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Nighttime Pedestrian Conspicuity: The Effects of Pedestrian Movement, Orientation and the Configuration of Retroreflective Material

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NIGHTTIME PEDESTRIAN CONSPICUITY: THE EFFECTS OF
PEDESTRIAN MOVEMENT, ORIENTATION AND THE
CONFIGURATION OF RETROREFLECTIVE
MATERIAL

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ABSTRACT

Most fatal collisions between vehicles and pedestrians occur at night; inadequate visibility is a key factor. Previous research has shown that positioning reflective markers on pedestrians in a manner that depicts biological motion greatly enhances conspicuity. This on-road experiment examined the conspicuity advantages of a full biological motion configuration relative to that provided by an ANSI class II safety vest. 120 healthy young participants were driven along a 3.5 mile route and pressed a button when they were confident they saw a pedestrian. A test pedestrian on the left shoulder of the roadway wore black clothing with either an ANSI class II safety vest, the same vest with added ankle straps, or a full biological motion configuration. The pedestrian either faced the oncoming vehicle or the roadway while either walking in place or standing still. Response distances were maximal when motion information was present and when the pedestrian faced the test vehicle. These results indicate the conspicuity of pedestrians wearing an ANSI class II safety vest can be significantly enhanced by simply adding retroreflective material to the ankles.

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INTRODUCTION

Over 4,500 pedestrians are killed, and approximately 15 times as many are injured, in vehicle collisions in the US each year (NHTSA, 2004). This equates to an average of one pedestrian fatality every 111 minutes and a pedestrian injury every 8 minutes. Despite a reduction in the density of both vehicle (National Safety Council) and pedestrian traffic at night, the majority of fatal vehicle-pedestrian collisions take place at night. In 2003, 64% of pedestrian fatalities occurred between 6pm and 6am.

Driver intoxication has long been cited as a casual factor in vehicle crashes. In fact, Evans (1991) asserted that 47% of traffic fatalities are the result of alcohol. However, an analysis of the Fatality Analysis Reporting System (FARS) (1980-1990) revealed that while alcohol does play a role in vehicle collisions, drinking drivers are more likely to be involved in other types of collisions than those involving pedestrians or pedalcyclists (Owens & Sivak, 1996). Most vehicle-pedestrian collisions are attributed to degraded visibility, especially nighttime conditions; and cannot be attributed to factors such as alcohol, day of the week, or time of the day. In other words, even when other factors are held constant, pedestrian fatalities increase as illumination decreases.   Further support for poor visibility as a key casual factor in the overrepresentation of

vehicle-pedestrian collisions at night is provided in another analysis of the FARS.

Sullivan and Flannagan (2002) examined vehicle crash data from the FARS between 1987 and 1997. Vehicle collision data from the weeks surrounding the time change associated with Daylight Savings Time (DST) were examined. (DST involves setting clocks one hour ahead in the spring and returning to standard time in the fall; effectively making sunrise and sunset 1 hour later. Daylight Savings Time is observed by the majority of the United States.) This scenario provides the ability to look at crash data during similar periods of the day, when there would presumably be little change in vehicle or pedestrian traffic patterns. It was found that within the relevant time periods, pedestrian fatalities were 3-6.75 times more likely in dark than in light conditions. Despite the increase in pedestrian fatalities, it was revealed that there was a negligible increase in other types of vehicle crashes. A theory of differential visual system degradation is explored next as one possible explanation of the aforementioned crash rate discrepancy.

Under low luminance conditions focal visual functions such as acuity, contrast sensitivity, and visual accommodation are degraded, and consequently the ability to recognize and identify objects is also reduced. In fact, (at moderate latitudes) the first 30 minutes after sunset and before sunrise contain the most drastic changes in our visual abilities (Owens, Francis and Leibowitz, 1989). However, during similar low luminance

conditions the ability to use vision to guide one's self through the world remains intact (see Schneider, 1967, 1969). It has been hypothesized that this selective degradation of the visual system is responsible for drivers' overconfidence in their abilities when driving at night (Leibowitz & Owens, 1977). That is, even when acuity is very low at night, drivers are surprisingly good at steering their vehicle to stay within their intended lane (Brooks, Tyrrell, & Frank, 2005; Owens & Tyrrell, 1999). As a result of the continual feedback in maintaining road lane position, the selective degradation hypothesis asserts that drivers are unable to appreciate the extent to which they are unable to detect and recognize obstacles (especially those of low contrast). Thus this pattern of selective visual functions being degraded while others are more robust can lead to a reduction in the ability to detect inconspicuous pedestrians in or along the roadway without a concomitant reduction in speed – a pattern commonly referred to as "overdriving one's headlights" (Leibowitz, Owens and Tyrrell, 1998).

One possible solution to decreasing the number of nighttime pedestrian fatalities is to drive at lower speeds. According to the assured clear distance ahead (ACDA) rule, drivers are responsible for avoiding collision with obstacles that may appear in the roadway. The ACDA rule is a commonly accepted guideline for safe vehicle operation. When considering vehicle stopping distance and low nighttime visibility, most drivers regularly overdrive their headlights. Leibowitz, Owens, and Tyrrell

(1998) calculated that the stopping distance (including driver reaction time), when traveling at a relatively low speed (25 mph or 40 kph) with low-beam headlights, is 1.2 to 3 times greater than the visibility distance of an unexpected pedestrian who is dressed in dark clothing. Thus most motorists routinely violate the ACDA rule when driving at night, presumably increasing the chances of experiencing a collision. However, estimates by both Solomon (1964) and Cirillo (1968) state that the risk of a crash can be increased by up to 10,000 times if a driver voluntarily reduces his speed to 25 mph (40 kph) while surrounding traffic remains at a speed of 55 mph (88 kph). Given that reducing traffic flow to 25 mph or less in low luminance conditions is unlikely, how then can the likelihood of recognizing a pedestrian in time to avoid collision be increased?

One emerging technique to enhance the nighttime safety of pedestrians came about from a surprising source. In 1973, Gunnar Johansson reported data from a laboratory-based study of human motion perception that years later came to have important implications for roadway safety. Using point-light displays consisting only of dots to represent the major human joints (shoulders, elbows, wrists, hips, knees, and ankles), Johannson found that participants were able to identify the human biological motion from stimuli that were available for as little as 100-200ms. This influential finding was the catalyst for a large number of lab-based studies of "biological motion." Eventually, perceptual researchers found that observers are able to extrapolate a great deal of

information from point-light displays of biological motion including gender, emotion, and weight (e.g. Pollick, Lestou, Ryu, 2002). Remarkably, the ability to visually identify patterns of biological motion to recognize other humans can be seen in infants as young as 3-5 months (Bertenthal, Profitt, & Kramer, 1987). Other animals are also able to recognize the biological motion patterns of their species. In fact, when cats are shown point light displays, they are able to discriminate between the biological motion of other cats and random motion (Blake, 1993).

The ability to perceive biological motion, and the neural mechanisms that support this ability, has received considerable attention in the basic scientific literature in recent years. Importantly, however, several researchers have also explored the potential safety benefits of capitalizing on the visual ability to perceive biological motion as a way to enhance the conspicuity of pedestrians at night.

Basic scientific research by Alhström, Blake, and Alhström (1997) also found that viewers are able to recognize the human form with less than the 11 points traditionally used to depict biomotion. Using point-light displays, participants were asked to describe the motion of a point light display. Participants viewed displays that gradually depicted more and more of the 11 point lights that are traditionally used to show biomotion. When only the two points representing the ankles were present, participants had difficulty recognizing the display as a human. The display was often given a description of some non-biological movement, such as

leaves blowing in the wind. However, simply adding the points representing the knees, a very different image was portrayed to participants. Even with these few elements of the human form present, observers readily described the biological motion of a human walker.

It has been suggested that if pedestrians take steps to increase their conspicuity, they will be less likely to be involved in a vehicle collision (Lesley, 1995). Retroreflective markings, which reflect light back towards the source, are often used to make objects more conspicuous at night (e.g. road signs, roadway lane delineators, tractor-trailers, clothing of emergency personnel). Evidence of the success of retroreflective material in enhancing object conspicuity can be seen in its application to heavy trailers.

