying to earn good scores on the video game task. As an added incentive, subjects received a 10¢ bonus for each correct braking response.

Prior to testing, each subject was informed of the procedure and encouraged to ask questions before signing an informed consent form. Also, before and after the test procedure, subjects filled out brief questionnaires (see Appendix B).

**Results**

Four subjects made an extraordinary number of false alarms (range = 14 to 37, $M = 20.75$, $SD = 11.10$) compared with the other subjects ($n = 16$, range = 1 to 8, $M = 4.75$, $SD = 2.24$). Using the same logic as described for Experiment 1, these subjects were excluded from further analysis.

The overall mean time before impact of braking responses was $1.31$ s ($SD = 1.64$), substantially shorter than that obtained in Experiment 1 ($3.11$ s), indicating that the secondary task did impede recognition of the joggers. Data for each of the retroreflective markings are illustrated in Figure 2 using a format comparable to that in Figure 1. As in Experiment 1, responses occurred longer before "impact" for all retroreflective treatments than for the dark control, and there is an overall tendency for longer times before impact for the stripes and biomotion markings than for the retroreflective vest. The mean times before impact, averaged across markings, for each road environment were: dark, $M = 1.57$ s ($SD = 1.89$); residential, $M = 1.39$ s ($SD = 1.97$); busy, $M = 1.04$ s ($SD = 1.37$); and lighted, $M = 1.46$ s ($SD = 1.66$).

An ANOVA showed a significant main effect for markings, $F(3,45) = 28.7$, $p < 0.0001$, $MS_e = 2.02$, and a significant interaction between roads and markings, $F(9,135) = 3.76$, $p < 0.05$, $MS_e = 1.69$, but no main effect of road environment, $F(3,45) = 1.41$, $p = 0.25$, $MS_e = 2.42$. Post hoc Tukey tests (alpha = 0.01) showed again that performance for all retroreflective treatments was significantly better than that for the dark control. Of greater interest, they also showed that performance was significantly better for biomotion...
Figure 2. Mean times-before-impact for four retroreflective markings in Experiment 2. Panel A presents data averaged across four road environments. Panel B–E illustrate the mean data separately for each road environment. Error bars represent ±1 standard error.

markings than for the vest, as was that for the stripes (alpha = 0.05). Moreover, although the Tukey test showed no performance difference between the biomotion markings and the stripes, a planned comparison for this contrast alone showed significantly better performance for the biomotion configuration than for the stripes, F(1,15) = 4.56, p < 0.05, MSc = 1.73.

Simple main effects analyses of the markings were again significant for all roads: dark, F(3,45) = 7.63, p < 0.0001, MSc = 2.47; residential, F(3,45) = 14.63, p < 0.0001, MSc = 1.72; busy, F(3,45) = 6.03, p < 0.002, MSc = 1.11; and lighted, F(3,45) = 10.41, p < 0.0001, MSc = 1.78. Post hoc Tukey tests (alpha = 0.01) showed that performance was better for the biomotion markings than for the dark control in the dark, residential, and lighted road environments. Also, the relative advantage of the biomotion treatment was greatest in the residential environment, where it yielded performance significantly better than that for the vest. The stripes treatment showed some advantage, being better than the dark control and the vest (p < 0.05) in the dark road environment.

The subjects’ responses (N = 20) to questionnaire items concerning their personal exposure and clothing as nighttime pedestrians are summarized in Table 1. Seventy percent of the subjects (14/20) indicated that they walked/jogged “sometimes” or “often” at night. Comparison of responses before and after the experiment showed that most subjects reported stronger inclinations to wear light or reflective clothing after completing the video task. Prior to the task, 25% reported “rarely” wearing white or light clothing when venturing out at night, and 30% reported “often” wearing such clothing at night. Following the task, only 5% reported that they would rarely “make it a point to wear white or light clothing,” whereas 70%
said they would “often” do so. This pattern of responses is significantly different from the initial pattern of responses, Wilcoxon $T^+$ (10) = 55, $p < 0.002$. Regarding use of reflective clothing, prior to the task 65% reported that they “rarely” used it. Following the task, 80% reported that they would “make it a point to wear” reflective clothing “sometimes” or “often” in the future, also a significantly different pattern of responses, $T^+(12) = 78, p < 0.0004$.

