# Perceptions of Visibility and Conspicuity of Biomotion Clothing Configurations for Road Workers at Road Work Sites

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**ABSTRACT**

**Aims:** This study determined whether the visibility benefits of positioning retroreflective strips in biological motion configurations were evident at real world road worker sites. **Methods:** 20 visually normal drivers (M=40.3 years) participated in this study that was conducted at two road work sites (one suburban and one freeway) on two separate nights. At each site, four road workers walked in place wearing one of four different clothing options: a) standard road worker night vest, b) standard night vest plus retroreflective strips on thighs, c) standard night vest plus retroreflective strips on ankles and knees, d) standard night vest plus retroreflective strips on eight moveable joints (full biomotion). Participants seated in stationary vehicles at three different distances (80m, 160m, 240m) rated the relative conspicuity of the four road workers using a series of a standardised visibility and ranking scales. **Results:** Adding retroreflective strips in the full biomotion configuration to the standard night vest significantly ($p<0.001$) enhanced perceptions of road worker visibility compared to the standard vest alone, or in combination with thigh retroreflective markings. These visibility benefits were evident at all distances and at both sites. Retroreflective markings at the ankles and knees also provided visibility benefits compared to the standard vest, however, the full biomotion configuration was significantly better than all of the other configurations. **Conclusions**: These data provide the first evidence that the benefits of biomotion retroreflective markings that have been previously demonstrated under laboratory and closed- and open-road conditions are also evident at real work sites.

## BACKGROUND

Collisions between vehicles and pedestrians represent a significant road safety problem. Importantly, crashes between vehicles and pedestrians are overrepresented at night, with pedestrians being three to seven times more likely to be involved in a fatal collision at night than in the day *(1)*. In addition, fatal crash data demonstrate that night-time construction at work sites is five times more hazardous than daytime construction *(2)*. There is strong evidence that visibility issues are a key causative factor; analyses of crash databases have shown that the increased incidence of crashes involving pedestrians at night is primarily a consequence of lower illumination rather than other factors that might vary between day and night, such as driver fatigue and the use of alcohol *(1; 3)*. This suggests that at night, drivers are often unable to recognize and respond to pedestrians from a safe distance *(4)*.

A variety of approaches have been used to make pedestrians more conspicuous to drivers at night, including evolving vehicle and roadway lighting technologies and night vision enhancement systems. An alternative approach is for pedestrians to wear clothing designs that take advantage of drivers' perceptual capacity to recognize the unique patterns of motion that specify normal human gait, known as biological motion (or biomotion).

Johansson (*5; 6)* was the first to explore human visual sensitivity to biological motion. He showed observers films of actors wearing points of light on their major joints (ankles, knees, waist, shoulders, elbows, wrists) while they made a series of natural movements within a darkened environment. Although only the tiny light points were visible in Johansson's films, observers could recognize a walking human form in as brief an exposure as 100–200 ms. Later research by Johansson and others confirmed that the patterns of human motion are rich sources of information to which the human visual system is particularly attuned. Based only on the motion information available in point-light displays, observers can quickly recognize an actor's gender and emotion as well as the identity of their friends and the weight of unseen objects that are lifted by the actor *(see 7-11 for a review of the literature)*. Researchers have also begun to identify the neural mechanisms involved in the perception of biomotion *(e.g., 12; 13)*. Meanwhile, there has been interest in capitalizing on our perceptual sensitivity to biomotion to enhance drivers' ability to recognize pedestrians (including road workers), from a safe distance at night.

While retroreflective materials (which are designed to reflect light back in the direction of its source) have long been used to add visual contrast to pedestrians, these materials are most commonly attached to the pedestrian's torso. However, retroreflective vests may not solve the conspicuity problem because the torso exhibits relatively little motion during normal gait, and the vests do not highlight the static human form.

