2015-09-30

The Impact of Speed and Orientation on Nighttime Recognition of Retro-reflectively Outfitted Pedestrians

Mian, Jasmine

UNIVERSITY OF CALGARY

The Impact of Speed and Orientation on Nighttime Recognition of Retro-reflectively Outfitted Pedestrians

by

Jasmine Mian

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

GRADUATE PROGRAM IN PSYCHOLOGY

CALGARY, ALBERTA

SEPTEMBER, 2015

Abstract

Objective: To determine how speed of motion and orientation impact observers' decisions about the recognisability of pedestrians in biological motion retro-reflectors.

Method: Forty undergraduate students observed videos of pedestrians who were standing, walking or running with the side or back of their body oriented towards the observer at three distances in high and low beams. Participants decided which of the two pedestrians was most recognizable as a person.

Results: For both orientations, observers found walking and running pedestrians more recognizable than standing pedestrians. Observers also found running pedestrians more recognizable than walkers. The impact of pedestrian orientation was dependent on speed. When standing, pedestrians in the back orientation were selected more often, but when running, side-oriented pedestrians were selected as the most recognizable.

Conclusions: Observers find pedestrians moving at faster speeds more recognizable than those moving more slowly. The effect of pedestrian orientation depends on speed of motion.

Acknowledgements

I am lucky to be surrounded by many wonderful people that I don't get the chance to thank often enough. I would like to start by expressing sincere gratitude to my advisor, Dr. Jeff Caird. Thank you for understanding and encouraging me to pursue my goals in both academics and athletics. Your patience and guidance played an integral role in my success both on and off the mats.

I would like to thank my committee members, particularly Dr. Chip Scialfa for his constructive feedback and assistance. I am also deeply indebted to Dr. Tak Fung, who not only helped with statistical analysis, but managed to make me laugh while doing statistics. I am also grateful to AUTO21, SSHRC, Sport Canada and the Canadian Sport Institute in Calgary for financially supporting my higher education.

I would like to acknowledge my CERL lab mates both past and present, particularly Sarah Simmons and Katelyn Wiley. Thank you for helping with the project and being such wonderful friends. I'd also like to thank my parents and teammates for being so supportive of all my endeavours. Big thanks to my coach Leigh Vierling, your words of encouragement and all the free coffee have kept me going over the years. And last but certainly not least, I'd like to thank my partner, Jake for being the best support system and model pedestrian a girl could ask for.

Table of Contents

Abstract....ii
Acknowledgements....iii
Table of Contents....iv
List of Tables....vi
List of Figures and Illustrations....vii

CHAPTER 1: INTRODUCTION....1
1.1 Retro-Reflective Clothing....2
1.2 Biological Motion Retro-Reflectors....4
1.3 Pedestrian Motion & Orientation....7
1.4 Limitations of Current Pedestrian Conspicuity Research....9
1.5 The Current Study....10
1.6 Hypotheses....10

CHAPTER 2: METHOD....13
2.1 Participants....13
2.2 Materials....13
2.3 Procedure....19

CHAPTER 3: ANALYSIS & RESULTS....24
3.1 2AFC Task Design and Analysis....24
3.2 Generalized Estimating Equations....24
3.3 Analysis of Pedestrian Speed Selections....25
3.3.1 Standing vs. Walking....25
3.3.2 Standing vs. Running....26
3.3.3 Walking vs. Running....28
3.4 Analysis of Pedestrian Orientation Selections....30
3.4.1 Orientation Selections for Standing Pedestrians....30
3.4.2 Orientation Selections for Walking Pedestrians....31
3.4.3 Orientation Selections for Running Pedestrians....32
3.5 Post-Task Questionnaire....33
3.5.1 Pedestrian Speed of Motion Questions....33
3.5.2 Pedestrian Orientation Questions....34

CHAPTER 4: DISCUSSION....36
4.1 Speed of Motion....36
4.2 Orientation....39
4.3 Post-Task Questionnaire....42
4.4 Limitations....42
4.5 Future Research....44
4.6 Practical Applications....45
4.7 Conclusions....46

REFERENCES....47

APPENDIX A: PARTICIPANT RECRUITMENT SCRIPT 52

APPENDIX B: DRIVER EXPERIENCE QUESTIONNAIRE 53

APPENDIX C: CONSENT FORM 55

APPENDIX D: DEBRIEFING FORM 58

APPENDIX E: POST-TASK QUESTIONNAIRE 59

List of Tables

Table 2.1 *Calculation of Visual Angle* 18

Table 2.2 *Luminance and Contrast Measurements* 19

Table 2.3 *Stimuli Pairings for Practice Trials* 21

Table 2.4 *Stimuli Pairings for Pedestrian Speed of Motion Trials* 22

Table 2.5 *Stimuli Pairings for Pedestrian Orientation Trials* 22

Table 3.1 *Chi-Square Goodness of Fit Tests for High Beam Speed Decisions* 26

Table 3.2 *Chi-Square Goodness of Fit Tests for Low Beam Speed Decisions* 26

Table 3.3 *Chi-Square Goodness of Fit Tests for High Beam Orientation Decisions* 30

Table 3.4 *Chi-Square Goodness of Fit Tests for Low Beam Orientation Decisions* 30

Table 3.5 *Post-Task Questionnaire Responses for Pedestrian Speed of Motion* 34

Table 3.6 *Post-Task Questionnaire Responses for Pedestrian Orientation* 35

Table 4.1 *Summary of Results for Speed of Motion Decisions* 37

Table 4.2 *Summary of Results for Orientation Decisions* 40

List of Figures and Illustrations

Figure 1.1 Back and side view of biomo configuration on a pedestrian. 4

Figure 2.1 Test Track at the Fire Training Academy 15

Figure 2.2 Biological Motion configuration depicted in back orientation and side orientation ...16

Figure 2.3 Model pedestrian at three filming distances in high and low beams...........................18

Figure 3.1 The probability of selecting running over standing pedestrians by distance...............28

Figure 3.2 The probability of selecting running over walking pedestrian in the side orientation by distance and beam setting 29

Figure 3.3 The probability of selecting the side orientation over the back orientation by distance for walking pedestrians..31

Figure 3.4 The probability of selecting the side orientation over the back orientation by distance for running pedestrians 33

Chapter 1: **Introduction**

Annually, an estimated 1.24 million people die on roads around the world (WHO, 2013). To address this problem, the general assembly of the United Nations released a global road safety plan for the 2011-2020 decade. A major component of the plan targets pedestrian safety. Pedestrians are considered vulnerable road users and account for one-fifth of the people killed on the roads each year. Not surprisingly, there are considerable regional differences in pedestrian fatality rates with a greater proportion of them occurring in low-income countries (WHO, 2013).

In Canada, motor vehicle fatalities are on a downward trend. From 1970 to 2010, the number of road deaths decreased by 57.1%, even as the number of registered motor vehicles more than doubled (International Traffic Safety Data and Analysis Group, 2011). Despite this promising trend, motor vehicle collisions remain the leading cause of death for Canadians under 25 years of age (Cardinal et al., 2012). In the most recent statistics released by Transport Canada (2013), pedestrians accounted for 15.6% of road user fatalities. While lower than the percentage for drivers and passengers, more pedestrian fatalities occur in Canada each year than those involving bicyclists and motorcyclists.

Sixty percent of the pedestrian fatalities that occurred in Canada between 2004 and 2008 occurred at night or in reduced lighting (Transport Canada, 2011). Pedestrians are most at risk during the first hour of darkness and twilight. This is likely the result of pedestrian volumes remaining high around sunset despite a sharp reduction in visibility (Griswold, Fishbain, Washington, & Ragland, 2011). To understand the contribution of ambient light in pedestrian fatalities, researchers have examined fatality rates before and after daylight saving time changes. Traffic patterns are primarily dictated by the clock rather than the sun and the volume of traffic on the road remains similar across the daylight saving time transition, even as light levels change. Sullivan & Flannagan (2002) examined pedestrian fatalities in the weeks before and after the transition over an 11-year period. They found that the number of fatal pedestrian crashes was between 3 and 7 times greater in dark conditions than at the same time of day in light conditions. The effect was present for pedestrian fatalities occurring at intersections and was most pronounced for rural roads with no fixed overhead lighting. Dark conditions reduce pedestrian conspicuity, making it harder for pedestrians to ‘stand out’ from their environment and more difficult for drivers to see.

1.1 Retro-Reflective Clothing

The use of retro-reflective clothing is an effective way for pedestrians to make themselves more conspicuous to drivers. Relative to other kinds of interventions, retro-reflective material on clothing is a simple and cost-effective way to alert drivers to pedestrian presence and behaviour. The material is often found on active wear (e.g., running shoes, jackets, backpacks) and safety apparel (e.g., safety vests, coveralls, hard hats). Unlike other light-reflecting surfaces, retro-reflective material is uniquely manufactured to return light to the source, which helps pedestrians ‘stand out’ in reduced lighting (Olson & Farber, 2003). As a result, the use and configuration of retro-reflectors has been a major variable of interest in the pedestrian conspicuity literature.