In December 1993 NHTSA amended Federal Motor Vehicle Safety Standard (FMVSS) Number 108 to require all new heavy trailers (e.g. tractor trailers) to be outfitted with red and white retroreflective tape, sheeting and/or reflectors. The amendment was designed to increase the conspicuity of heavy trailers. Eight years later, an analysis of crash data involving heavy trailers revealed the success of the reflective markings (NHTSA, 2001). The analysis utilized data from the states of Florida and Pennsylvania. After outfitting heavy trailers with reflective material there were significant reductions in many different types of collisions. In dark conditions, when retroreflective tape is most effective, there was a 44% reduction in crashes resulting in injury (both fatal and non-fatal) to at least

one driver. In addition there was a 17% reduction in side-impact collisions and a 43% reduction in rear collisions. It can be concluded then, that the use of retroreflective material, which is inexpensive and which does not require a power source, can successfully reduce crashes with inconspicuous hazards.

It has also been shown that retroreflective material is successful in allowing pedestrians to be visible from greater distances (e.g. Hazlett & Allen, 1968; Shinar, 1984; Blomberg, Hale, & Preusser, 1986; Owens, Antonoff, & Francis, 1994; Luoma, Schumann, & Traube, 1996). Several studies have shown that positioning retroreflective markers in the biological motion configuration established by Johansson has shown to be greatly effective in increasing nighttime pedestrian conspicuity. For example, in a recent study participants were driven along a test track and asked to press a touch pad when a pedestrian (walking in place) was recognized along the side of the roadway. Both younger and older drivers participated in the experiment. In the most difficult condition (low-beam headlights and glare), only 5% of the pedestrians wearing all black clothing were recognized by participants. Amazingly, under the same difficult conditions, all pedestrians (100%) wearing the full biomotion retroreflective configuration elicited responses from the young drivers; and the older drivers 70% of pedestrians under the same conditions (Wood, Tyrrell, and Carberry, 2005).

Blomberg, Hale, and Preusser (1986) applied aspects of the basic scientific research on biological motion to nighttime pedestrian conspicuity. In this on-road study, participants drove along a 13.68 kilometer (8.5 mile) route and verbally responded when they detected a possible pedestrian and when confident in the presence of a pedestrian walking in place along the roadway. The pedestrians wore one of five clothing conditions:

1. Jeans and white T-shirt (baseline)

2. Baseline clothing + 2 retroreflective dangle tags at the waist

3. Baseline clothing + a flashlight

4. Baseline clothing + a jogging vest consisting of fluorescent and retroreflective materials

5. Baseline clothing + rings retroreflective material on a headband, wrists, ankles, and a belt

The rings condition, although it does not incorporate all points at which Johansson placed biological indicators, maintains the human form and conveys some degree of biological motion. In fact, despite the lack of markings on the elbows, shoulders, and knees, the pedestrians wearing the 'rings' were recognized as humans at a mean distance of 133 m (436 ft), which was greater than all other conditions. It should also be noted that the pedestrians carrying the flashlight were *detected* at a much greater distance than all other conditions. However, they were not able to

be *recognized* as humans at a comparable distance; a factor that presumably effects how drivers react to objects along the roadway.

The first study to take full advantage of the basic scientific research of Johansson and apply it to nighttime pedestrian conspicuity was conducted by Owens, Antonoff, and Francis in 1994. In this study, participants watched a film of a nighttime roadway environment and were asked to respond to the presence of pedestrians by pressing a brake pedal. Jogging pedestrians wearing retroreflective material on the major joints (ankles, knees, hips/waist, wrists, elbows, and shoulders) were significantly more conspicuous than joggers wearing a retroreflective jogging vest or no retroreflective material (i.e., all black). Subsequent research has supported these findings and it is well established that the biological motion configuration (from here forward referred to as biomotion) greatly increases pedestrian conspicuity (e.g., Luoma, Schumann & Traube, 1996; Wood, Tyrrell & Carberry, 2005, Balk, Carpenter, Brooks, & Tyrrell, 2006).

One study, however, failed to observe a conspicuity advantage of the biomotion configuration of retroreflective material. Moberly and Langham (2002) filmed a pedestrian wearing either an EN471 (European safety standard) class I safety vest, consisting of two horizontal retroreflective stripes or a biomotion configuration of retroreflective material. The pedestrian was positioned along the side of the roadway which contained a reflectorized bridge and either stood still or walked in place along the

roadway. The pedestrian was in a side-on orientation; that is they were facing the roadway, not the oncoming vehicle. Participants viewed the recording and were asked to respond when confident that a pedestrian was in view. Not surprisingly, when the pedestrian was walking in place (which reveals a great deal of biological information) he was seen from a greater distance than when standing still. Surprisingly, however the biomotion condition failed to yield a conspicuity advantage over the vest condition. The authors attribute this result to substantial visual clutter (including ambient lighting). However, insufficient information about the nature of clutter is given. Nevertheless, this video-based study is the only one to date which has failed to observe a conspicuity advantage with biomotion; while a great deal research provides evidence for the conspicuity benefits associated with biomotion configurations of retroreflective material.

Basic scientific research has demonstrated that the observers are readily able to recognize the human biological motion in both a 'face-on' view and a 'side-on' (profile) view (e.g. Johansson, 1973; Varnie and Verfaillie, 2004). By comparison, however, there are only two studies that explore the benefits biomotion retroreflective configurations when pedestrians are not facing oncoming traffic; specifically, when pedestrians are in a position to cross the roadway. Only, one study has systematically varied pedestrian orientation. As many vehicle-pedestrian collisions occur in intersections (NHTSA, 2004), some subset of pedestrians are struck

when crossing the roadway. It is therefore important to examine the extent to which biomotion and other retroreflective material configurations can increase the conspicuity of pedestrians in position to cross the roadway.

Luoma, Schumann, and Traube (1996) examined the effects of biomotion on both pedestrians facing an oncoming vehicle and pedestrians that were in a side-on orientation (a profile view of the pedestrian to the participant). Participants (sitting in the front and rear passenger seats of an experimental vehicle) were asked to respond to pedestrians along the roadway that were wearing either no retroreflective material, retroreflective material on the ankles and wrists, the torso, or in the biomotion configuration. In addition to these configurations, pedestrians were either walking along the right-hand shoulder of the road toward the experimental vehicle or walking back and forth across the roadway (thus a side-on orientation). As expected, pedestrians wearing the biomotion configuration were seen at a distance greater than the test pedestrians wearing only retroreflective material on the torso (two vertical strips, similar to a jogging vest) or no retroreflective material at all. Pedestrians wearing reflective material on the ankles and wrists were detected by participants at similar distances as pedestrians wearing the biomotion configuration. This perhaps is not surprising when taking into consideration that (especially when moving) there is presumably still a great deal of human biological information maintained and portrayed to the

observer when the ankles and wrists are marked (see Alhström, Blake, and Alhström, 1997).

Luoma, Schumann, and Traube also found that the pedestrians crossing the street back and forth were detected at a distance significantly greater than those pedestrians walking toward the oncoming test vehicle. Interpreting this finding, however, is made difficult by the fact that the orientation of the pedestrian was confounded with the location of the pedestrian. That is, the pedestrians walking toward the vehicle were positioned to the right of the roadway and the crossing pedestrians were always positioned *in* the roadway. Those pedestrians crossing the roadway were presumably more likely to spend more time in the participants' foveal vision, where pattern recognition (i.e. human motion pattern) is the greatest. Those pedestrians walking toward the vehicle, however, were less likely to be fixated by the participants, especially at short distances. In addition, the vehicle's headlight beam presumably provided more illumination on the center of the roadway than its side. Beyond this, the pedestrian crossing the street was not always seen in the same location on the roadway. That is, as a result of the pedestrian continually crossing the street (back and forth), he could be seen more to the right or left of the road. The pedestrian could also be seen crossing the street the right or crossing to the left.

In addition to pedestrian orientation, the presence or absence of motion is an important aspect to consider when investigating pedestrian

conspicuity. Nearly all pedestrian conspicuity research involves the test pedestrians walking – whether in place or locomoting along the roadway. Until recently, it has been assumed that the motion aspect of the biological motion configuration has been the 'key' to the conspicuity advantages of its application to nighttime pedestrians. Recent research however, has shown that the biomotion configuration can enhance pedestrian conspicuity even without pedestrian movement (i.e., Balk, et al., 2006). Balk, et al. point out that one possible advantage of the biological motion configuration is that outlining the human form can facilitate pedestrian detection. Thus form perception may be partly responsible for the biological "motion" advantages. This possibility has implications for those situations in which pedestrians stand in or near traffic flow with minimal movement (e.g. a construction worker holding a stop/slow sign, a police officer directing traffic, a pedestrian waiting to cross the street, etc.).