Emerging research by our group and others has demonstrated that pedestrians are even more conspicuous to drivers at night when retroreflective material is attached to the pedestrian's major moveable joints, in a full biomotion configuration, which provides significant visibility benefits over and above that of standard retroreflective vests *(14-21)*. These studies have demonstrated, using video-based representations, closed road circuits or isolated stretches of open road, that retroreflective strips positioned in the biological motion or full biomotion pattern provide substantial advantages for improved pedestrian visibility. In the study by Wood et al. *(21)* for example, drivers using low beams on a closed road recognized a pedestrian walking while wearing biomotion markers at a distance that was 3.4 times greater than when the pedestrian wore a vest that included an equal amount of retroreflective material. The visibility advantages of biomotion configurations have been shown to be robust to the effects of driver age *(21; 22)* and clutter *(20)*.

However, while these studies have strong face validity, having been in the most part undertaken in real road conditions rather than in the laboratory, they have not been conducted under in-traffic conditions, where lighting conditions, working practices, and driver expectations may have a significant impact on the outcomes. So the critical next step, before making recommendations for such a practice to be widely adopted, is to undertake parallel studies at real road work sites. Such "real world" testing represents an important translation of research into practice, and is vital because premature adoption of visibility aids that have not been proven outside a controlled setting could be a waste of resources, and possibly even counterproductive. For example, in a cluttered construction environment, oncoming drivers might find more reflectors confusing and hence they may be less likely to recognize the presence of road workers in time to safely avoid a collision. Confirmation that biomotion configurations are beneficial in genuine road work sites is needed.

This research consists of a feasibility study to establish whether the full biomotion markings have the potential to increase visibility in the field. The research was undertaken under in-traffic conditions at two road work sites (one suburban and one freeway). We sought to determine drivers' subjective ratings of the relative conspicuity and visibility of road workers wearing a range of different clothing options.

## METHODS

### Participants

Twenty volunteers participated in this study (mean age = 40.3± 15.6 years; range 22-69 years), of whom 13 were male. All participants were licensed drivers and reported that they drove regularly. All participants passed the minimum Australian drivers' licensing criteria for binocular visual acuity of 6/12 (20/40) or better, and wore the optical correction they normally wear while driving, if any.

The study was approved by the Queensland University of Technology Human Research Ethics Committee. All participants were given a full explanation of the experimental procedures and written informed consent was obtained, with the option to withdraw from the study at any time.

### Road Work Sites

The experiment was conducted over two evenings (2 weeks apart) under night-time conditions at two separate road work sites (i.e., one site was evaluated per evening), when the road surfaces were completely dry. Data collection began at least 60 minutes after sunset in both cases.

*Suburban Site*

The first road work site was situated in a built-up, suburban environment. The road environment consisted of a three-lane dual carriageway road (with a normal speed limit of 60 km/h) with an additional shoulder/slip lane. Overhead lighting was present in the form of streetlamps, along with additional ambient light sources including shops, restaurants, advertising billboards and the headlamp beams from passing and oncoming traffic. Average ambient illumination at this site was approximately 17 lx. A 1.1 km section of the road was used to replicate a real road work site, of which only the final 240m was used by the research team. The initial 860m section of road featured all relevant and appropriate signage, safety devices and traffic calming equipment, as determined by the Department of Main Roads/RoadTek and as dictated by Part 3 of the Manual of Uniform Traffic Control Devices (MUTCD, 2007). The road workers were positioned at the work site, with the observational vehicles situated at 80 m, 160 m and 240 m from that point. These distances were selected to represent key distances at which approaching drivers might recognize that a road worker was present, with 240 m representing the longest distance at which road workers wearing reflective strips in a full biomotion configuration have been detected in previous closed road studies *(20; 21)*, with the other two distances representing a middle and a relatively short distance where braking would be critical to avoid a collision. The section of road selected for the study was relatively straight and flat, with only a slight dip in the middle, such that the vehicles at the 80m and 160m points were slightly lower than both the vehicle at 240m and the road workers, which were at the same level, relative to one another. Each of the observational vehicles (2008 Holden Commodore Omega Station Wagons) were positioned such that their low beam headlights directly illuminated the four road workers, and were offset from each other to prevent any of the vehicles obstructing the headlights of one another and to allow optimal viewing of the road workers by participants.