Identifying the ideal retro-reflector configuration is important because different configurations have different consequences for pedestrian identification. Given that there are many retro-reflective objects on the road (e.g., signage, lane markings, delineators), the mere presence of retro-reflectors on a pedestrian does not signal to the driver that a person is near. This has been most clearly shown in work examining the identification of pedestrians in traditional retro-reflective safety vests. Balk, Tyrrell, Brooks, & Carpenter (2008) found that identification distances for pedestrian in vests were no better than when pedestrians wore no retro-reflective markings at all. Furthermore, Wood, Tyrrell, & Carberry (2005) found that drivers’ ability to identify pedestrians while wearing all white was actually better than it was for pedestrians in retro-reflective vests. These results suggest that the mere presence of retro-reflective material is not sufficient for the nighttime recognition of pedestrians. For retro-reflectors to aid pedestrian identification, they need to be configured in a way that allows pedestrian identification to follow first detection as closely as possible (Owens, Antonoff, & Francis, 1994). If drivers detect something in their visual field and immediately identify it, they have more time to respond appropriately than if identification takes longer. Retro-reflective vests do little for identification of pedestrians because they confine all material to the torso. As a result, they are poor at conveying important cues such as human motion and shape. Moving some of the retro-reflective material from the torso to the extremities has been shown to have a positive impact on the distance at which drivers identify pedestrians (Wood et al., 2005)

Researchers have incorporated aspects of 'Biological Motion' or 'biomo' into their studies of retro-reflective pedestrian clothing. Biological motion is a perceptual phenomenon that was first identified by a Swedish researcher named Gunnar Johansson. By attaching small light bulbs to the movable joints of a person wearing all black, Johansson (1973) developed a method for studying human motion that was not affected by other variables such as hair, clothing, size, skin colour, etc. When he presented these moving displays to participants, they recognized the stimuli as humans even with exposure times as short as 100-200 ms (Johansson, 1975). Biomo retro-reflectors are a real-world application of Johansson's work that are created by highlighting the movable joints of a pedestrian's body (e.g., shoulders, elbows, wrists, hips, knees and ankles) with retro-reflective material (Figure 1.1). Unlike safety vests, biomo retro-reflectors highlight both human motion and shape allowing pedestrian identification and detection to occur almost simultaneously (Owens et al., 1994).

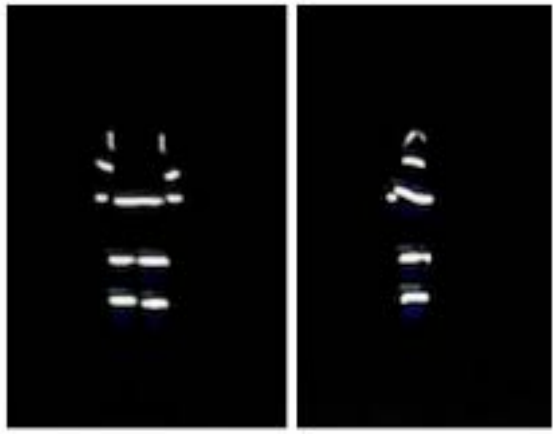

Figure 1.1 Back and side view of biomo configuration on a pedestrian.

1.2 Biological Motion Retro-Reflectors

Field studies that investigated different biomo retro-reflector configurations found that they significantly improved pedestrian identification compared to configurations that confine retro-reflective material to the torso (Balk, Graving, Chanko, & Tyrrell, 2007; Balk et al., 2008; Blomberg, Hale, & Preusser, 1986; Luoma & Penttinen, 1998; Luoma, Schumann, & Traube, 1996; Owens, Wood, & Owens, 2007; Sayer & Mefford, 2004; Tyrrell et al., 2009; Wood, Marszalek, Lacherez, & Tyrrell, 2014b; Wood et al., 2005; Wood et al., 2012). This pattern of results is known as the 'biomo advantage'. Compared to other configurations, the biomo configurations in these studies are identified either at greater distances, with greater frequency or both. These studies typically require participants to search for pedestrians while driving or while seated as a passenger in a test vehicle. The biomo advantage has been shown for American and European drivers (Luoma & Penttinen, 1998) and is robust in the presence of variables such as glare (Wood et al., 2005) and visual clutter (Tyrrell et al., 2009). The advantage appears to be robust to driver age as well. Although the response distances of older drivers are much shorter than younger drivers overall, identification of the biomo configuration is significantly better than vest conditions in both age groups (Tyrrell et al., 2009; Wood et al., 2005; Wood, Lacherez,

& Tyrrell, 2014). The advantage has been observed when participants assume the role of drivers (Tyrrell et al., 2009; Wood et al., 2012; Wood et al., 2005; Wood et al., 2014b) or passengers (Balk et al., 2007, 2008; Luoma & Penttinen, 1998; Luoma et al., 1996). It has also been observed for bicyclists (Wood et al., 2012), suggesting that biomo retro-reflectors aid identification even when pedestrians are engaging in activities with different movement patterns.

Owens et al. (1994) found a biomo advantage in a laboratory setting where participants identified pedestrians in a video of nighttime driving. Biomo recognition was significantly better than all other retro-reflector configurations, but only when participants played a nighttime driving game that divided attention in a manner similar to driving. An investigation by Moberly & Langham (2002) is the only study, despite a comprehensive search of the literature that did not report a biomo advantage. Methodological differences may have contributed to their unique results. In their study, participants passively viewed videos of a nighttime journey without completing a secondary task. It is possible that the biomo advantage is sensitive to task demands, at least in a laboratory setting. Thus, with one exception, studies of the biomo configuration have shown that it affords pedestrians conspicuity advantages that exceed those of traditional retro-reflective vests. This has led researchers to speculate about which aspect of this unique configuration is most important to the biomo advantage.

The biomo configuration is unique because it highlights both human motion and form. Biological motion is a particularly salient cue, but so is the highlighting of the human form or shape. To gain a better understanding of how these variables individually contribute to the biomo advantage, Balk et al. (2008) attempted to quantify the unique contribution of form and motion. To quantify the effect of form, they compared the response distances to standing pedestrians in a full biomo configuration with the response distances to pedestrians standing in a vest configuration. Full biomo configurations provide maximal form highlighting, whereas vests only highlight the torso. This allows for an estimation of the impact of form because both configurations had an equivalent amount of retro-reflective material, but they provide very different levels of form highlighting. The response distances for the standing biomotion configuration were about 4 times greater than the standing vest condition. To quantify the effect of motion, Balk et al. (2008) compared the response distances to walking pedestrians in an ankles configuration (i.e., retro-reflective rings around the ankles) with response distances to a standing ankles condition. These conditions have equivalent amounts of retro-reflective material and form information, but provide a different amount of motion information. The walking ankles condition conveys the pendular movement of the feet, whereas the standing ankles condition shows no movement at all. Interestingly, the contribution of motion was found to be similar to the contribution of form. The response distances of the walking ankles condition was about 4 times greater than the standing ankles condition. Balk et al. (2008) only found significant effects of motion for conditions that marked the extremities (e.g., biomo, ankles, ankles + wrists). They concluded that the contributions of form and motion are similar and synergistic such that the benefits of highlighting form are greater when pedestrians move. Pedestrians who walked and maximally highlighted their form by wearing the full biomo configuration were identified at the greatest average distance of approximately 117 m, while those who wore no retro-reflectors and stood were recognized at the shortest distance of approximately 10 m. To summarize, it appears that it is the combination of form and motion information provided by biomo retro-reflectors that results in this configuration being identified at greater distances than other configurations.

Despite the clear benefits of the biomo configuration, it requires that pedestrians wear 11 retro-reflective stripes and this has been a barrier to its widespread acceptance (Balk et al., 2008). This has led researchers to explore simpler configurations that take advantage of the form and motion aspects of the biomo concept without adopting the full configuration. Studies that have examined retro-reflective highlighting of only the ankles and wrists (A+W) have found that it is not significantly worse than the full biomo configuration (Balk et al., 2008; Luoma & Penttinen, 1998; Luoma et al., 1996; Tyrrell et al., 2009). Although, Balk et al. (2008) and Tyrrell et al. (2009) report similar identification distances for both the full biomo and A+W configurations, pedestrians were only seen standing and walking parallel to the roadway. It is possible that the A+W configuration would perform much worse when pedestrians face the roadway as if to cross. Luoma and Penttinen (1998) and Luoma et al. (1996) reported no significant differences in recognition distances between the full biomo and A+W configurations for pedestrians in a crossing orientation, however all the test pedestrians examined were walking. Whether the A+W configuration can elicit similar recognition distances to the full biomotion configuration while standing in a crossing orientation remains unknown. When positioned in this way, the form and motion information of both configurations is reduced considerably. From this it becomes clear that what can be concluded about retro-reflector configuration may depend on other important variables such as how a pedestrian is moving (standing or walking) and how they are oriented to the observer (facing, side). For this reason, it is important to investigate retro-reflector configuration across various levels of pedestrian motion and orientation.