The subjects also revised their estimates of pedestrian visibility after participating in the simulated night driving task. The mean estimates of visibility distance for light- and dark-clad pedestrians obtained before and after the task are presented in Table 2. Following the simulated night driving task, the estimated visibility distance for a light-clad pedestrian decreased by 61.8%, from 38 m (123.6 ft) to 14.5 m (47.2 ft), which represents a significant shift, $t(19) = 3.19, p < 0.005$; that for dark-clad pedestrians decreased by 70.3%, from 17.7 m (57.4 ft) to 5.2 m (17 ft), also a significant shift, $t(19) = 3.65, p < 0.001$.

On the post-task questionnaires, 85% (17/20) of the subjects selected the biomotion markings as the “easiest to see.” Of the remaining three subjects, two selected the vest and one selected the stripes as the “easiest to see.”

**GENERAL DISCUSSION**

The present experiments provide new evidence that dynamic visual information created by retroreflective markings on the limbs can enhance recognition of pedestrians at night. Our results indicate that limb markings are particularly effective when attached to the major joints, to exploit the perceptual benefits of biological motion (Johansson, 1973, 1975, 1985).

Beyond the well-known advantage of retroreflective material on the torso, both experiments showed that markings of the limbs yielded significantly earlier recognition and response to the jogger. In Experiment 1, performance was significantly better (i.e., greater times before impact) for the biomotion and stripes treatments than for the retroreflective vest. The addition of a secondary task in Experiment 2 resulted in an overall reduction of recognition performance, yet the biomotion treatment still yielded significantly earlier recognition than did the retroreflective vest, whereas the stripes configuration yielded intermediate performance. Performance for the biomotion treatment was found to be significantly better than that

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**TABLE 1**

Percentage of Subjects Responding to Each Questionnaire Item Before and After the Simulated Driving Task

<table>
<thead>
<tr>
<th>Response Category</th>
<th>Exposure at Night</th>
<th>Would Wear White or Light Clothing</th>
<th>Would Wear Reflective Clothing</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>Rarely</td>
<td>30%</td>
<td>25%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(5)</td>
<td>(1)</td>
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<tr>
<td>Sometimes</td>
<td>40%</td>
<td>45%</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>(8)</td>
<td>(8)</td>
<td>(5)</td>
</tr>
<tr>
<td>Often</td>
<td>30%</td>
<td>30%</td>
<td>70%</td>
</tr>
<tr>
<td></td>
<td>(6)</td>
<td>(6)</td>
<td>(14)</td>
</tr>
</tbody>
</table>

*Note: Number of subjects that responded are in parentheses.*
for the stripes, which marked the limbs but not at the major joints. A perceptual advantage of the biomotion configuration was also evident to the subjects, as 85% of them selected it as the "easiest to see."

The data also provide some evidence of interactions between the road environment and marking configurations. Such interactions might be expected because of variations in conspicuity of the targets that are associated with the overall quality, and the signal-to-noise ratio, of the visual information. The present results are not consistent in this regard, however, and they are not easily interpreted. In Experiment 1 (Figure 1), performance with the biomotion markings was superior to that for the vest in the busy environment. No such difference (and indeed a contrary trend) was obtained with the same busy environment in Experiment 2 (Figure 2). Also, in Experiment 1 performance for the stripes marking was found to be superior to that of the biomotion treatment in the lighted environment, yet no such difference was obtained with the same environment in Experiment 2. Perhaps the most interesting comparison lies in the residential environment, where the biomotion markings yielded superior performance in Experiment 2, but because of technical problems, this finding could not be corroborated by data from Experiment 1. The discrepancies between the two experiments may reflect higher-order, and as-yet-uninvestigated, interactions among the tasks, marking configurations, and road environments. It is possible, for example, that earlier recognition of the biomotion markings occurs in the visually complex busy condition only when the subject has no distractions and that this advantage is lost in the presence of a secondary task.