*Freeway Site*

The second road work site was situated along a relatively straight section of high speed (normally 80 km/h) motorway. The road environment consisted of a two-lane dual carriageway separated by a 6 m-wide grassed median strip. No overhead lighting was present and minimal ambient light fell on the road work site apart from that generated by oncoming and passing vehicle headlights. Average ambient illumination at this site was approximately 1.7 lx. A 1.2 km section of the road was used to simulate a real road work site, only the final 240m section of the simulated road work site was utilized by the research team and participants. The 960 m section of road prior to the testing site featured all relevant and appropriate signage, safety devices and traffic calming equipment as determined by the Department of Main Roads/RoadTek (MUTCD, 2007). The road workers were positioned at the work site, with observational vehicles again positioned at 80, 160 and 240 m intervals from the road workers. The road at this point sloped slightly upwards so that the road workers were marginally higher than the observational vehicles to allow optimal viewing of the road workers by participants. The road also featured a slight curve to the right when seen from the observers' point of view. To compensate for this, each observational vehicle was positioned so as to facilitate a clear view of the road workers, and all vehicles were oriented such that their low beam headlights faced and illuminated the road workers.

At both road work sites, the four road workers were positioned 1 m from each other and at least 1.2 m from the retroreflective cones demarcating the border of the closed lane. Both road work sites used signage and traffic controllers to limit passing vehicle speeds to 40 km/h.

**Road Worker Clothing**

The clothing configurations of the four road workers were the same across both road work sites and each road worker wore the same clothing configuration for all trials. The four clothing configurations were designated as: standard, thigh, ankle & knee and full biological motion (full biomotion) (as illustrated schematically in Figure 1).

- Standard: The road worker wore a standard road worker outfit, consisting of a fluorescent orange long-sleeve shirt and navy blue work pants. A fluorescent orange vest was worn over the shirt. The vest featured silver retroreflective strips (Scotchlite® 8910 fabric, 3M), 50 mm wide on the chest and shoulders (two horizontal strips on the chest and one vertical strip on each shoulder). This vest conformed to the Australian/Standard AS/NZS 4602:1999 and was classified as a Class D/N garment.
- Thigh: The Thigh condition consisted of the same Standard D/N Reflective Vest, with the addition of a retroreflective strips (Scotchlite® 8910 fabric, 3M) placed midway around each thigh, halfway between the hip and knee joints. This configuration represents a modification of Appendix A of AS/NZS 4602:1999, which includes the recommended use of standard retroreflective strips on the legs. The configuration was chosen as it represented a commonly worn outfit by road workers at night.
- Ankle & Knee: In the Ankle & Knee condition, the road workers wore the Standard D/N Reflective Vest, with the addition of standard retroreflective strips (Scotchlite® 8910 fabric, 3M) positioned around both the ankle and knee joints. This configuration was included due to its greater convenience (relative to the full biomotion configuration) and because previous research *(e.g., 14)* has suggested that this configuration can be roughly as conspicuous as the full biomotion configuration.
- Full Biomotion: The Full Biomotion condition consisted of the Standard D/N Reflective Vest with the addition of standard retroreflective strips (Scotchlite® 8910 fabric, 3M) positioned around the elbow, wrist, ankle and knee joints of the road worker.

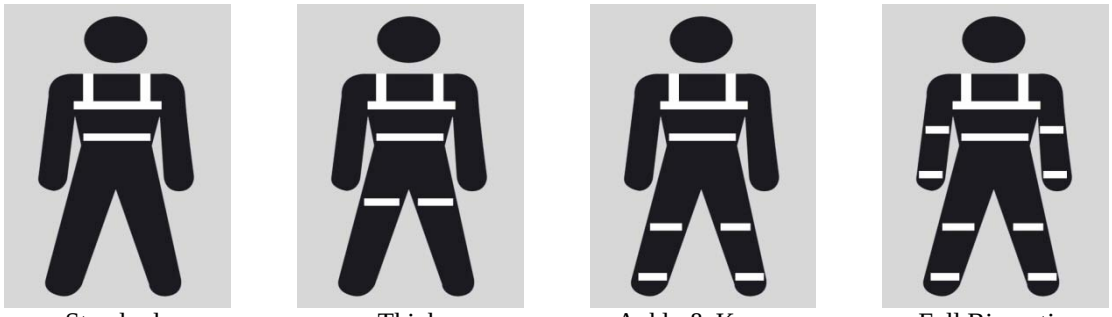


**FIGURE 1 Schematic diagram of the four road worker clothing configurations.**

The order (from left to right) in which the road workers appeared to the participants was randomized between distances and sites using an incomplete Latin Square design in order to avoid any order effects in the perceptual judgments.