1.3 Pedestrian Motion & Orientation

When wearing retro-reflective configurations, pedestrians that walk are recognized at greater distances than those who stand (Balk et al., 2008; Tyrrell et al., 2009). Not surprisingly, this effect is strongest for configurations that highlight the movable joints of the body. Tyrrell et al. (2009) reported that adding motion to a vest configuration only increased recognition frequency by 4% compared to standing, but adding motion to an A+W configuration improved recognition frequency by 38%. It is worth noting that even in the absence of retro-reflective material, moving pedestrians are detected and recognized at greater distances than standing pedestrians (Bhagavathula & Gibbons, 2013).

While motion seems to improve pedestrian recognition, the impact of orientation on the recognition of retro-reflectively outfitted pedestrians needs further investigation. Three studies have manipulated pedestrian orientation for a full biomo configuration and the results are conflicting. Luoma et al. (1996) reported greater recognition distances for crossing pedestrians (side-oriented) than approaching pedestrians (facing the observer). Whereas Balk et al. (2007) reported that facing pedestrians were detected at greater distances than those who were side-oriented. Finally, Wood et al. (2014b) reported no effect of pedestrian orientation in their study of retro-reflectively outfitted roadway workers. An important difference between these three studies is that participants only saw one kind of pedestrian motion in the investigations by Luoma et al. (1996) and Wood et al. (2014b). All of the pedestrians in these investigations were walking in both orientations and no pedestrians were seen standing or running. Pedestrian speed of motion must be considered when investigating pedestrian orientation because they are related in an important way. A side orientation conveys motion to a greater extent than a facing orientation. This means that the conspicuity of a side-oriented pedestrian is likely affected by a lack of motion to a greater extent than the conspicuity of a facing pedestrian. Balk et al. (2007) reported a significant effect of motion for both orientations, however the magnitude of the effect appears larger for side-oriented pedestrians. The difference in mean recognition between standing and walking pedestrians was 44.27 m for facing pedestrians and 74.47 m for side-oriented pedestrians. This difference between orientations may result because standing, side-oriented pedestrian do not convey human form very well, and in the absence of motion, they can easily be mistaken for a retro-reflective post or sign. This results in recognition distances that are closer to a vehicle because it takes observers longer to identify the retro-reflective stimulus as a person.

Understanding the relationship between pedestrian orientation and motion when wearing biological motion retro-reflectors has important implications for pedestrian safety. Compared to the walking side-oriented pedestrians recognized on average at 89.81 m in the study by Balk et al. (2007), those who were standing and side-oriented were recognized at only 15.34 m. These differences are alarming when you consider how often pedestrians are encountered standing in a side orientation. Pedestrians waiting to cross the street position themselves this way, as do police officers when they talk to drivers who have been pulled over to the side of the road.

1.4 Limitations of Current Pedestrian Conspicuity Research

Speed of pedestrian motion. There have been many studies examining different retro-reflective configurations and the effect of highlighting human form in different ways. To date, research that has investigated the motion of retro-reflectively outfitted pedestrians has been quite basic; motion is either present or absent and the pedestrian is walking or standing still. The complexity of pedestrian motion can be manipulated by increasing pedestrian speed. Pedestrians often use the roads to run or jog, but no study, to my knowledge, has examined perceptions of pedestrians running in biomo clothing. Given that pedestrians do more than stand and walk on roadways, an investigation of pedestrian motion that includes running would be of value.

Pedestrian Orientation. The impact of pedestrian orientation is another area that needs further investigation. In their review of pedestrian conspicuity research, Langham and Moberly (2003) outline some potential reasons why there appears to be discrepancy when discerning whether a facing or side orientation makes pedestrians more conspicuous. Frontal orientations maximize the amount of retro-reflective material returning light back to the driver, while side orientations convey the sweeping biological motion of the human body to a greater extent. The amount of light differs between orientations, but so too does the amplitude of motion cues that can be seen. Given this reasoning, it seems logical that the relative conspicuity of the frontal vs. side orientation may be dependent on the speed of pedestrian motion. This makes it important to investigate pedestrian speed of motion and orientation in the same study.

1.5 The Current Study

The overwhelming consensus of the literature indicates that biomo retro-reflectors improve the identification of pedestrians at night. However, less is known about how pedestrian speed of motion and orientation impact identification when biomo retro-reflectors are worn. The current study has two main objectives that explore how these variables may impact pedestrian identification. The first is to determine if observers choose pedestrians moving at faster speeds (e.g., running) as more recognizable as people than pedestrian who move more slowly (e.g., walking) or not at all (e.g., standing), and whether the pattern of results is the same for both pedestrian orientations (e.g., side & back). The second objective is to determine if observers choose pedestrians oriented in one direction (e.g., side) as more recognizable as people than pedestrians oriented a different way (e.g., back), and whether the pattern of results is the same for all levels of pedestrian motion (e.g., standing, walking, running).

In the current investigation, two pedestrians conveying either different motion speeds or different orientations were shown on the screen at once in the form of a two-alternative forced-choice task (2AFC). Participants were asked to select which of the two pedestrians they believed was most recognizable as a person. As explained by Wood et al. (2011), it is important to investigate recognition of pedestrians rather than detection of pedestrians as stimuli in the field of view. Pedestrians may be detected at greater distances, but it is upon identification of the stimulus as a person that drivers are likely to prepare for evasive action. It may also be the case that drivers perceive road situations containing people as particularly hazardous. Borowsky & Oron-Gilad (2013) had participants provide hazard ratings of 8 videos containing various kinds of driving hazards. Two of the three videos with the highest ratings contained pedestrian hazards as the main event.

1.6 Hypotheses

Pedestrian speed of motion. Two hypotheses were made about how speed of motion would impact the frequency with which a pedestrian was selected as the most recognizable. These hypotheses were developed based on prior research that found moving pedestrians are recognized at greater distances than those who are standing (Balk et al., 2008; Tyrrell et al., 2009).

1) In comparisons between standing and walking pedestrians, it was hypothesized that walking pedestrians would be chosen as the most recognizable as a person more often than standing pedestrians for both side and back pedestrian orientations.
2) In comparisons between standing and running pedestrians, it was hypothesized that running pedestrians would be chosen as the most recognizable more often than standing pedestrians for both pedestrian orientations.

Whether pedestrians moving quickly (e.g., running) would be chosen over pedestrians moving slowly (e.g., walking) was an exploratory question of the current investigation. While the increased speed of running pedestrians may help them be detected sooner, it is unknown whether running pedestrians would be perceived as more recognizable as people than walking pedestrians. Previous literature has not addressed this question.

Pedestrian orientation. Three hypotheses were made about how orientation would impact the frequency with which a pedestrian was selected as the most recognizable.

1) The back orientation would be chosen as the more recognizable more often than the side orientation when pedestrians were standing;
2) The side orientation would be chosen as the more recognizable more often than the back orientation when pedestrians were walking;
3) The side orientation would be chosen as the most recognizable more often than the back orientations when pedestrians were running.

When pedestrians are standing, they do not convey motion cues. As a result, it is the form information provided by the retro-reflectors that conveys their identification. It is for this reason that the back orientation is hypothesized to be selected more frequently than the side orientation for standing pedestrians. When walking and running, it is hypothesized that the side orientation would be selected more frequently because it better conveys the forward and backward movements of the extremities.

Chapter 2: **Method**

2.1 Participants

A total of 40 University of Calgary students (18-33 years; *M* = 22.4 years; 22 males) participated in this study. Participants were recruited using an online research participation system called SONA, which is operated by the Department of Psychology at the University of Calgary (see Appendix A for the online recruitment script). In exchange for participation, volunteers received one percent credit, which could be applied to a grade in an undergraduate psychology course. Participants were made aware of the eligibility requirements when they signed up online. They were required to be licensed, regular drivers with normal or corrected-to-normal vision. Upon arriving at the Cognitive Ergonomics Research Laboratory (CERL), their eligibility for the study was assessed. Participants filled out the Driver Experience Questionnaire (DEQ, Appendix B). All participants reported holding a valid Class 5 license and driving at least 5,000 km annually. Visual screening ensured that participants met or exceeded Alberta's minimum 20/50 visual acuity standard, which is required for Class 5 licensure (CCMTA, 2013). In addition, participants were required to have contrast sensitivity within normal ranges. All participants that were tested passed visual screening. Within the DEQ, participants were screened for avoidance of nighttime driving and involvement in a pedestrian collision (either as a driver or pedestrian). Three participants reported that they avoided nighttime driving, but were included in the study because they provided conditional reasons such as "I will avoid driving at night if I am tired" or "…if I am driving to an obscure place in the mountains". Their responses did not reflect a general tendency to avoid nighttime driving for visual reasons. No participants reported being involved in a pedestrian collision.

2.2 Materials

Driver Experience Questionnaire. The Driver Experience Questionnaire (DEQ) (Appendix B) was administered to gather demographic information such as age, gender and annual distance driven.