Interpreting the interactions between pedestrian markings and road environment is also problematic because of limitations inherent to video reproduction. Rendition of the night road appeared qualitatively realistic for areas and objects of low to moderate luminance, but because of restricted dynamic range, video recordings of high-luminance stimuli appeared overexposed, creating an unrealistic "blooming" of the image. This effect was especially troublesome for small, bright targets, such as the components of the biomotion configuration, which looked like small balloons rather than the distinct light points seen under natural viewing. Although subjects did not complain, this effect may have diminished the clarity and salience of the jogger's limb movements. Indeed, video rendition of all retroreflective markings appeared somewhat unrealistic to the experimenters, particularly when combined with other irrelevant luminous stimuli in the busy environment. We believe, however, that limitations of the video image cannot account for superior performance with the biomotion markings. To the contrary, video blooming degraded the appearance of the biomotion configuration more than it did the other retroreflective markings.

Our subjective impression of limited image fidelity is consistent with the fact that recognition responses with the video simulation came at substantially shorter distances than those found in field studies. When converted to distances through multiplication by speed of the recording vehicle (36.7 ft/s, or 11.3 m/s),
one finds in Experiment 1 that mean recognition distances varied from 7.7 m (25 ft) for the dark-clad jogger to 48 m (156 ft) for the stripes and biomotion markings. In Experiment 2, the mean recognition distances were shorter, ranging from 2.2 m (7 ft) for the dark-clad jogger to 29.2 m (95 ft) for the biomotion marking. For comparison, the median recognition distance reported by Johansson and Rumar was 23 m (74.8 ft), and mean values reported by Blomberg et al. (1986) ranged from 15 m (49 ft) for a dark-clad pedestrian to 134.2 m (436 ft) for the retroreflective rings marking. Clearly, field tests will be necessary to determine (1) the magnitude of improvements in pedestrian conspicuity afforded by biological motion and (2) the extent to which such improvements interact with variations in the road environment. It would also be interesting to investigate the effectiveness of various retroreflective markings from different points of view. As noted earlier, perceptual advantages of biological motion may be greater from a side view, which would present more evident pendular motions of the limbs.

The video simulation had an unexpected effect on subjects' impressions of the hazards associated with night driving. Following the test procedure in Experiment 1, many subjects expressed astonishment at how difficult it was to see the joggers. Their comments did not indicate dissatisfaction with the quality of the video reproduction but, rather, implied that the video test had increased their appreciation of a general visibility problem in night traffic environments. As a first step toward assessing such effects, questionnaires were introduced in Experiment 2. Subjects' responses after the test procedure suggested increased willingness to take personal precautions at night (Table 1). Subjects also significantly reduced their estimates of the visibility distances of pedestrians at night (Table 2). It is possible that these responses were influenced by demand characteristics of the experimental situation, but such social effects might also be expected at the outset of the experiment, when the subjects expressed less caution.

It would be interesting to know whether participation in the video simulation test led to behavioral changes and, if so, how long these changes persist. The literature indicates that many road users, drivers and pedestrians alike, fail to appreciate the hazards of nighttime driving (Allen et al., 1969; Hazlett and Allen, 1968; Leibowitz and Owens, 1986; Olson, 1987; Olson and Sivak, 1983; Shinar, 1984). Greater efforts to inform the public about the dangers of night driving might be beneficial, but it is not clear how such information is best presented. Perhaps a video simulation that involves recognition of low-visibility hazards would be more effective than verbal admonitions. Further exploration of this approach to road-user education may be worthwhile.