Recent work by Balk, et al. (2006) explored the benefits of different retroreflective material configurations both while standing still and walking in place. This technique provides the ability to examine the separate and combined effects of configuration and human motion (i.e. form perception and motion perception). Participants were passengers in a vehicle; who sat in either the front passenger seat or the rear left passenger seat. The person in the back seat was encouraged to lean forward and toward the center of the vehicle in order to achieve a more approximate view to that of the participant in the front passenger seat. The participants responded

to pedestrians who wore one of five clothing configurations, positioned to the right of the roadway. The clothing configurations included:

    1. Black: no retroreflective material

    2. Vest: a custom-made vest containing a rectangular patch of retroreflective material

    3. Ankles: retroreflective straps on both ankles

    4. Ankles + Wrists: retroreflective straps on both ankles and both wrists

    5. Biological Motion: retroreflective straps on the ankles, wrists, knees, elbows, shoulders, and waist.

The amount of retroreflective material that was exposed to the participants (302 cm^2) was held constant across conditions 2-5 above. No significant differences in pedestrian detection distances were found between the front and back seat positions. Much like previous research, pedestrians clad in the biomotion configuration were detected at greater distances than the other clothing configurations (*see* Figure 1).
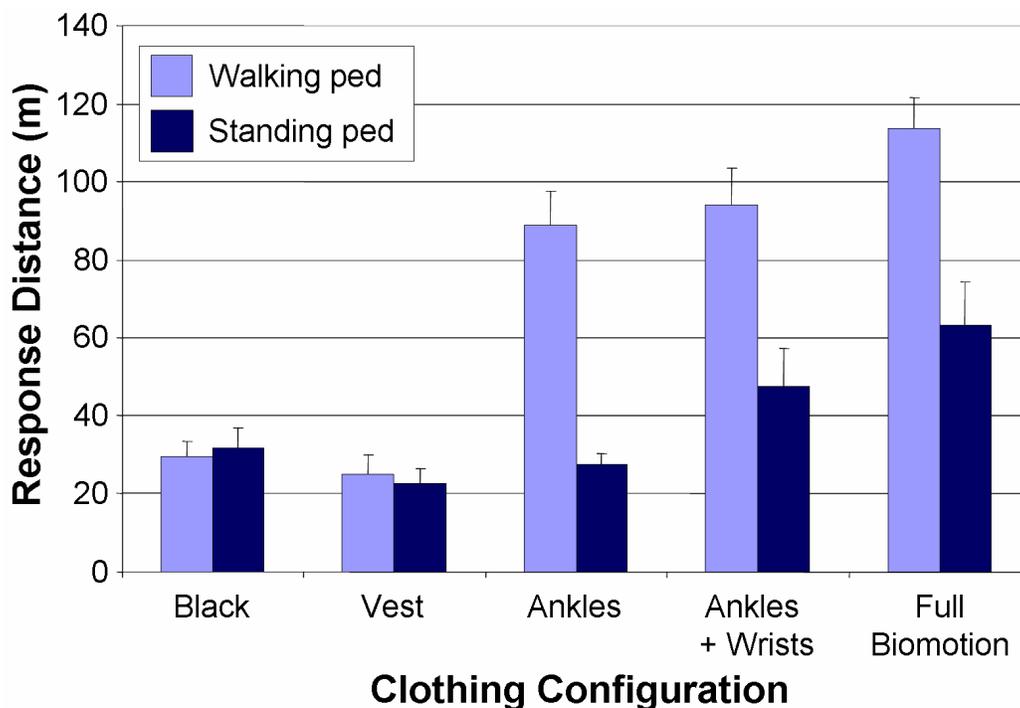
Figure 1. (From Balk et al., 2006) Mean response distance (+1 SEM) for the five clothing configurations, including pedestrians walking in place and standing still.

Interestingly, the biomotion advantage was present even when the pedestrians remained motionless. This illustrates the effects of outlining the static human form. This however, is not to say that motion does not aid in the ability to recognize pedestrians. In fact, pedestrians wearing the three configurations which identified the limbs with retroreflective material were seen at significantly greater distances when walking in place, as compared to those same clothing configurations when standing still. Perhaps the most surprising finding is present in the configuration for which the ankles alone are marked. Here, when standing still, the pedestrian is detected at distances similar to those wearing all black or a rectangle of retroreflective material on the chest. However, by simply

adding motion to the ankle straps, pedestrians were detected at a distance 3.3 times greater. These results suggest that *both* form perception and motion perception should be considered when designing configurations to maximize pedestrian conspicuity.

The present study seeks to explore the extent to which nighttime pedestrian conspicuity is influenced by retroreflective material configuration, motion, and pedestrian orientation. Specifically, it explores the benefits of retroreflective material in the full biomotion pattern and configurations that convey less biological motion information; both when pedestrians are in a side-on orientation to oncoming traffic and along the roadway facing oncoming traffic. Thus the advantages of biological motion configurations will be examined both in the presence and absence of pedestrian motion, and from two orientations. By testing the effects of the above manipulations in the context of an on-road investigation of pedestrian conspicuity, this study seeks to contribute to both basic (e.g., motion and form perception) and applied (pedestrian conspicuity) elements of the literature on human perception and performance. A key element of the design of the study is that it will rely on between-subjects manipulations in order to eliminate the possibility that the data could be influenced by any learning effects that might be associated with repeated exposure to experimental pedestrians. The following configurations of retroreflective material are tested: Full Biomotion, a Vest that complies with ANSI/ISEA class II garment standards, the same Vest with added

reflective Ankle straps. Each of the three clothing configurations maintains a consistent total retroreflective material surface area.

The vest chosen here was selected for several reasons. In 1999 the American National Standard Institute (ANSI) and the International Safety Equipment Association (ISEA) released the American National Standard for High-Visibility Safety Apparel and Headwear (standard number 107-1999). While the standard is voluntary, compliance with the standard is generally encouraged. The Occupational Safety and Health Administration (OSHA) standards require that employees that are exposed to traffic to wear high visibility clothing. OSHA points to the ANSI/ISEA 107-1999 standard as a viable method which employers/employees can use to comply with its requirement (OSHA regulation: 29 CFR 1926.651(d)). As many employers seek to provide their employees to standard-compliant attire, it is important to better understand at what distances pedestrians wearing compliant clothing are actually recognized. Furthermore, it is important to determine if compliant clothing generates response distances similar to those of a full biological motion configuration, which has shown to generate great pedestrian recognition distances. Is it also possible to increase the conspicuity of pedestrians wearing an ANSI/ISEA class II garment by adding a small amount of biological form information (i.e. highlighting the ankles via ankle straps)? If so, this simple application of two ankle straps can provide a practical way (low cost, easy to put on, does not add heavy clothing in warm

weather, maintains compliance with ANSI/ISEA standard, etc.) to increase

roadway worker conspicuity. Thus a key purpose of the present study is to

quantify the extent to which the incorporation of biological motion

elements can enhance conspicuity above what is provided by ANSI-

certified safety vests.

METHOD

Participants. 152 undergraduate Clemson University students (18 – 28 years, M = 19.4 years; 65 males) participated in this study in exchange for extra credit. Data from 32 participants were eliminated (and replaced) in the data set as a result of the presence of headlights from extraneous vehicles, or technical difficulties. Thus data from a total of 120 participants are reported (10 participants in each of the 12 possible pedestrian clothing x movement x orientation combinations). In order to eliminate the possibility of practice effects, a between subjects design was utilized. That is, each participant was only exposed to one experimental pedestrian.

Procedure. Each experimental session was divided into two portions, lasting a total of 20 – 30 minutes. Two participants participated in most trials. Half of these participants sat in the back seat of the test vehicle; the other half sat in the front passenger seat.

Data collection occurred at least one hour after sunset and concluded before midnight each night. No data were collected if there was rain, fog/haze or any other inclement weather present or if the roadways were not completely dry.