Visual assessment. Participants' photopic acuity and contrast sensitivity were measured using a Snellen acuity eye chart (RJ's Ophthalmic Services, INC. Product # RJ 016) and the Vistech Contrast Test System Chart, VISTECH 6500. For a more in-depth description of how visual screening was conducted, see the procedure section.

Video recording. The stimuli used in this study were videos of a retro-reflectively outfitted pedestrian taken in a nighttime road environment. Filming took place approximately two hours after sunset on a night free of precipitation and adverse weather on a test track at the Fire Training Academy in Calgary, Alberta (Figure 2.1). The filming was conducted by a professional videographer from the driver's seat of a stationary 2007 Toyota Yaris hatchback. The footage was captured through the windshield of the car, which was positioned in the right lane of the road. The lane itself was 3.5 m wide, the standard lane width for undivided highways in Alberta (Alberta Ministry of Transport, 2007). Filming was conducted using a Panasonic HPX370 video camera recording in AVC Intra 100 mb/s format at 1080 60i. The gamma curve preset was HD Norm and the black level preset was 7.5 IRE. The gain on the camera was at 0 db. The camera was mounted on boxes in the vehicle to approximate the view of the driver. The distance from the ground to the focal plane of the camera was 122 cm. The distance from the seat to the focal plane of the camera was 65 cm. The focal length was set to 20 mm and the lens was set to the maximum aperture (f/2.0). At each filming distance, the camera and a field monitor were set up to allow for comparison between the live camera image and what could be seen with the naked eye. Three observers examined the images on the video monitor and compared it to the scene. Adjustments were made until the three observers agreed that the images being collected best approximated what could actually be seen in the environment.

Figure 2.1 Test Track at the Fire Training Academy (Google Maps, 2015). Filming took place along the straight section, which is boxed in a dotted yellow line. A indicates the location of the pedestrian on the treadmill. A shows the vehicle filming locations of 80 m, 160 m, 240 m from the pedestrian.

The headlamps of the vehicle were equipped with standard halogen HB2 bulbs (60/55 watts). A certified mechanic aimed the headlamps using an optical headlight-aiming tool prior to the night of filming and the windshield of the vehicle was cleaned upon arrival at the test track.

Model Pedestrian. The model pedestrian was a male (height = 165 cm, weight = 65 kg) with an approximate walking stride length of 66 cm and running stride length of 114 cm. The model wore retro-reflectors in a biological motion configuration that was created by attaching 2.5 cm strips of 3M Scotchlite retro-reflective material to the wrists, ankles, elbows, knees, waist and shoulders of a black running suit (Tyrrell, Wood & Carberry, 2004) (Figure 2.2). The model pedestrian was filmed at 3 distances (80 m, 160 m and 240 m) (see Wood et al. 2011) and in two headlight settings (high beams, low beams) (Figure 2.3).

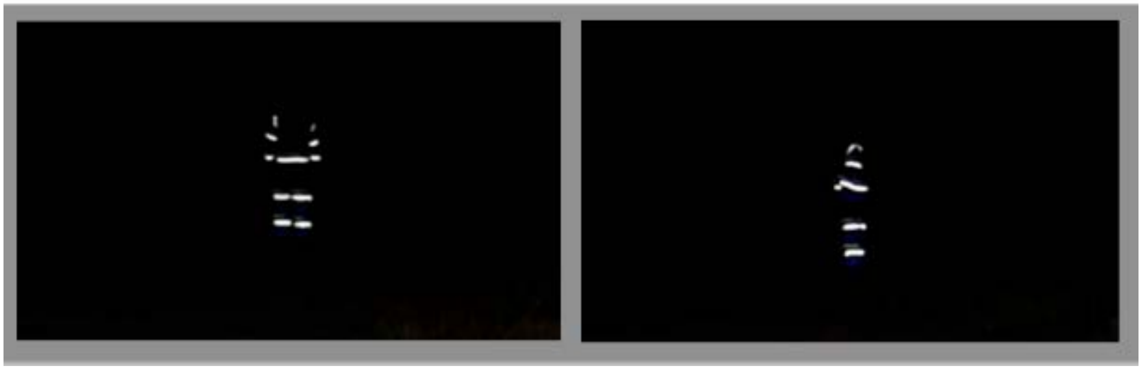

Figure 2.2 Biological Motion configuration depicted in back orientation (left) and side orientation (right)

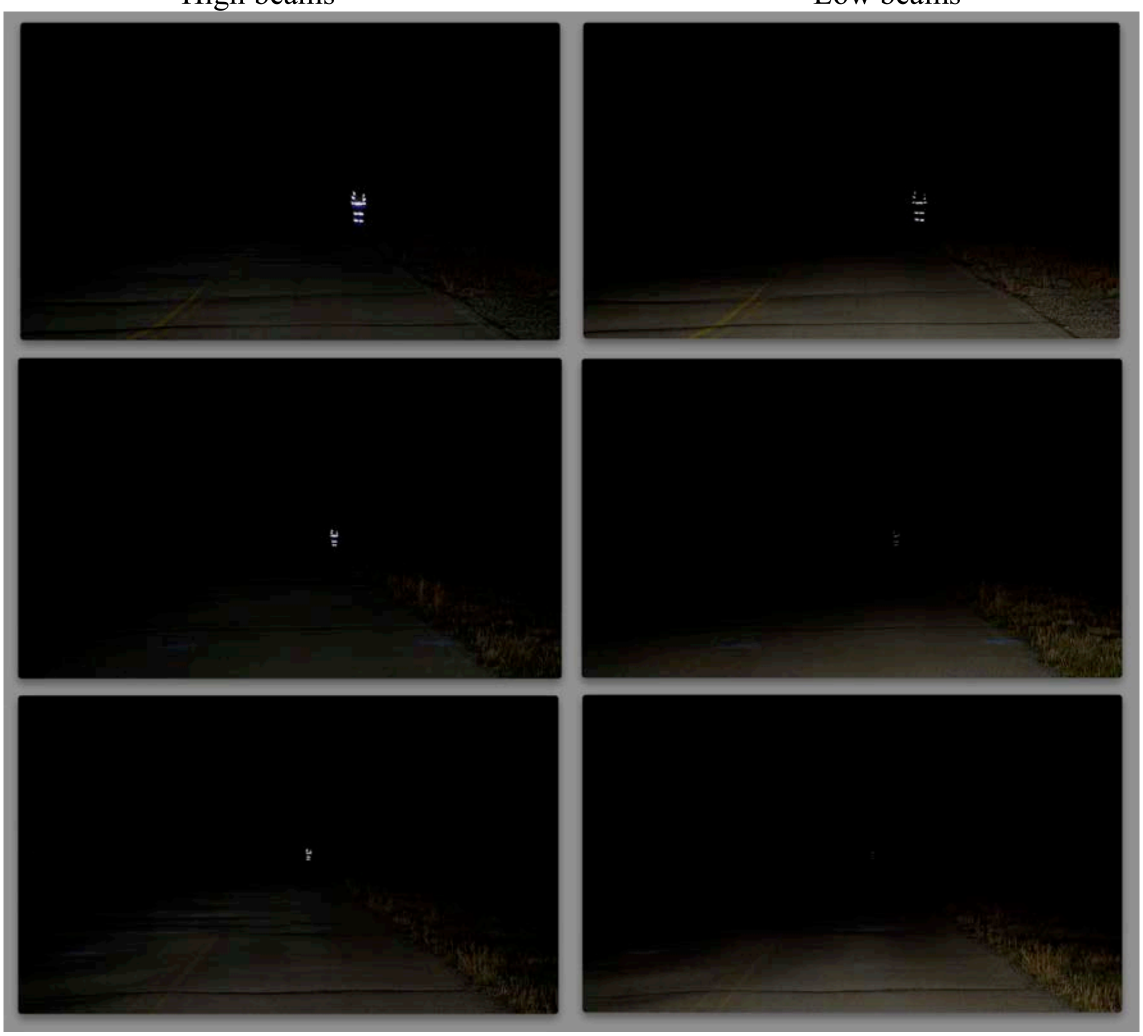

Figure 2.3 Model pedestrian at three filming distances in high and low beams. Shown here in back orientation.

The pedestrian was filmed on the right side of the road in three motion speeds (standing, walking, running) crossed with two orientations (side, back). This resulted in the creation of six different stimulus types (standing-side, standing-back, walking-side, walking-back, running-side, running-back). The pedestrian stood, walked and ran on a Weslo Free Spirit treadmill. The treadmill was modified for the study by removing the side safety bars and relocating the display console to the ground. The console remained attached to the platform of the treadmill so that the speed could be adjusted during filming. The treadmill ensured that the pedestrian maintained a constant speed, but elevated the pedestrian six inches off the ground. It also resulted in a more realistic stride than walking or running on the spot, which is how previous investigations of pedestrian conspicuity have had pedestrians move (see Balk et al., 2007, 2008; Moberly & Langham, 2002; Tyrrell et al., 2009; Wood et al. 2014b). The three observers agreed that the actual platform of the treadmill was not visible from the filming distances.