Previous efforts to predict and improve the visibility of pedestrians at night have emphasized the role of luminance, contrast, and area of clothing or supplemental markings (e.g., Hills, 1975a, 1975b, 1976; Shinar, 1985). These variables are critical for detection of a weak visual stimulus, but they do not predict recognition of complex suprathreshold targets, such as a pedestrian. The present study emphasizes a different approach to visual perception. As outlined earlier, research by Johansson and others has demonstrated that perception of complex events is readily afforded by dynamic visual information. The fidelity and utility of this dynamic information are independent of static spatial variables, provided that stimulation exceeds the threshold for detection. The structure of biological motion is not defined by luminance or area but, rather, by relative movements.
within the stimulus array. The motion per se constitutes information for perception. When visible elements are properly isolated, as with biomotion markings, their relative movements accurately convey the biomechanical characteristics of the object in motion or, in the case of humans, the person in action. This information is sufficient for compelling and practically instantaneous recognition. The present experiments aimed to extend these theoretical insights to the problem of nighttime pedestrian visibility. Although more work will have to be done to establish the value of this approach, the preliminary findings are promising.

ACKNOWLEDGMENTS

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APPENDIX A
Order of Video Segments (Road/Jogger)

<table>
<thead>
<tr>
<th>Tape A</th>
<th>Tape B</th>
<th>Tape C</th>
<th>Tape D</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Dark/Vest</td>
<td>(16)</td>
<td>(6)</td>
<td>(11)</td>
</tr>
<tr>
<td>— Busy/(No jogger)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— Residential/(No jogger)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) Residential/Biomotion</td>
<td>(15)</td>
<td>(5)</td>
<td>(12)</td>
</tr>
<tr>
<td>— Busy/Stripe</td>
<td>(14)</td>
<td>(8)</td>
<td>(9)</td>
</tr>
<tr>
<td>— Lighted/(No jogger)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3) Lighted/Dark</td>
<td>(13)</td>
<td>(7)</td>
<td>(10)</td>
</tr>
<tr>
<td>— Dark/Biomotion</td>
<td>(12)</td>
<td>(2)</td>
<td>(15)</td>
</tr>
<tr>
<td>— Residential/(No jogger)</td>
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</tr>
<tr>
<td>(4) Residential/Stripe</td>
<td>(11)</td>
<td>(1)</td>
<td>(16)</td>
</tr>
<tr>
<td>— Residential/(No jogger)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(5) Residential/No jogger</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

(7) Busy/Dark                  | (10) | (4) | (13) |
(8) Lighted/Vest               | (9)  | (3) | (14) |
(9) Dark/Stripe                | (8)  | (14) | (3) |
  — Busy/(No jogger)           |      |      |      |
(10) Residential/Dark          | (7)  | (13) | (4) |
(11) Busy/Vest                 | (6)  | (16) | (1) |
(12) Lighted/Biomotion         | (5)  | (15) | (2) |
(13) Dark/Dark                 | (4)  | (10) | (7) |
  — Residential/Vest            | (3)  | (9)  | (8)  |
  — Dark/(No jogger)           |      |      |      |
(14) Busy/Biomotion            | (2)  | (12) | (5)  |
(15) Lighted/Stripe            | (1)  | (11) | (6)  |

APPENDIX B
Questionnaires for Experiment 2

Pretask:
1. How often do you take walks and/or jog at night?
   rarely sometimes often

2. Do you ever make it a point to wear reflective clothing?
   rarely sometimes often

3. Do you ever make it a point to wear white or light clothing?
   rarely sometimes often

4. Do you run/walk on the street or on the sidewalk?

5. Estimate the distance at which a pedestrian can be seen at night
   wearing light clothing________________
   wearing dark clothing_________________

Posttask:
1. Will you ever make it a point to wear reflective clothing?
   rarely sometimes often

2. Will you ever make it a point to wear white or light clothing?
   rarely sometimes often

3. Estimate the distance at which a pedestrian can be seen at night
wearing light clothing

wearing dark clothing

4. Which pattern was the easiest for you to see?

- dark stripes
- vest
- biological

REFERENCES


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