**Visibility Judgment Questionnaire**

For each of the three distances at which judgments were made, three items were completed by participants:

- "At this distance, it is obvious to me that this is a person"
- "At this distance, I would always recognize that this is a person" and
- "If I were driving toward this scene I would immediately know that this is a person".

These questions were designed to reflect the issue that while road workers may well be detected (as stimuli) at long distances, it is only when they are recognized (as people) that oncoming drivers are likely to take appropriate evasive action, to prepare to do so, and/or to slow down. Participants indicated their level of agreement on a visual analog scale ranging from "strongly agree" to "strongly disagree" by placing an "X" on the scale at the point that corresponded to their level of agreement for each road worker and for each item. The ratings of the three dimensions were then averaged to create an overall visibility score. At each of the three observation distances, participants were also asked to rank the four clothing outfits from "1" (most conspicuous

or easily recognizable as a person) to "4" (least conspicuous). After the judgments were completed at each distance, participants were then asked to rank all four clothing configurations for overall visibility.

**Procedures**

The twenty participants were run in groups of three or four. Participants were transported to and from each of the road work sites in a minibus driven by an experimenter. Upon arrival at each site, all participants were issued with standard retroreflective safety vests and a brief safety induction was then given by a Main Roads/RoadTek Workplace Health and Safety Advisor.

Participants were allocated randomly to an observational vehicle at a specific distance (80 m, 160 m and 240 m) and once the ratings had been completed by all participants at a given distance they moved on to the next vehicle, following a pre-determined randomized order. While making their ratings, the participants viewed all four of the road workers at the same time. Road workers were instructed to walk in place facing the observational vehicles for the duration of each rating session. Participants sat in the front and rear passenger seats of the observational vehicles while responding to the items. Where there were groups of four participants, the researcher stood outside the vehicle (on the passenger side for safety purposes) to give his/her instructions, allowing the extra participant to sit in the driver's seat.

## RESULTS

**Overall Rankings**

Overall rankings of the visibility of the clothing aids were highly consistent between participants. Overall participants ranked the Full Biomotion configuration to be most visible (95% of participants in the suburban condition and 95% in the freeway), the Ankle & Knee configuration as second most visible (ranked second by 90% and 95%), the Thigh configuration third (ranked third by 95% and 95%), and the Standard configuration least visible (ranked least visible by 100% of participants in both conditions).

**Visibility Ratings**

A three-way repeated-measures ANOVA was conducted on the average visibility ratings with the factors of Work Site (Suburban versus Freeway), Distance (80 m, 160 m, 240 m) and Clothing (Standard, Thigh, Ankle & Knee, and Full Biomotion). Analysis revealed a significant main effect of clothing $F(3,57) = 98.02$, $p < .001$. Visibility ratings were highest for Full Biomotion, followed by the Ankle & Knee configuration, the Thigh configuration, and lastly the Standard configuration (all differences significant at $p < .001$). There was also a main effect of Distance $F(2,38) = 39.55$, $p < .001$. Visibility ratings declined significantly with distance (all differences significant, $p < .001$). There was no overall main effect of Work Site $F(1,19) = 0.057$, $p = .814$.

There was a significant interaction between Site and Clothing $F(3,57) = 21.58$, $p < .001$. At both sites, visibility ratings were highest for Full Biomotion, followed by the Ankle & Knee configuration, the Thigh configuration, and lastly the Standard configuration (all differences significant at $p \leq .034$), however the differences among configurations were larger at the freeway site. There was also a significant interaction between Clothing and Distance $F(6,114) = 4.08$, $p = .001$. At all distances, visibility ratings were highest for Full Biomotion, followed by the Ankle & Knee configuration, the Thigh configuration, and lastly the Standard configuration (all differences significant at $p \leq .013$), however the differences among configurations were weaker at the longest distance. There was also a significant interaction between Site and Distance $F(2,38) = 9.15$, $p < .001$. At both sites, the visibility of road workers decreased as distance increased (all differences significant at $p \leq .01$), but this effect was significantly greater at the suburban site.