When filming the *standing* stimuli, the pedestrian stood in place on the treadmill and looked directly forward with their back or left side to the digital video camera. *Walking* stimuli were created by having the pedestrian walk at a speed of 2.5 mph (4.02 km/hr), which is a reasonable walking pace for non-elderly pedestrians (Knoblauch, Pietrucha & Nitzburg, 1996). Running speeds are highly variable among people making it difficult to choose a ‘typical’ running speed. Given that no previous pedestrian studies have investigated running speeds, 6 mph (9.65km/hr) was selected as a reasonable speed because it was twice as fast as the walking pedestrian and approximated an encounter with a jogger at night. An experimenter monitored the speed of the walking and running model during filming using the display console. The pedestrian practiced walking and running at a constant pace prior to filming. For each of the stationary, walking and running speeds, the model pedestrian was oriented either perpendicular to the roadway to produce the side orientation or parallel to the roadway facing away from the camera to create the back orientation (see Figure 2.2).

Presentation Apparatus. Videos of the pedestrian stimuli were presented on a 27-inch Apple iMac computer with 5k Retina display. Two 1080-60i videos were presented side-by-side, which was required for the two-alternative, forced-choice task (2AFC) (see below for details). The video display was viewed at a distance of 100 cm, which provided visual angle dimensions that approximated the original nighttime environment (see Table 2.1 for calculations of the visual angle). Superlab 5 (www.cedrus.com) was used to present the videos and to collect responses from participants. Weber's contrast was calculated from luminance readings taken off the display screen (Table 2.2). Luminance measurements were taken from retro-reflectors positioned in two locations (i.e., waist and right leg) as well as for the adjacent background area for both beam settings. High and low beams not only project light at different intensities, but also in different patterns. High beam patterns are symmetrical, whereas low beam patterns concentrate the illumination below to horizon and to the right in North America to avoid glare for oncoming drivers (Olson & Farber, 2003). When low beams are used, luminance contrast measurements are maximal on the lower part of the pedestrian's body, whereas high beam patterns produce more uniform results.

Table 2.1

Calculation of Visual Angle

Nighttime environment			Laboratory environment		
Pedestrian	Distance	Angle	Pedestrian	Distance	Angle
162.56 cm	8000 cm	1.164	2 cm	100 cm	1.146
162.56 cm	16000 cm	0.582	1 cm	100 cm	0.573
162.56 cm	24000 cm	0.388	.7 cm	100 cm	0.401

Table 2.2

Luminance and Contrast Measurements

	Location	Reflector ML	Background ML	WC
High beam				
	Waist	57.24	.056	1021.1
	Right leg	52.48	.056	936.1
Low beam				
	Waist	37.36	.055	678.27
	Right leg	41.90	.055	760.82

Note. ML = mean luminance measured in cd/m^2. Weber's contrast (WC) is calculated by dividing the difference in luminance between the reflector and background by the luminance of the background

2.3 Procedure

Informed Consent and Debriefing Forms. Upon arrival at CERL, participants provided informed consent (Appendix C). Following participation, participants were verbally debriefed and were given a debriefing form that explained the purpose of the study (Appendix D).

Visual Screening. After completing the questionnaires, participants underwent tests of visual acuity and contrast sensitivity. All tests were conducted under photopic illumination. Visual acuity was assessed using a Snellen acuity eye chart. Participants were positioned 6.1 meters (20 ft) away from the chart and acuity was assessed separately for each eye. Participants were asked to cover one eye with a visual occluder and read each row of letters aloud. Visual acuity was recorded as the last row that participants could read without error.

Contrast sensitivity was assessed using the Vistech Contrast Test System Chart positioned 3.05 meters (10 ft) from the participant. Participants were required to report the orientation of sine-wave gratings (left, right or up) of five spatial frequencies and nine levels of contrast.

Dark Adaptation. Prior to the commencement of the 2AFC, participants were dark adapted for a period of 10 minutes. All lights in the laboratory were turned off and to block lighting coming from outside the lab, a black dark-out curtain was drawn between the participant and the entrance to CERL.

Two-Alternative Forced-Choice Task. Following the dark adaptation period, participants were seated at a computer to complete the 2AFC that was structured into practice and testing phases. A chin rest and adjustable office chair were used to maintain a viewing distance of 100 cm and to generate a gaze angle of 15 degrees below the horizontal resting point of the eyes. In the 2AFC, participants were shown two side-by-side videos and asked to make a decision between them. The following verbal protocol was presented on the screen and read aloud by the experimenter:

> In this task, you will see videos of retro-reflectively outfitted pedestrians behaving in different ways. Two videos will be presented side-by-side. Each video will contain one pedestrian. You must decide which pedestrian is most recognizable as a person. Sometimes it may be difficult to decide, but please observe the videos and make a decision. To select the pedestrian on the left, press L on the controller, to select the pedestrian on the right, press R on the controller.

The participant used a Gravis Gamepad Pro controller to indicate their responses. They were instructed to hold the controller with both hands using their right thumb for right-side responses and their left thumb for left-side responses.

Practice phase. Following the instructions, participants completed 8 practice trials (4 low beam, 4 high beam). The practice trials were included to give participants some practice with the task prior to the testing phase and were not used as a basis for exclusion from the study. The practice trials were designed to be 'easy' which meant that the two videos were paired such that one pedestrian appeared more recognizable as a person than the other. For example, a close running pedestrian (i.e., Side-Running pedestrian at 80 m) was paired with a distant stationary pedestrian (i.e., Side-Standing pedestrian at 240 m) (see Table 2.3 for a list of practice stimuli pairings). Manipulation of distances within a trial did not occur during the testing phase of the study. None of the practice trials contained stimuli pairings that occurred during the testing phase.

Table 2.3

Stimuli Pairings for Practice Trials

	Practice Trials
High Beams	80 m Side Running vs. 240 m Back Standing
	80 m Side Running vs. 240 m Side Standing
	160 m Side Walking vs. 240 m Back Standing
	160 m Side Walking vs. 240 m Side Standing
Low Beams	
	80 m Side Running vs. 240 m Back Standing
	80 m Side Running vs. 240 m Side Standing
	160 m Side Walking vs. 240 m Back Standing
	160 m Side Walking vs. 240 m Side Standing

After completion of the practice phase, participants could ask questions and if they indicated that they understood the task, the experimenter started the testing phase.

Testing phase. The testing phase contained a total of 54 trials. For the stimuli paired in pedestrian speed of motion trials, see Table 2.4. For stimuli paired in pedestrian orientation trials, see Table 2.5.

Table 2.4

Stimuli Pairings for Pedestrian Speed of Motion Trials

	High Beams		
	80 m	160 m	240 m
Side Orientation	Stand vs. Walk	Stand vs. Walk	Stand vs. Walk
	Stand vs. Run	Stand vs. Run	Stand vs. Run
	Walk vs. Run	Walk vs. Run	Walk vs. Run
Back Orientation			
	Stand vs. Walk	Stand vs. Walk	Stand vs. Walk
	Stand vs. Run	Stand vs. Run	Stand vs. Run
	Walk vs. Run	Walk vs. Run	Walk vs. Run
	Low Beams		
Side Orientation	80 m	160 m	240 m
	Stand vs. Walk	Stand vs. Walk	Stand vs. Walk
	Stand vs. Run	Stand vs. Run	Stand vs. Run
	Walk vs. Run	Walk vs. Run	Walk vs. Run
Back Orientation			
	Stand vs. Walk	Stand vs. Walk	Stand vs. Walk
	Stand vs. Run	Stand vs. Run	Stand vs. Run
	Walk vs. Run	Walk vs. Run	Walk vs. Run

Table 2.5

Stimuli Pairings for Pedestrian Orientation Trials

	High Beams		
	80 m	160 m	240 m
Stand	Back vs. Side	Back vs. Side	Back vs. Side
Walk	Back vs. Side	Back vs. Side	Back vs. Side
Run	Back vs. Side	Back vs. Side	Back vs. Side
	Low Beams		
	80 m	160 m	240 m
Stand	Back vs. Side	Back vs. Side	Back vs. Side
Walk	Back vs. Side	Back vs. Side	Back vs. Side
Run	Back vs. Side	Back vs. Side	Back vs. Side

Speed and orientation trials were blocked separately and the three distances were fully randomized within each block. Whether a stimulus appeared on the left or right side of the screen in the

2AFC was also fully randomized without replacement. Beam was blocked so that participants made all of their speed and orientation judgments within one beam setting before moving to the next. One-half of participants started with low beams and one-half started with high beams. Within each beam block, one-half completed speed trials followed by orientation trials, while the other one-half completed orientation trials followed by speed trials.

Post-task questionnaire and debriefing. After the testing phase was completed, the lights in CERL were turned on and the participant filled out the post-task questionnaire (see Appendix E) to ascertain whether participants were consciously adopting a strategy when making their selections (e.g., always picking the pedestrian that was moving the fastest, or always selecting the pedestrian in back orientation). This was an opportunity for participants to provide feedback about the task which may help us better understand their response patterns in the 2AFC. Following completion of the questionnaire, participants were debriefed and the experimenter answered any questions.