The first portion of the session took place in a laboratory. After the procedures were described and informed consent was obtained,

participants' binocular visual acuity was quantified using a high contrast

Bailey-Lovie chart; all achieved at least 6/12 (20/40) acuity. Contrast

sensitivity was also assessed using the Pelli-Robson letter sensitivity

chart; all achieved at least a score of 1.65 (M = 1.68). After the

completion of vision testing and instructions, participants walked outside to

the test vehicle (2005 Scion Xb).

In each pair of participants, each was randomly assigned to either the

front right seat or the rear right seat of the test vehicle. An experimenter

encouraged the participant in the back seat to lean forward and to the

center of the vehicle, in order to more closely approximate the view of the

participant in the front seat. Once in the vehicle, the participants fastened

their seatbelts and held a response device (Logitech dual shock game

controller). This controller was connected, via USB port, to a laptop

computer that an experimenter in the back seat held. Music was played at

a moderate volume in order to mask any noise made by responses on the

controller (which might otherwise trigger the second participant to

respond). The experimenter in the back seat reminded participants of the

task instructions and were told:

"Please press the padded button on your controller as soon as you are

confident that you see a pedestrian."

After the experimenter in the back seat answered any questions the

participants asked, the driver of the test vehicle started driving a 5.6 km

(3.5 mile) route. Throughout the drive low beam headlights were used

and the driver did not exceed the posted speed limits. The headlights and windshield were wiped clean each night prior to data collection. The test pedestrian (one of three male experimenters, each approximately 173 cm, 178 cm, and 180 cm tall) stood on the grassy shoulder to the left of a stretch of a two-lane roadway (Old Stadium Road) in an area free of ambient lighting (light meter measurement). (Each of the three males who acted as the pedestrian wore each of the clothing configurations an approximately equal number of times.) In daylight, the pedestrian could be seen at a distance of 206.7 m (678 ft). The roadway, which approaches an entrance to a golf course, travels through a low traffic, non-residential, semi-rural area. Data from trials in which extraneous traffic was present near the test pedestrian were excluded. This allowed for consistent conditions across trials. If the driver detected either oncoming or trailing traffic near the road on which the experimenter pedestrian was standing, the driver followed an alternative route. The alternative route involved driving past the Old Stadium Road turn, making a loop and returning to Old Stadium Road. This was generally successful at preventing extraneous traffic (*see* Figure 2).

Figure 2. Route driven by the experimenter. The rectangle represents the starting location and the stick figure represents where the pedestrian was positioned. The alternative route utilized to avoid extraneous traffic involved following Cherry Road and turning left on to Lewis Road, making a loop and returning to Cherry Road. (The underlying map was taken from Google Maps, http://maps.google.com.)

The pedestrian wore one of three different clothing configurations, either stood still or walked in place, and either faced the approaching test vehicle or faced the roadway such that the pedestrian's right side faced the test vehicle. The pedestrian always wore all black clothing; including long-sleeve shirt, pants, gloves, hat, socks, and shoes. The clothing configurations utilized the all black clothing plus 1591.3 cm^2 (246.6 in^2) silver (glass bead technology) retroreflective material added. The route leading to the test pedestrian included numerous retroreflective stimuli, including road signs and raised pavement markers. To help determine the extent to which retroreflective objects in the environment might trigger

participants to respond (i.e., to elicit false alarms), a traffic cone (approximately 28" tall with two retroreflective bands) with retroreflective trim was positioned on the right shoulder at a point of the route prior to the test pedestrian. The cone elicited no response from any participant. Throughout the trial, participant responses were monitored (at a minimum of 4 locations) to ensure both that participants did not respond at random and that responses were made to non-experimenter pedestrians.

Each of the three clothing configurations Vest, Vest + Ankles, and Full Biomotion (described in greater detail below) contained the same total retroreflective surface area and an equal amount of material on the front and the back of each garment. This was achieved by disassembling vests identical to that used in the Vest only and Vest + Ankles configurations and using the strips of retroreflective material to create the Full Biomotion configuration and the ankles straps for the Vest + Ankles configuration. In order to achieve the same amount of total retroreflective surface area, in the Vest only configuration small strips of material were added to each of the vertical strips (front and back) and the horizontal strip of material on the vest. The total amount of material added to the vest is equivalent to the surface area of the ankle strips in the Vest + Ankles and the Full Biomotion configurations. The Vest remained compliant with ANSI class II garment standards. The addition of material to the ankles served to add a degree of biological form and movement that is not present in the Vest only condition. Recall, that previous work has shown that viewers are able

to recognize human movement even when not all of the traditional elements of the full biomotion configuration are present (e.g., Alhström, Blake, and Alhström, 1997; Balk et al., 2006). The potential benefit of moving a small amount of retroreflective material is quite large. That is, it is expected that the vest in the Vest + Ankles configuration the vest will act as an attention capturing mechanism (a lot of retroreflective material in a concentrated area + an aspect of familiarity) and the straps on the ankles will serve to identify the retroreflective object as human, by revealing both human form and motion.

1. *Vest:* a commercially available lime yellow vest, compliant with ANSI class II garment standards (American National Standard for High-Visibility Safety Apparel, standard number: ANSI/ISEA 107-1999, June 1999). Additional retroreflective material (from an identical vest) was added to the vest. To equate the total amount of retroreflective material while not fundamentally altering form / outline of the retroreflective trim, 210.8 cm^2 of retroreflective material was added to the vest by slightly widening each strip of retroreflective material. This was done in order to maintain the same total amount of retroreflective material across clothing configurations. The vest remained compliant with ANSI class II garment standards (*see* Figures 3 & 4).

2. *Vest + Ankles*: the same commercially available vest plus retroreflective straps on both ankles (each approximately 40 cm long and 2.6 cm wide). Only 13% of the total retroreflective material [from the Vest

only configuration was moved to the ankles in this configuration. The ankle straps were constructed by disassembling an identical ANSI class II vest (*see* Figures 3 & 4).

    3. ***Full Biological Motion***: retroreflective straps (obtained by dissecting two vests identical to those used in the two other clothing configurations) on the ankles, wrists, knees, elbows, shoulders, and waist (each 2.6 cm wide) (*see* Figures 3 & 4).

Figure 3. Frontal view of the three clothing configurations: Vest only, Vest + Ankles, and Full Biomotion.
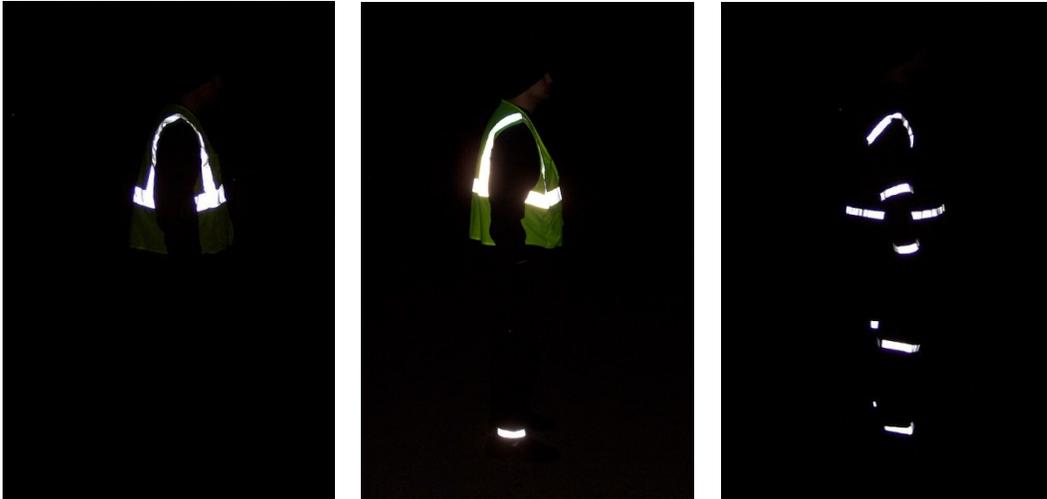
Figure 4. Side view of the three clothing configurations: Vest only, Vest + Ankles, and Full Biomotion.