In addition, there was a significant three-way interaction between the factors $F(6,114) = 2.66$, $p = .019$. This interaction resulted primarily from the differences among clothing configurations being smaller when the raters were at the suburban site and at the farthest viewing distance. As can be seen in Figure 2, at both sites, and at all distances, the visibility ratings were highest for Full Biomotion, followed by the Ankle & Knee configuration, the Thigh configuration, and lastly the Standard configuration. At the freeway site all differences were significant except for the difference between the Full Biomotion and the Ankle and Knee configuration at the middle distance (160m, $p = .057$). At the suburban site, however, the differences were considerably weaker at the longest distance, such that only the Standard configuration differs significantly from the others. At the shorter distances all clothing configurations differ significantly from one another with the exception of the difference between Full Biomotion and the Ankle & Knee configuration at the middle distance (160m, $p = .304$).

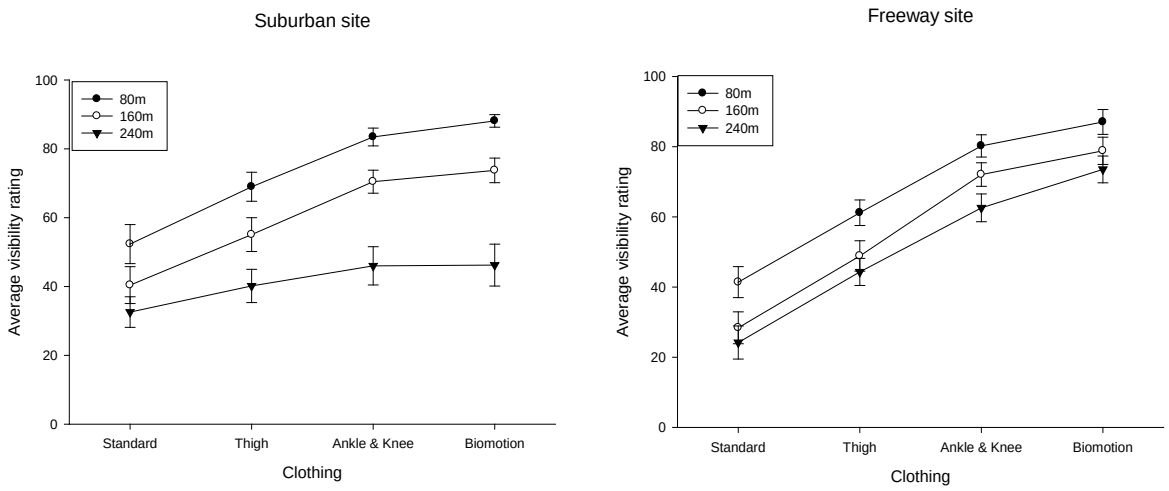


**FIGURE 2 Average visibility ratings as a function of road worker clothing configurations for three viewing distances and at the suburban (left) and freeway (right) sites.**

## DISCUSSION

The most important finding of this study is a confirmation that biomotion clothing has significant visibility benefits in work zones, where adding retroreflective strips in the full biomotion configuration to the standard road worker vest consistently enhanced the perceptions of road worker visibility compared to the standard night-time configurations currently being worn by road workers. This included both the standard vest alone, and the standard vest in combination with the thigh retroreflective markings. These visibility benefits were evident at all of the distances tested and at both the suburban and freeway work zones.

Together, these findings provide strong evidence that when wearing the full biomotion configuration together with the standard vest, road workers are significantly more likely to be detected and recognized as a person, rather than confused as part of the general roadway surrounds, than when wearing the standard vest alone, or the vest along with retroreflective thigh markings.