Chapter 3: **Analysis & Results**

3.1 2AFC Task Design and Analysis

This study was designed to test the impact of pedestrian speed of motion and orientation on the frequency with which a pedestrian is selected as being most recognizable as a person. Pedestrian speed of motion is how quickly the pedestrian is moving and was comprised of three levels (standing, walking, running). The pedestrian orientation variable was comprised of two levels (side, back) and refers to the direction that the pedestrian faced. Both variables were categorical and were presented within-subjects in a 2AFC task. For each trial, participants made decisions between pedestrians showing different levels of pedestrian speed (i.e., standing vs. walking, standing vs. running, walking vs. running) or the different levels of pedestrian orientation (i.e., side vs. back). Pedestrian speed and orientation were never varied within the same trial. All trials assessing the different levels of pedestrian speed and orientation were repeated at three distances from the observer (80 m, 160 m, 240 m) and in two beam settings (high, low). Because a level of the speed and orientation variables was either selected or not, the data is binary in nature and a traditional repeated measures ANOVA could not be used. Chi-square goodness of fit tests were used to analyze differences in category selection and the Generalized Estimating Equations (GEE) were used to analyze how the proportion of responses to a particular category was impacted by the repeated measures of distance and beam setting. (A brief overview of GEE is presented below). The GEE analysis was conducted using SPSS v.22.

3.2 Generalized Estimating Equations

Generalized Estimating Equations (GEE) were developed by Zeger and Liang (1986) as an extension of the General Linear Model (GLM). GEE has been popular in fields such as biology and epidemiology, where the collection of correlated data is particularly common. Despite its many advantages over other regression models, it remains relatively underutilized in the social sciences (Ghisletta & Spini, 2004). Some advantages of GEE include: 1) it makes no strict distribution assumptions, 2) the estimation of standard errors is consistent and unbiased, even with a mis-specified correlation structure, 3) it can accommodate missing data and, 4) it can integrate various forms of outcome variables such as binary, count and continuous data.

GEE was chosen to analyze responses across the repeated measures of distance and beam. It is important to not only understand if participants select certain speed and orientation categories more often than others, but also if the pattern of response changes as a function of distance and beam setting.

3.3 Analysis of Pedestrian Speed Selections

3.3.1 Standing vs. Walking

Side Orientation. When side-oriented, walking pedestrians were selected more than standing pedestrians 100% of the time across distance and beam setting, χ^2 (1) = 40.0, $p < .0001$ (see Table 3.1 and Table 3.2). Given that no variation existed in the side orientation, analysis of distance or beam effects, and a distance x beam interaction could not be conducted and clearly there is no interaction or main effect.

Back Orientation. When oriented with the back to the observer, walking pedestrians were selected over standing pedestrians at each distance in both high beams and low beams. See Table 3.1 and Table 3.2 for tests of significance and effect sizes (Cohen's *W*) for each distance in both beam settings. Distance ($p = .698$) and beam effects ($p = .733$) were not significant, nor was the distance x beam interaction ($p = .633$).

Overall, the results of the analysis of standing vs. walking pedestrians shows that the faster moving pedestrian was selected as the most recognizable significantly more often than the slower or in this case, non-moving pedestrian. This pattern of results held for both pedestrian orientations at all distances and in both beam settings.

Table 3.1

Chi- Square Goodness of Fit Tests for High Beams Speed Decisions

	Decision	High Beams					
		80 m		160 m		240 m	
		χ^2 (1)	*W*	χ^2 (1)	*W*	χ^2 (1)	*W*
Side Orientation							
	S/W	40.0**	1.00	40.0**	1.00	40.0**	1.00
	S/R	40.0**	1.00	40.0**	1.00	40.0**	1.00
	W/R	16.9**	0.65	12.1**	0.55	25.6**	0.80
Back Orientation							
	S/W	32.4**	0.90	32.4**	0.90	28.9**	0.85
	S/R	40.0**	1.00	22.5**	0.75	28.9**	0.85
	W/R	14.4**	0.60	14.4**	0.60	19.6**	0.70

Note. S/W = standing vs. walking; S/R = standing vs. running; W/R= walking vs. running.
W = Cohen's W. Small effect = .10, medium effect = .30, large effect = .50
*$p < .05$. ** $p < .01$.

Table 3.2

Chi- Square Goodness of Fit Tests for Low Beam Speed Decisions

	Decision	Low Beams					
		80 m		160 m		240 m	
		χ^2 (1)	*W*	χ^2 (1)	*W*	χ^2 (1)	*W*
Side Orientation							
	S/W	40.0**	1.00	40.0**	1.00	40.0**	1.00
	S/R	40.0**	1.00	40.0**	1.00	40.0**	1.00
	W/R	28.9**	0.85	22.5**	0.75	4.9*	0.35
Back Orientation							
	S/W	36.1**	0.95	28.9**	0.85	32.4**	0.90
	S/R	32.4**	0.90	19.6**	0.70	32.4**	0.90
	W/R	16.9**	0.65	10.0**	0.50	10.0**	0.50

Note. S/W = standing vs. walking; S/R = standing vs. running; W/R= walking vs. running.
W = Cohen's W. Small effect = .10, medium effect = .30, large effect = .50
*$p < .05$. ** $p < .01$

3.3.2 Standing vs. Running

Side orientation. When oriented to the side, running pedestrians were selected over standing pedestrians 100% of the time across distance and beam setting, χ^2 (1) = 40.0, $p < .0001$ (see Table 3.1 &

Table 3.2). Because no variation was found in the side orientation data, GEE could not be computed to test for distance or beam effects.

Back orientation. Running pedestrians were selected over standing pedestrians at each distance in both high and low beams. Table 3.1 and Table 3.2 list the results of significance tests for each distance in both beam settings. GEE were used to test for distance and beam effects. The model would not converge with the interaction term, so it was dropped. When it was removed, there was no main effect of beam (p = .528), but there was a significant main effect of distance, Wald χ^2 (2)= 9.74, p = .008. For the remaining analysis, the beam term was also dropped from model allowing for the calculation of the probability of selecting running over standing by distance without the effect of beam. When the beam term was removed, the main effect of distance remained significant, Wald χ^2 (2)= 10.09, p = .006. Pairwise comparisons revealed significant differences in the proportion of running responses between 80 m and 160 m, β = -1.85, p = .009 and between 160 m and 240 m, β = -.965, p = .033. The probability of selecting running over standing was greater at 80 m and 240 m than 160 m (see Figure 3.1).

Overall, the results of the analysis of standing vs. running pedestrians shows that the faster moving pedestrian was selected as the most recognizable significantly more often than the slower or in this case, non-moving pedestrian. A main effect of distance was found for the back orientation, which was driven by the fact that the probability of selecting running over standing was higher at the closest and furthest distance from the observer.

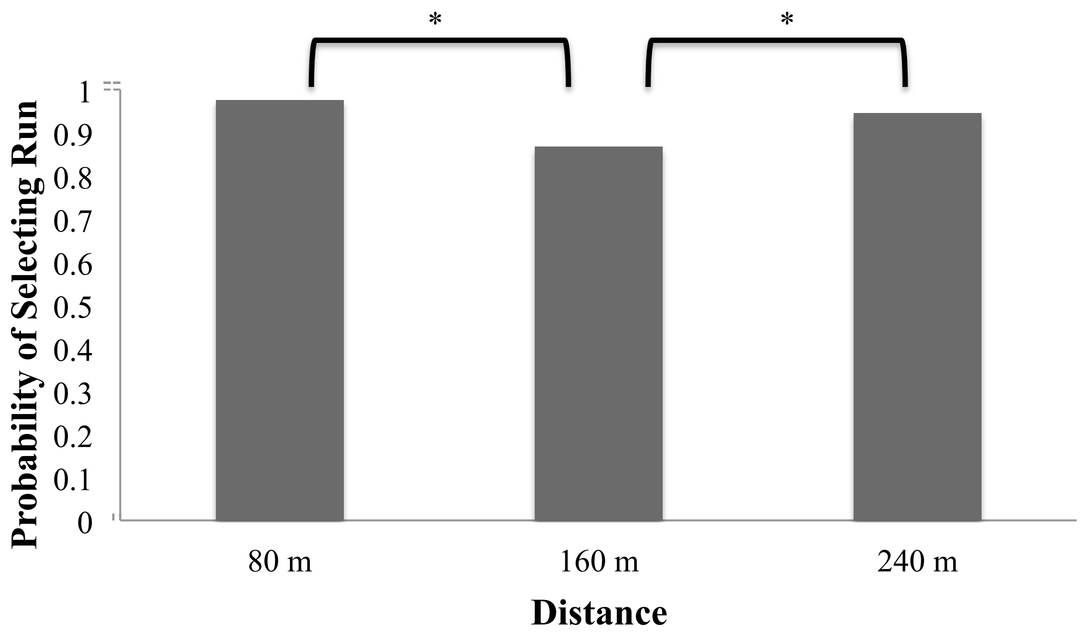

Figure 3.1 The probability of selecting running over standing pedestrians by distance

3.3.3 Walking vs. Running

Side orientation. When side-oriented, running pedestrians were selected significantly more often that walking pedestrians at each distance in both beam settings (see Table 3.1 and Table 3.2 for the results of significance tests.) There is no overall effect of either beam (p = .828) or distance (p = .239), but there is a statistically significant distance x beam interaction effect, Wald χ^2 (2)= 7.40, p =.025, which means that the distance effect varies by beam category. The interaction results because the probability of selecting running at both 80 m and 160 m is greater for low beams, but at 240 m, it is greater for high beams (see Figure 3.2).