Participant response distances were measured using a combination of a laptop, the on-board vehicle computer, and participant response buttons. Software calculated the distance at which participants pressed a button to indicate their confidence in the presence of a pedestrian. A device connected to the test vehicle's on-board computer continuously sampled the vehicle speed and relayed that information to the laptop computer in the backseat. The laptop began recording vehicle speed as soon as the participant pressed the response button. This experimenter in the backseat pressed a button when the test pedestrian passed through the center of the vehicle's rear window; this stopped the vehicle speed sampling. Software then used the time between the participant and experimenter button presses to calculate time. Response distance was calculated as the product of the time between button presses and the mean speed during this interval. A calibration process confirmed the

accuracy of this measurement process (correlation between actual

distances and measured distances was .99, with a mean absolute error of

3.2%). The calibration was used to create a trend line (y = 1.047x - 8.479)

see Figure 5. This was used to correct raw participant detection distance

data prior to analysis.
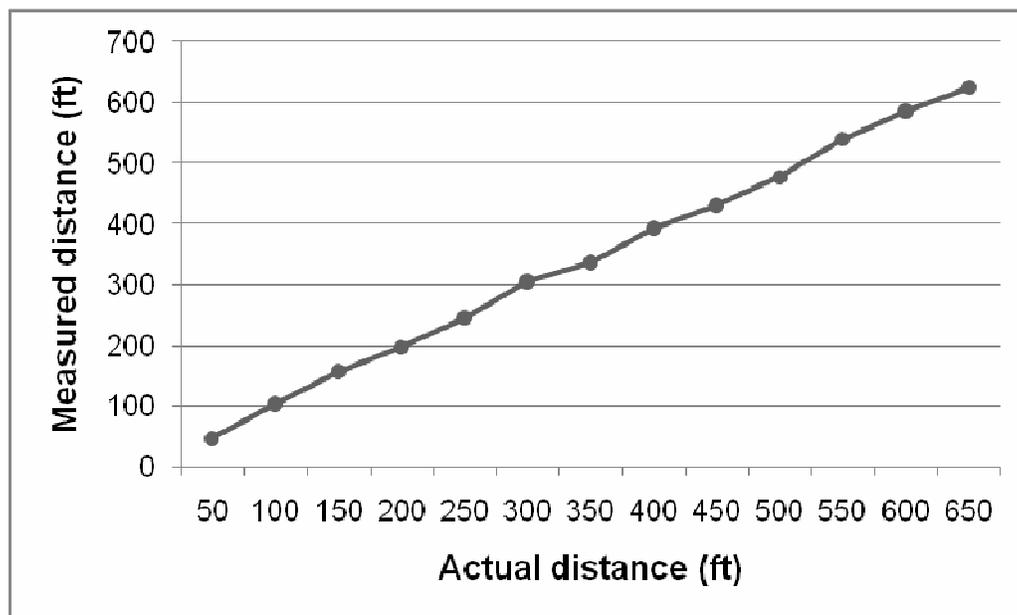
Figure 5. Trend line showing the relationship between actual distance and
measured distance attained during calibration, r^2 =.99.

After the test vehicle passed the test pedestrian, the experimenter in

the back seat informed the participants that the trial was complete and that

they could relax. The experimenter also answered any additional

questions that participants asked. Participants were then driven back to

Brackett Hall and released.

RESULTS

There were a total of 12 trials (10%) in which participants failed to respond to the test pedestrian; response distances were coded as zero in these trials. No pedestrians were missed when facing the oncoming vehicle, nor when walking in place. Table 1 reports the conditions in which these 12 trials occurred.

Table 1. The number of times that participants failed to respond to pedestrians as a function of condition.

Clothing	Orientation	Movement	Number of instances not detected
Full Biological Motion	Facing the Oncoming Vehicle	Walking	0
		Standing	0
	Facing the Roadway	Walking	0
		Standing	4
Vest only	Facing the Oncoming Vehicle	Walking	0
		Standing	0
	Facing the Roadway	Walking	2
		Standing	3
Vest + Ankles	Facing the Oncoming Vehicle	Walking	0
		Standing	0
	Facing the Roadway	Walking	0
		Standing	3

The response distance values were analyzed using a between-subjects analysis of variance (ANOVA) using an alpha level of .05; partial eta-squared (η_p^2) quantified effect size. An initial ANOVA was conducted

on the response distances that included participant seat position (front seat or back seat), pedestrian clothing (Vest only, Vest + Ankles, or Full Biomotion), pedestrian orientation (side facing vehicle or front facing vehicle), and pedestrian movement (walking in place or standing still). No main effect of seat position was found F $(1, 96) = 3.02$, $p > .05$, $\eta_p^2 = .031$; as a result, this variable was excluded from further analyses.

To determine whether any unusual (outlying) values existed, response distances were converted into standardized (z) scores within each of the 12 groups (clothing x orientation x movement). No response distances were greater than three standard deviations away from their group mean. No participant responded at a distance greater than the maximal sight distance. Thus, no outliers were replaced or excluded from the analyses that follow.

A 2 x 2 x 3 ANOVA revealed a main effect of clothing F $(2, 108) =$ 18.76, $p < .001$, $\eta_p^2 = .258$ (*see* Figure 6). A Bonferroni follow-up test explored the differences in response distances among the three clothing configurations. When averaged across pedestrian movement and orientation, participants responded to the Full Biological Motion (89.7 m or 294.1 ft) and to the Vest + Ankles (79.2 m or 259.8 ft) configurations at significantly greater distances than when the pedestrian wore the Vest only (40.8 m or 133.8 ft), $p < .001$. That is, participants responded to the pedestrian wearing the Full Biomotion configuration at a distance 2.2 times greater than when wearing the Vest alone. Participants responded

to the pedestrian wearing the Vest + Ankles configuration at a mean

distance 1.9 times greater than when the pedestrian wore the Vest alone.

However, response distances did not differ between the Full Biomotion

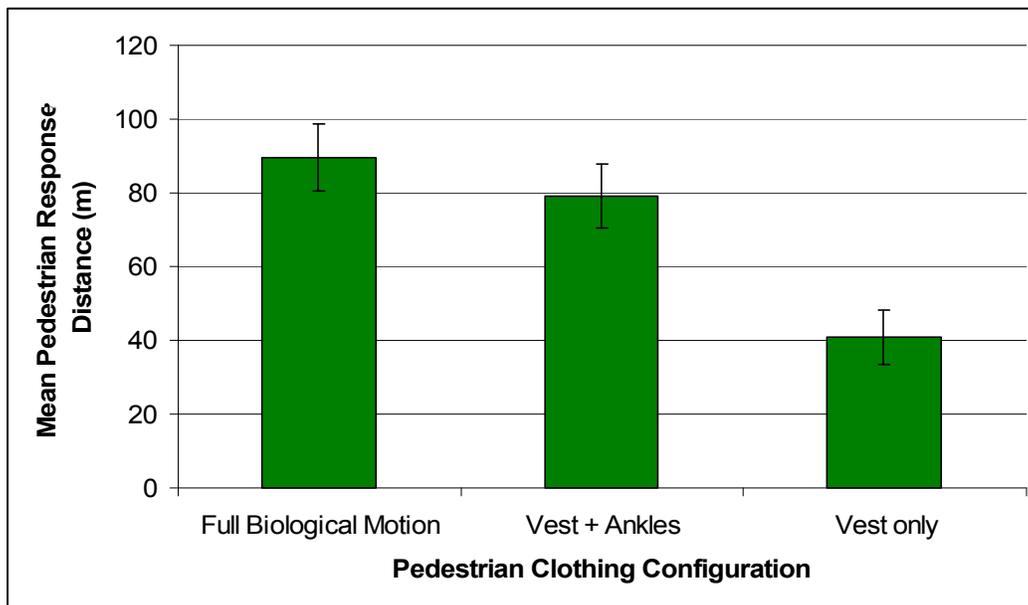and the Vest + Ankles configurations, $p > .05$.

Figure 6. Mean response distances (m) as a function of clothing
configuration. Error bars represent ±1 standard error of the mean.