Adding retroreflective markings around the ankles and knees, in addition to the standard vest, was also found to provide significant visibility benefits over the standards currently adopted for night-time work. At the suburban site, the ratings of relative visibility for the ankle & knee and full biomotion configurations were in general superior to that of the standard configurations, but not significantly different from one another at the longer distances. At the freeway site, however, the full biomotion configuration was significantly better than all of the other configurations. The finding that the benefit of full biomotion, over and above all of the configurations, including ankle & knee, was most evident at the freeway site is not unexpected on theoretical grounds. The effects of biological motion have been shown to be most evident under totally dark conditions. In addition, the freeway site most closely mirrors the closed road conditions under which the effects of full biomotion clothing configurations have been previously demonstrated *(e.g., 21)*. The finding that full biomotion is most obvious at the freeway site, where road speeds are highest and road workers are potentially in greatest danger, underscores the usefulness of full biomotion clothing configurations in improving road worker safety.

As anticipated, participants' recognition of the road workers as people decreased significantly as the viewing distance increased, regardless of the perceptual judgment on which these ratings were made. Importantly, at the longest distance (240 m), participants' recognition of the road worker as a person were relatively poor, especially when the road worker was wearing a standard road worker vest, and at the suburban site. These findings suggest that road workers need to be made aware that drivers will not necessarily recognize their presence when the drivers are at longer distances.

Overall, the ratings of the visibility of the road workers were similar at both the suburban and freeway sites, however, this varied depended on the aspect of recognition, clothing condition, and viewing distances. For example, while for both sites the degree to which it was obvious to participants that the road workers were people declined with distance, this effect was greater in the suburban than in the freeway site. This suggests that at suburban sites, which have relatively high levels of ambient lighting, and also high levels of visual complexity involving other lighting sources (shops, advertisement hoardings, passing traffic) and people traffic (pedestrians interacting with the traffic mix), recognition of the retroreflective markings as a person is much less obvious. It is thus important that road workers are mindful of this fact and behave accordingly when they are working in these situations. In addition, the beneficial effects of the full biomotion clothing were more evident

at the freeway site, rather than at the suburban site, again indicating that there are subtle but important differences between the different types of work sites. These findings underscore the importance of undertaking studies at real world road work sites, such as the ones included in this study, as there are some aspects of closed road studies that fail to adequately reflect the complexity and surrounding activity typically encountered at suburban or freeway work sites.

Another important finding that lends weight to the validity of our findings is that, regardless of the wording of the questions for the visibility scales and also the rankings, the order in which the clothing configurations were ranked was consistent, with full biomotion being superior, followed by ankle & knees, and thigh, with the standard vest rated as worse. The visibility scale questions tapped into important suprathreshold components of perception, including whether the road workers were "*obvious*", "*always recognisable*" or "*immediately recognisable*" as a person when wearing them. These questions are important because they underscore the issue that, while road workers' retroreflective tape may well be seen at long distances, it is only when the road worker is recognized as a person that oncoming drivers are likely to prepare to take appropriate evasive action or slow down.

Roadways typically contain a number of retroreflective markers attached to cones, barriers, poles and signs, none of which necessarily present an imminent safety hazard to the oncoming driver (in the sense that, unlike pedestrians, work zone "furniture" is likely to remain stationary). However, the presence of road workers who may or may not move within and outside the road work site should warn the driver to take appropriate action and in time. Indeed, in our previous studies we demonstrated that it is not the amount of retroreflective tape that pedestrians wear that is important for recognition at night, indeed, when the tape is distributed in one large area, such as a retroreflective vest, oncoming drivers do detect that something is there, but more often than not this is mistaken for a flag or some other retroreflective object rather than as a person *(21; 22)*. It is only when the retroreflective tape is configured in a full biomotion format that oncoming drivers accurately recognise the presence of a person even in the presence of clutter *(20; 21)*.

Collectively, these data provide the first evidence that the benefits of full biomotion markings generalize to real world work zones. It is important, however, to be aware that these data relate to perceptions of relative visibility rather than actual distance measurements and it is imperative that these preliminary studies are followed up in future research that measures the relative visibility distances of road workers wearing these configurations from the perspective of drivers in moving vehicles. This is essential as roadwork sites need to be effectively marked so as to enable sufficient response time to avoid incidents.

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