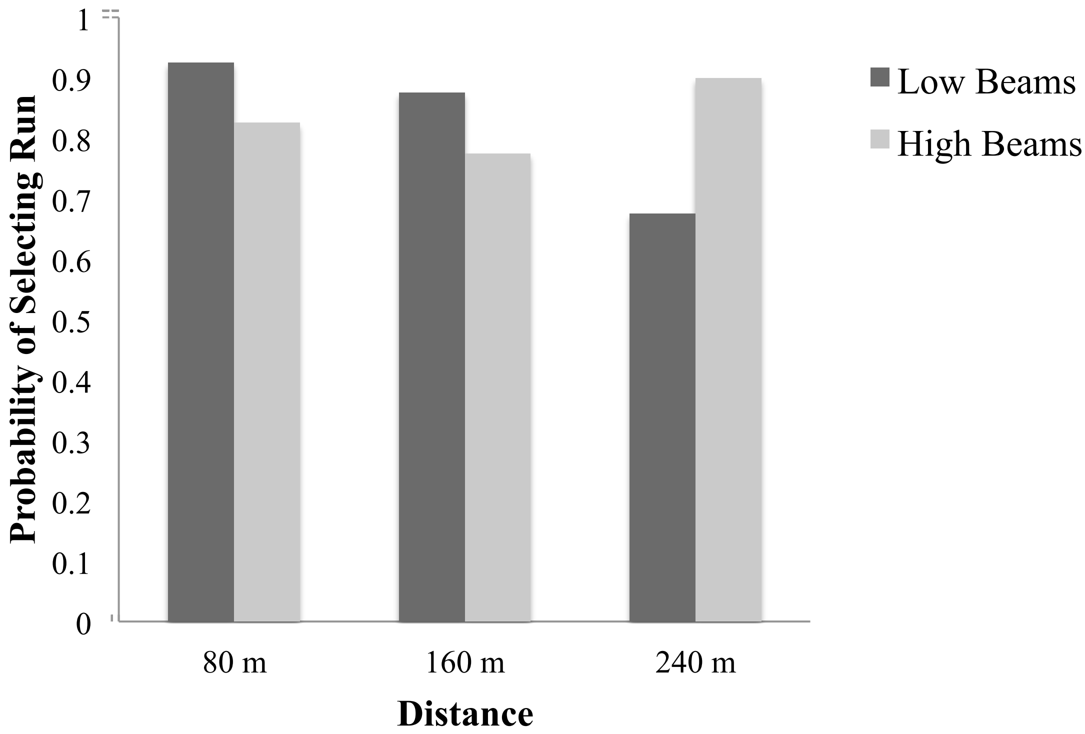

Figure 3.2 The probability of selecting running over walking pedestrians in the side orientation by distance and beam setting.

Back orientation. When the pedestrian was oriented with his back to observers, running pedestrians were selected significantly more often than walking pedestrians at each distance in both beam settings. (See Table 3.1 and Table 3.2 for the results of significance tests.) Neither the main effects of beam (p = .284) and distance (p = .764) were significant, nor was the beam x distance interaction (p = .465).

Overall, the results of the analysis of walking vs. running pedestrians shows that the faster moving pedestrian was selected as the most recognizable significantly more often than the slower moving pedestrian. The proportion of running responses for side-oriented pedestrians was impacted by an interaction of distance and beam factors. At 240 m, the probability of selecting running over walking was higher for high beams than low beams.

3.4 Analysis of Pedestrian Orientation Selections

3.4.1 Orientation Selections for Standing Pedestrians

When standing, back-oriented pedestrians were selected as most recognizable as a person significantly more often than pedestrians in the side orientation. (See Table 3.3 & 3.4 for significance tests at each distance in both beam settings). At all three distances and in both beam settings this pattern of significant results was found. There was no significant effect of beam (p = .768), distance (p = .098), or a beam x distance interaction (p = .229) for standing orientation selections.

Table 3.3

Chi-Square Goodness of Fit Tests for High Beam Orientation Decisions

		High Beams					
		80 m		160 m		240 m	
Speed	Decision	χ^2 (1)	*W*	χ^2 (1)	*W*	χ^2 (1)	*W*
Stand	B/S	28.9**	0.85	28.9**	0.85	28.9**	0.85
Walk	B/S	3.6	-	14.4**	0.60	1.6	-
Run	B/S	8.1**	0.46	19.6**	0.70	12.1**	0.55

Note. B/S = Back vs. Side
W = Cohen's W. Small effect = .10, medium effect = .30, large effect = .50
*p < .05. ** p < .01

Table 3.4

Chi-Square Goodness of Fit Tests for Low Beam Orientation Decisions

		Low Beams					
		80 m		160 m		240 m	
Speed	Decision	χ^2 (1)	*W*	χ^2 (1)	*W*	χ^2 (1)	*W*
Stand	B/S	36.1**	0.95	19.6**	0.70	28.9**	0.85
Walk	B/S	10**	0.50	16.9**	0.65	1.6	-
Run	B/S	6.4*	0.40	22.5**	0.75	6.4*	0.40

Note. B/S = Back vs. Side
W = Cohen's W. Small effect = .10, medium effect = .30, large effect = .50
*p < .05. ** p < .01

3.4.2 Orientation Selections for Walking Pedestrians

Side orientation was selected significantly more often than back orientation for walking pedestrians at 160 m in high beams and 80 m and 160 m in low beams (see Tables 3.3 and 3.4 for significance tests). The effect of beam (p = .449) and the beam x distance interaction were not significant, p = .666. There was a significant main effect of distance on the overall probability of selecting side orientation, Wald χ^2 (2) = 13.27, p = .001. The analysis was re-run with the beam and interaction term removed, which allowed for the calculation of response probabilities at each distance without the effect of beam. The distance effect was significant in this model, Wald χ^2 (2) = 14.13, p = .001. Pairwise comparisons revealed significant differences between 80 m and 160 m, β = .605, p = .027 and between 160 m and 240 m, β = 1.08, p < .001, see Figure 3.3. Participants were more likely to select the side orientation at 160 m than at 80 m or 240 m.

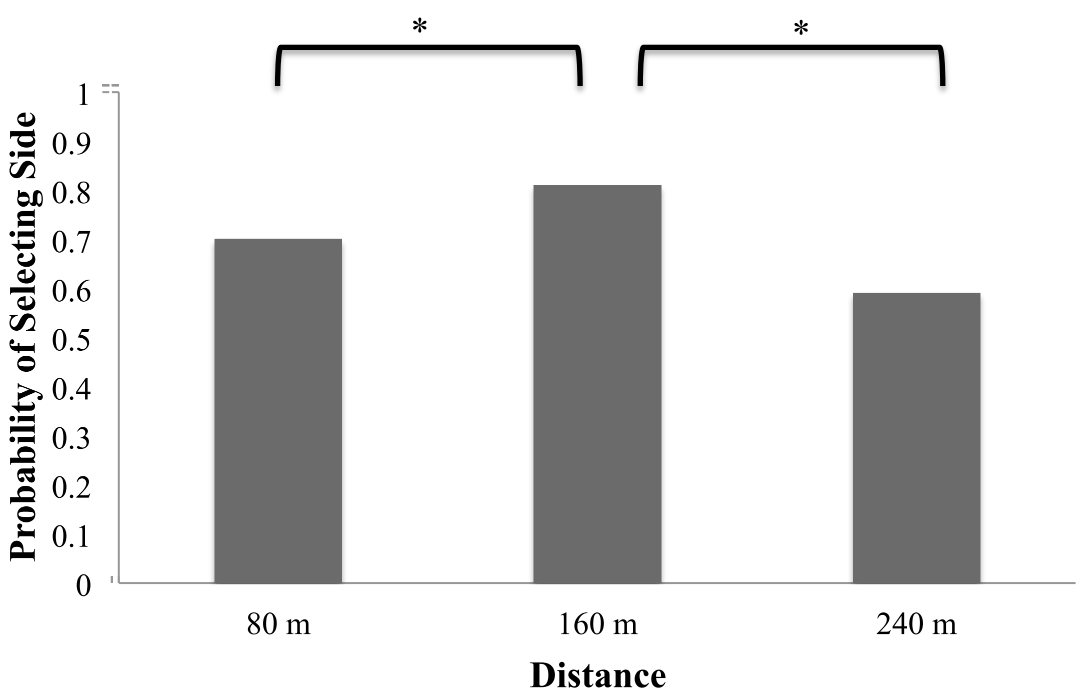

Figure 3.3 The probability of selecting the side orientation over the back orientation by distance for walking pedestrians. These probabilities were calculated with the non-significant beam and interaction terms removed from the model.