The ANOVA also revealed a main effect of motion, $F (1, 108) = 74.83$,

$p < .001$, $\eta_p^2 = .409$ (*see* Figure 7). Participants responded at a mean

distance that was 2.5 times greater when the pedestrian walked in place

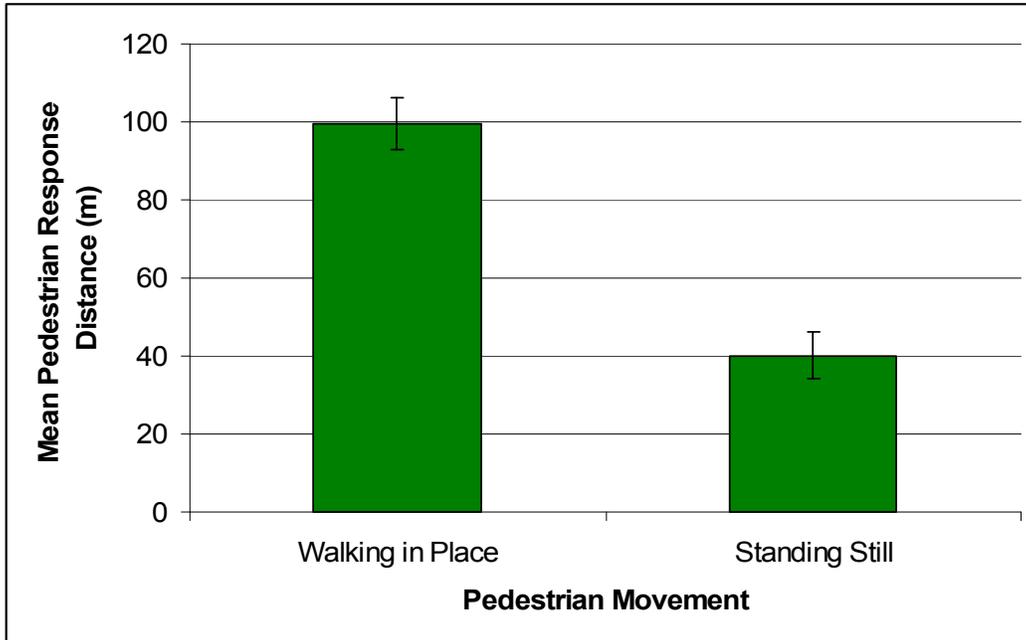(99.5 m or 326.6 ft) than when he stood still (40.2 m or 131.9 ft).

Figure 7. Mean response distances (m) as a function of pedestrian movement. Error bars represent ±1 standard error of the mean.

In each of the three clothing configurations, the walking pedestrian elicited greater participant response distances when walking than when standing still (*see* Figure 8). In the Full Biomotion configuration, participants responded at a distance 2.6 greater when walking in place (129.5 m or 424.9 ft) than when standing still (49.8 m 163.4 ft), F (1, 38) = 36.46, p < .001, η_p^2 = .490. When the pedestrian wore the Vest + Ankles configuration, participants responded at a distance approximately 2 times greater when walking in place (105.0 m or 344.6 ft) than when standing still (53.3 m or 175.0 ft), F = (1, 38) 11.23, p = .002, η_p^2 = .228. When the pedestrian wore the Vest only, participants responded at a distance approximately 4 times greater when the pedestrian walked in place (64.1

m or 210.3 ft) than then he stood still (17.5 m or 57.3 ft), F (1, 38) = 13.14,
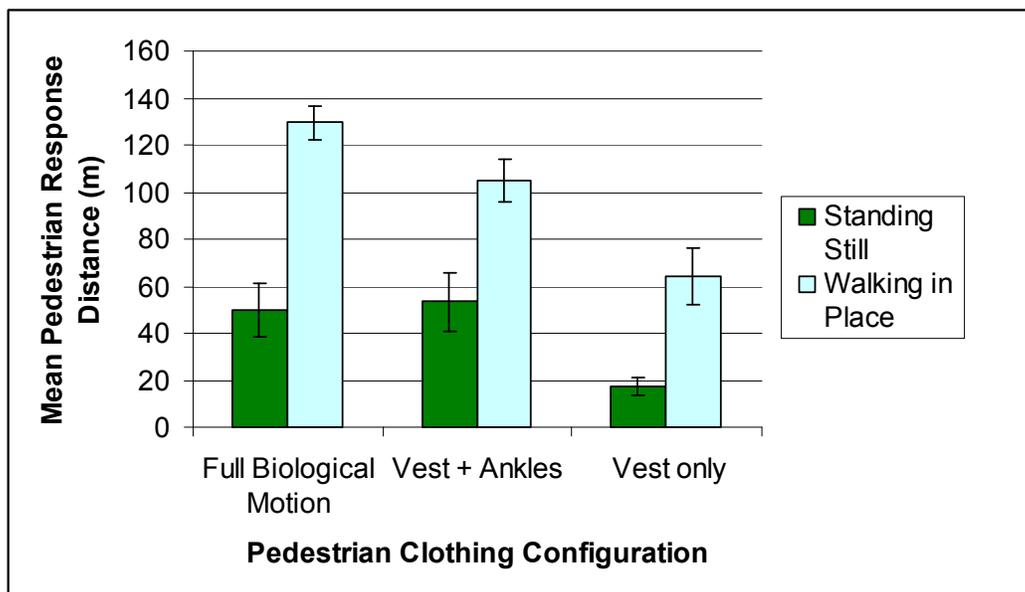
p = .001, η_p^2 = .257.

Figure 8. Mean response distances (m) as a function of pedestrian clothing configuration and movement. Error bars represent ±1 standard error of the mean.

In addition, a main effect of pedestrian orientation was revealed by the

ANOVA F $(1, 108)$ = 25.38, $p < .001$, η_p^2 = .190. Participants responded

to the pedestrian who faced the oncoming vehicle (87.2 m or 285.9 ft) at a

distance 1.7 times greater than the pedestrian who faced the roadway with

his right side facing the oncoming vehicle (52.7 m or 172.5 ft).

A significant interaction existed between clothing configuration and

orientation, F $(2,108)$ = 6.19, p = .003, η_p^2 = .103 (*see* Figure 9). Simple

effects tests revealed that the effect of clothing configuration was not

significant when the pedestrian faced the roadway, F $(2, 57)$ = 1.19, $p >$

.05, η_p^2 = .040. When the pedestrian faced the oncoming vehicle, however, the effect of clothing configuration was significant, $F(2, 57)$ = 14.04, $p < .001$, η_p^2 = .330. Here, a Bonferroni corrected follow-up test revealed that participants responded to both the Full Biomotion (114.0 m or 374.1 ft) and the Vest + Ankles configurations (106.4 m or 348.9 ft) at a distance greater than the Vest alone (41.1 m or 134.8 ft), $p < .001$.

This interaction was also examined by examining the effect of orientation within each of the three clothing configurations. When the pedestrian wore the Full Biological Motion configuration and faced the oncoming vehicle (114.0 m or 374.1 ft) participants responded at a distance 1.7 times greater than when he faced the roadway (65.3 m or 214.2 ft), $F(1, 38)$ = 8.52, $p = .006$, η_p^2 = .183. When the pedestrian wore the Vest + Ankles configuration and faced the oncoming vehicle (106.3 m or 348.9 ft) participants responded at a distance 2 times greater than when he faced the roadway (52.0 m or 170.6 ft), $F(1, 38)$ = 12.81, $p = .001$, η_p^2 = .25. However, when the pedestrian wore the Vest only configuration, there was no conspicuity advantage gained by facing the oncoming vehicle (41.1 m or 134.8 ft) over facing the roadway (40.8 m or 132.8 ft), $F(1, 38)$ = .002, $p > .05$, $\eta_p^2 < .001$.
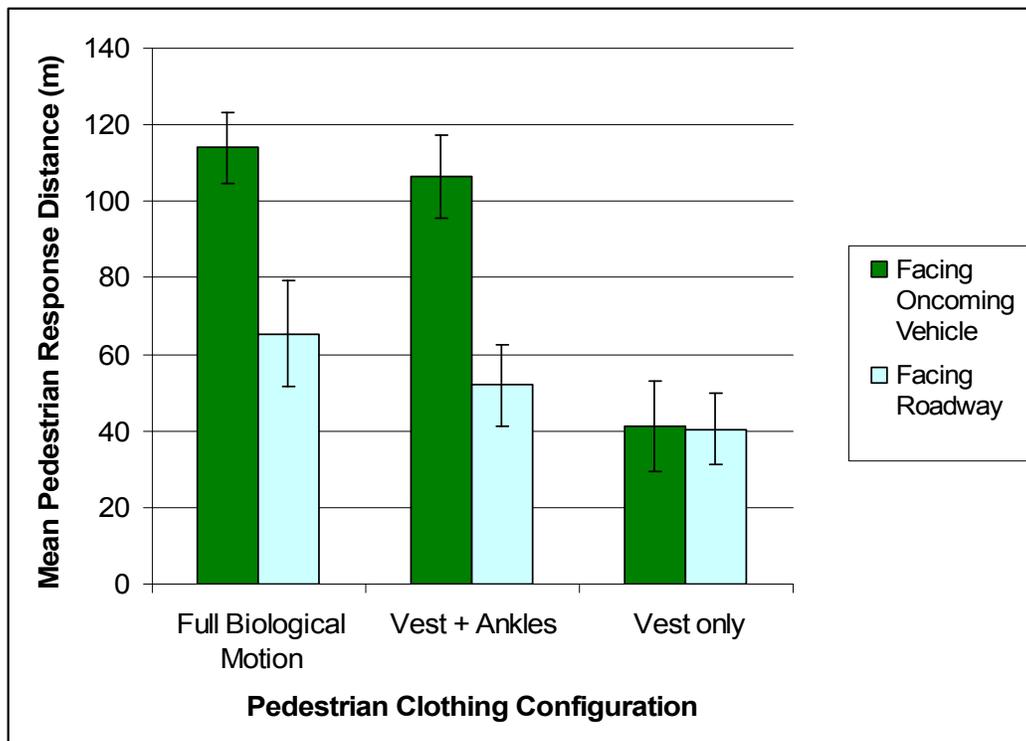
Figure 9. Mean response distances (m) as a function of pedestrian clothing configuration and orientation. Error bars represent ±1 standard error of the mean.

A significant interaction between pedestrian motion and pedestrian orientation also existed, F (1, 108) = 4.84, p = .03, η_p^2 = .043 (*see* Figure 10). A test of simple effects revealed that the effect of pedestrian movement was significant when the pedestrian faced the vehicle F (1, 58) = 10.29, p = .002, η_p^2 = .151. When averaged across the three clothing configurations and the pedestrian faced the oncoming vehicle while walking in place (109.3 m or 358.5 ft) participants responded at a mean distance 1.7 times greater than when he stood still in the same conditions (65.0 m or 213.4 ft). The effect of pedestrian movement was also significant when the pedestrian faced the roadway F (1, 58) = 68.19, p <

.001, η_p^2 = .540. When the pedestrian faced the roadway and walked in placed (89.8 m or 294.6 ft) participants responded at a mean distance 5.84 times greater than when he stood still (15.3 m or 50.5 ft), illustrating that the effect of motion is larger when facing the roadway than when facing the oncoming vehicle.
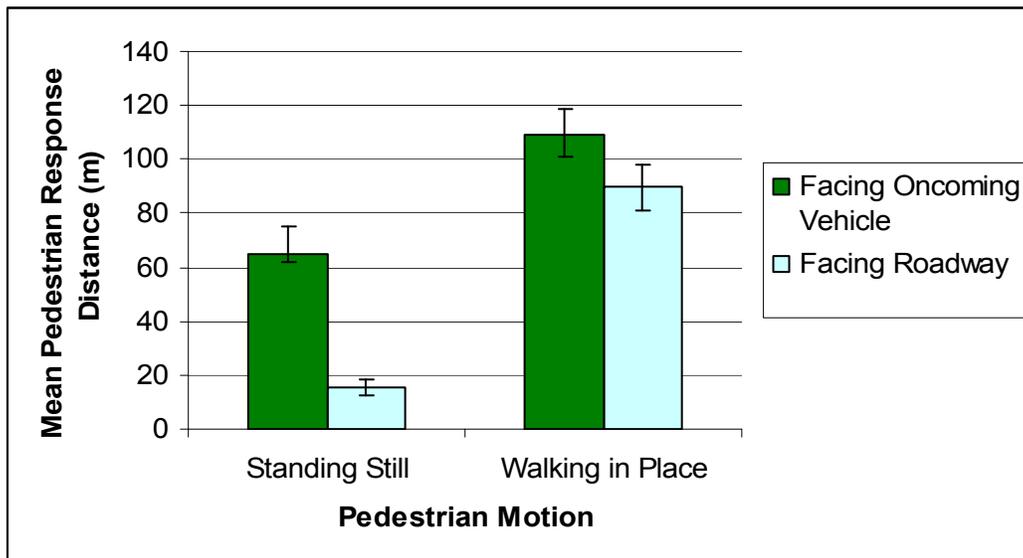
Figure 10. Mean response distances (m) as a function of pedestrian motion and orientation. Error bars represent ±1 standard error of the mean.

Neither the two-way interaction between pedestrian clothing configuration and motion, F $(2, 108)$ = 2.25, p > .05, η_p^2 = .040 nor the three-way interaction among clothing configuration, motion, and orientation, F $(2, 108)$ = 2.44, p > .05, η_p^2 = .043 were significant. For more detail, see Table 2 for mean participant response distances by pedestrian clothing configuration, orientation, and movement.

Table 2. Summary of average pedestrian response distances by
pedestrian clothing configuration, orientation, and movement.

Clothing	Orientation	Movement	Response Distance	Standard Error of the Mean
Full Biological motion	Facing oncoming vehicle	Walking	137.57 m (451.35 ft)	9.65 m (31.67 ft)
		Standing	90.47 m (296.82 ft)	12.36 m (40.55 ft)
	Facing roadway	Walking	121.42 m (398.35 ft)	9.73 m (31.92 ft)
		Standing	9.14 m (29.99 ft)	3.58 m (11.75 ft)
Vest + Ankles	Facing oncoming vehicle	Walking	123.65 m (405.67 ft)	8.62 m (28.29 ft)
		Standing	89.05 m (292.15 ft)	18.77 m (61.58 ft)
	Facing roadway	Walking	86.40 m (283.45 ft)	13.76 m (41.15 ft)
		Standing	17.62 m (57.80 ft)	5.29 m (17.36 ft)
Vest only	Facing oncoming vehicle	Walking	66.58 m (218.43 ft)	20.81 m (68.27 ft)
		Standing	15.57 m (51.07 ft)	3.20 m (10.50 ft)
	Facing roadway	Walking	61.60 m (202.10 ft)	14.50 m (47.56 ft)
		Standing	19.37 m (63.56 ft)	6.55 m (21.49 ft)

DISCUSSION

Prior studies of the relative value of vests and biomotion configurations on the nighttime conspicuity of pedestrians used custom-made vests that consisted of a rectangle. Because such vests are not commercially available the generalizability of these studies is questionable. The current study examined the distances at which participants detected and responded to the presence of a test pedestrian who was either standing or walking in place on the left shoulder of an unilluminated two-lane roadway. The pedestrian wore a constant amount of silver retroreflective material in one of three configurations: Full Biological Motion, ANSI Class II Vest, or ANSI Class II Vest + straps around the Ankles. The pedestrian either faced the roadway or faced the oncoming test vehicle.

The present study found that conspicuity was minimal when the pedestrian wore only the ANSI Class II Vest. On average, response distances nearly doubled (from 40.9 m to 79.2 m) when a portion of retroreflective material was moved from the vest to the ankles. This result supports previous findings that when pedestrians' limbs are marked, they can be recognized at distances about 2 times greater than when the limbs are not highlighted (e.g. Owens, Antonoff, & Francis, 1994; Wood et al., 2005; Balk et al., 2006). In other words, marking the ankles while wearing a reflective vest significantly enhances nighttime conspicuity, perhaps by

reducing the ambiguity about whether the object/thing the driver sees is a human. Somewhat surprisingly, when the pedestrian wore the ANSI class II vest + ankle straps, response distances were similar to those when the pedestrian wore the full biological motion configuration, which previous studies have shown to maximize response distances (e.g. Owens, Antonoff, & Francis, 1994; Wood et al., 2005; Balk et al., 2006). This finding that the Vest + Ankles configuration is nearly as conspicuous as the full biomotion configuration is particularly encouraging in light of its convenience. While the ANSI 107-1999 standard is voluntary, most roadway workers comply with the standard. As a result, a minimal amount of effort would be required to add retroreflective ankle straps to roadway worker attire. The Vest + Ankles configuration attains nearly as much conspicuity while being substantially less cumbersome than donning the 11 bands of retroreflective material present in the full biomotion configuration. It is worth noting that the conspicuity value of the ankle straps may be a result of the combined effects of enhancing the motion information plus the fact that by virtue of their lower placement ankle straps receive greater illumination from low-beam headlamps. The relative contribution of these two effects has yet to be untangled.

As found in previous work, participants in the current study responded to the pedestrian at a greater distance when he walked in place than when he stood still. On average, detection distances were approximately 2.5 times greater when walking in place (99.5 m when walking vs. 40.2 m

when standing in place). This finding provides further support for the assertion that pedestrian conspicuity is dramatically enhanced when the pedestrian's nighttime clothing capitalizes on drivers' extraordinary capacity to perceive biological motion.

Motion is, however, is not entirely responsible for the conspicuity benefits that are often attributed to the biological motion configuration. Even when the pedestrian stood still both of the clothing configurations that contain aspects of biological motion (i.e., the Full Biomotion and Vest + Ankles configurations) elicited greater participant response distances than in the Vest only condition. Consistent with the findings of Balk et al. (2006), this finding shows that the benefits of biological motion clothing configurations are not solely due to motion per se. Rather, the conspicuity advantages are to some extent also a result of facilitating form perception. That is, clothing configurations which highlight the human form, via marking the major joints with retroreflective material, provide a conspicuity advantage even when the pedestrian is motionless.

Participants responded to the pedestrian at a greater distance when he faced the oncoming vehicle (87.2 m) than when he faced the roadway (52.6 m). This outcome is likely to be a result of a reduction in biological information presented to the viewer. That is, when the pedestrian faces the roadway, only the profile view is presented to the oncoming vehicle; with more of the pedestrian's body coming in to view as the vehicle approaches. In other words, when pedestrians are facing the viewer,

there is more information available to the viewer that depicts the human form. This result again supports the hypothesis that the more components/aspects of biological motion/human form are available to the viewer, the more conspicuous the pedestrian.

This finding is in contradiction to that of Luoma, Schumann, and Traube (1996), who found that pedestrians walking back and forth across the roadway were recognized at a distance greater than pedestrians walking toward the oncoming vehicle containing the participants. This difference may be attributed to the location of the pedestrian. That is, in the current study, the pedestrian maintained the same location on the far shoulder of the roadway. However, in the Luoma, Schumann, and Traube (1996) study, the pedestrian that presented a profile view (facing the roadway) continually walked back and forth across the roadway. As a result the pedestrian that crossed the roadway presumably received much greater headlight illumination than the pedestrian on the shoulder of the road. Further, given the typical gaze direction of drivers (and participants in a vehicle) the image of a pedestrian who is crossing the roadway would be more likely to fall on the drivers' fovea than a pedestrian walking along the road's shoulder. While the present data suggest that a pedestrian on the left shoulder of the road would be more conspicuous when facing the oncoming vehicle than when facing the roadway, it is unknown if this advantage would remain if the pedestrian is located in the path of the vehicle.

The effects of pedestrian orientation can be examined further by looking at the interaction between pedestrian orientation and movement. When the pedestrian faced the oncoming vehicle, an effect of movement was present. Participants responded to pedestrians at a distance 1.7 times greater when the pedestrian faced the oncoming vehicle and was walking in place (109.26 m) than when the pedestrian was similarly oriented but standing still (65.03 m). The effect of pedestrian motion was also present when the pedestrian faced the roadway. Motion, however, showed a much stronger effect when the pedestrian faced the roadway. Here, participants responded to pedestrians at a distance nearly 6 times greater when walking in place (89.81 m) than when standing still (15.34 m). As mentioned previously, when a pedestrian faces the roadway only the human profile is presented to the viewer. As a result, when standing still, only a column of retroreflective strips is presented to the viewer. It is easy to see how a few bands of motionless retroreflective material could be mistaken for a roadway sign, post, or other non-human object. However, when walking motion is added to the retroreflective material (which also occludes and reveals retroreflective material) there is more information present to portray a human. In other words, the motion of the pedestrian's arms alternately occludes and reveals the retroreflective material on the pedestrian's waist, thus resulting in a dramatic increase in pedestrian conspicuity.

In each of the three clothing configurations, there was an effect of pedestrian motion such that participants responded at a significantly greater distance when the pedestrian was walking in place compared to when standing still. This result is not surprising for the two clothing configurations which incorporate aspects of biological motion (i.e. Full Biomotion and Vest + Ankles). In these clothing configurations the limbs are marked with retroreflective material and obviously facilitate the perception of biological motion. However, an effect of motion in the Vest only configuration was not anticipated and is somewhat surprising. The vest used in this study (as well as most common safety vests) only covers the chest and waist area and does not mark the limbs. When walking in place, the chest remains relatively motionless. Thus, without limb markings it appears that it would not be likely that the Vest only configuration would benefit from motion. However, a closer examination of the walking motion of the pedestrian revealed that the walking action resulted in the passing of the (non-reflectorized) arms over the front of the retroreflective material that was positioned on the waist and chest. Thus, it is hypothesized that the movement of the arms, which alternately occluded and revealed retroreflective material in a very distinct pattern, provided enough motion information to quickly determine that there was indeed a pedestrian along the roadway. It is likely that an effect of movement when wearing a vest was not found in previous studies as a result of the configuration of the vest. In many other studies that use a

vest, the vest is simply a rectangle of retroreflective material that is placed on the chest. This configuration provides no retroreflective material on the waist over which the arm can pass while walking in place, therefore the distinct pattern of moving arms cannot be seen.

The effects of pedestrian orientation also varied as a function of clothing configuration. When averaged across the two motion conditions, both the Full Biomotion and the Vest + Ankles clothing configurations showed a conspicuity advantage when facing the oncoming vehicle over facing the roadway. This finding is not surprising. As mentioned previously, there is a great deal more biological information presented to the viewer when facing the vehicle than when facing the roadway. However, when wearing the Vest only, no conspicuity advantage was gained by facing the oncoming vehicle. When considering the lack of limb markings that highlight the human form, this is not surprising.

In general, when the pedestrian faced the oncoming vehicle the effects of clothing configuration were largely as expected. That is, participants responded to the pedestrian, who faced the oncoming vehicle, wearing both the Full Biomotion and Vest + Ankles configurations at a distance approximately 2.5 times greater than when the pedestrian wore the Vest alone. This is generally consistent with the existing literature (e.g. Owens, Antonoff, & Francis, 1994; Wood et al., 2005; Balk et al., 2006), which illustrates that conspicuity increases with increases in biological motion information. However, when the pedestrian in the present study faced the

roadway no significant differences among clothing configurations existed.

This finding is both interesting and surprising. It suggests that pedestrians

facing the roadway face increased danger and that the ability of any

clothing configuration to compensate for this effect may be limited.

The finding that when facing the roadway there was no conspicuity

advantage of wearing a biological motion clothing configuration over a

common safety vest is consistent with the findings of Moberly & Langham

(2002). The Moberly and Langham study is the only previous study in

which no advantage was found in wearing a biological motion

configuration. As this paper is also the only in which the pedestrian

remains facing the roadway while positioned along the shoulder, it

appears that the key to the failure to observe a conspicuity advantage of a

biological motion configuration over a non-biological motion configuration

(i.e. a safety vest) lies in the pedestrian's orientation. Much like the

current study, when Moberly & Langham's pedestrian faced the roadway

the walking pedestrian was more conspicuous then when standing still.

These results emphasize the importance of movement (especially when

facing the roadway). While no conspicuity advantage of clothing

configurations which incorporate biological motion was seen when the

pedestrian faced the roadway, the conspicuity advantages provided by

these clothing configurations when facing oncoming vehicles is

indisputable. It is again important to recall that the conspicuity of the side-

facing pedestrian may have been different had the pedestrian been located in the path of the vehicle rather than on the left shoulder.

In sum, there are two practical implications of this study. First, the present data provide confirming evidence that pedestrian conspicuity can be greatly enhanced by marking the pedestrian's extremities. This strategy capitalizes on our extraordinary perceptual ability to visually recognize other humans. Here, human biological information was manipulated by varying both the pedestrian's movement and the placement of the retroreflective markings. Both manipulations were found to significantly affect pedestrian conspicuity. Second, the present data reveal that adding retroreflective ankle markings to a commercially available (and ANSI-compliant) safety vest provides substantial conspicuity value. Indeed, adding ankle straps to the safety vest affords conspicuity levels that are similar to the full biological motion configuration that has repeatedly been shown to maximize conspicuity. This finding is of particular importance to roadway workers, many of whom already wear ANSI class II safety vests but not ankle markings. Adding the straps to the ankles is an easy and cost effective way to increase pedestrian conspicuity, while remaining compliant with a widely accepted safety standard.

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