3.4.3 Orientation Selections for Running Pedestrians

Side orientation was selected significantly more often than back orientation for running pedestrians across distance and beam setting (see Tables 3.3 and 3.4 above for significance tests). The effect of beam (p = .759) and the beam x distance interaction were not significant, p = .654. There was a significant main effect of distance on the overall probability of selecting side orientation, Wald χ^2 (2) = 7.67, p = .022. The analysis was re-run with the beam and interaction term removed, which allowed for the calculation of response probabilities at each distance without the effect of beam. The distance effect was significant in this model, Wald χ^2 (2) = 8.04, p = .018. Pairwise comparisons revealed significant differences between 80 m and 160 m, β = .949, p = .008 and between 160 m and 240 m, β = .788, p = .023, see Figure 3.4. Participants were more likely to choose the side orientation at 160 m than at 80 m or 240 m.

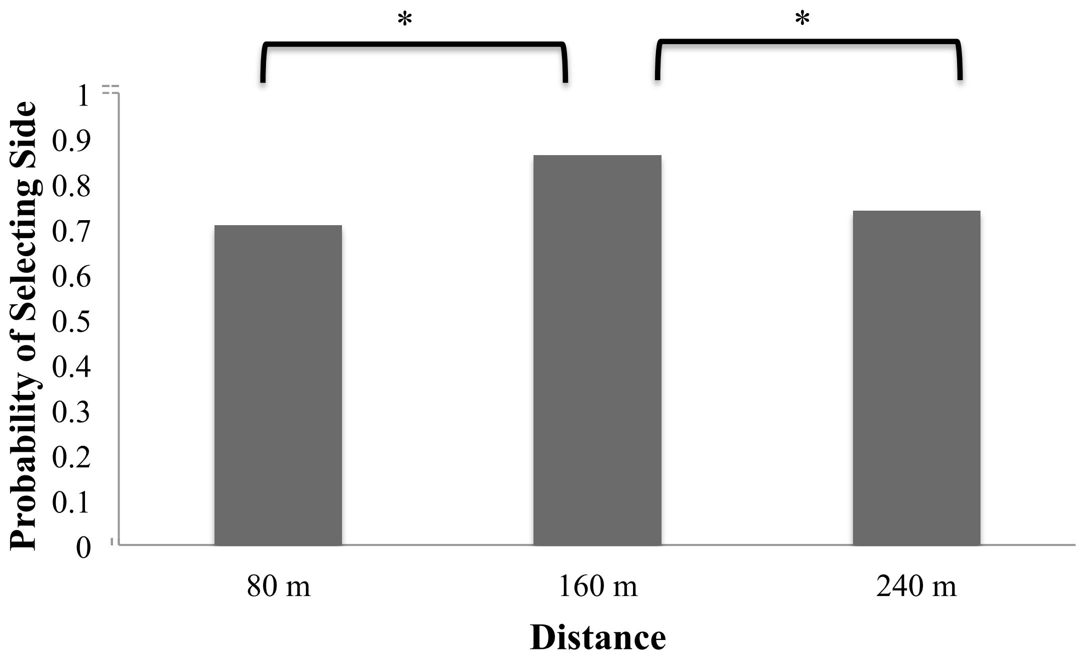

Figure 3.4 The probability of selecting the side orientation over the back orientation by distance for running pedestrians. These probabilities were calculated with the non-significant beam and interaction terms removed from the model.

3.5 Post-Task Questionnaire

After completing the 2AFC, participants filled out the Post-Task Questionnaire (Appendix E), which explored the strategies that participants may have used when deciding which pedestrian in the two videos was most recognizable as a person. Alignment of questionnaire responses to the results of the 2AFC, would suggest that participants were aware at some level how they chose one video over another. Questionnaire items addressed how speed and orientation affected participant choices.

3.5.1 Pedestrian Speed of Motion Questions

These questions asked participants to report how pedestrian speed of motion impacted their selections within each orientation. Participants could choose from three provided response options or select none of the above and write their own response. The three provided options were: 1) I tended to pick the pedestrian that was not moving, 2) I tended to pick the pedestrian that was moving, but not necessarily the fastest, and 3) I tended to pick the pedestrian that was moving fastest. Table 3.5 lists the questions and a summary of responses.

Table 3.5

Post-Task Questionnaire Responses for Pedestrian Speed of Motion

Post-Task Questionnaire	Percent Responding			
Pedestrian Speed of Motion Questions	Not moving	Moving, but not fastest	Moving Fastest	None of the above
When both pedestrians on the screen were in SIDE orientation, how did pedestrian speed of motion impact your selections?	0	17.5	82.5	0
When both pedestrians on the screen were in BACK orientation, how did pedestrian speed of motion impact your selections?	5	35	60	0

According to questionnaire responses, participants indicated that speed of motion seemed to be more salient in side orientation than in back orientation. A greater percentage of respondents chose the fastest moving pedestrian when they were side-oriented than back-oriented. This response pattern is somewhat similar to the results of the 2AFC task where participants chose moving pedestrians, both walking and running, over standing pedestrians 100% of the time when they were side-oriented.

3.5.2 Pedestrian Orientation Questions

Participants were asked to report how pedestrian orientation impacted their selections within each speed of motion. Participants could choose from two provided response options or select none of the above and write their own response. The two provided options were: 1) I tended to pick the pedestrian in side orientation, and 2) I tended to pick the pedestrian in back orientation. Table 3.6 lists questions and response percentages.

Table 3.6

Post-Task Questionnaire Responses for Pedestrian Orientation

Post-Task Questionnaire	Percent Responding		
Pedestrian Orientation Questions	Side orientation	Back orientation	None of the above
When both pedestrians on the screen were not moving at all, how did pedestrian orientation impact your selections?	15	85	0
When both pedestrians on the screen were moving slowly, how did pedestrian orientation impact your selections?	55	42.5	2.5
When both pedestrians on the screen were moving quickly, how did pedestrian orientation impact your selections?	72.5	27.5	0

Responses to the Post-Task Questionnaire orientation items suggest that selections are affected by pedestrian speed of motion. When pedestrians were standing, 85% of participants responded that they tended to choose back-oriented pedestrians. When pedestrians were moving slowly or walking, the majority (55%) of participants said they tended to choose the side orientation. One participant chose the 'none of the above' response and chose to write their own answer to this question, which was "I chose side orientation when further away and back orientation when closer". This was the only participant who indicated that distance played a role in their orientation selections. When pedestrians were moving quickly or running, the percentage of participants who said they tended to choose side orientation was 72.5%.

Chapter 4: **Discussion**

There were two main objectives in the current study. The first was to determine if observers choose pedestrians moving at faster speeds (e.g., running) as more recognizable as people than pedestrians who move more slowly (i.e., walking) or not at all (i.e., standing), and whether the pattern of results is the same for both pedestrian orientations (i.e., side & back). It was predicted that moving pedestrians (i.e., walking, running) would be selected more frequently than non-moving pedestrians (i.e., standing) across pedestrian orientation. The second objective was to determine if observers choose pedestrians oriented in one direction (e.g., side) as more recognizable as people than pedestrians oriented a different way (e.g., back), and whether the pattern of results is the same for all levels of pedestrian motion (i.e., standing, walking, running). It was predicted that side orientation would be selected more often than back orientation when pedestrians were moving (i.e., walking, running), but back orientation would be selected more often than side orientation when pedestrians were not moving (i.e., standing). In this section, the results of the current investigation are summarized and reviewed in light of how they align with the existing literature. Limitations, suggestions for future research and practical applications of the findings are also explored.

4.1 Speed of Motion

A portion of the stimuli pairings in the 2AFC tested how pedestrian speed of motion impacted the frequency with which a pedestrian was selected as being most recognizable as a person. Table 4.1 provides a summary of the results of speed of motion decisions.

Table 4.1

Summary of Results for Speed of Motion Decisions

Decision		Distance effect	Beam effect	Distance x Beam	Selection Result
Side	Standing vs. Walking 	**X**	**X**	**X**	W > S*
	Standing vs. Running 	**X**	**X**	**X**	R > S*
	Walking vs. Running 	X	X	✓ Probability of selecting run > for LB at 80 m & 160 m, but > HB at 240 m	R > W*
Back	Standing vs. Walking 	X	X	X	W > S*
	Standing vs. Running 	✓ Probability of selecting run > at 80 m & 240 m than 160 m	X	NT	R > S*
	Walking vs. Running 	X	X	X	R > W*

Note. S = Standing; W = Walking; R = Running; X = non-significant; ✓ or * = significant ($p < .05$); **X** = no variation in the data to test for effects, NT = not tested (see results section for explanation)

Moving vs. standing pedestrians. As predicted, moving pedestrians (i.e., those who were walking or running) were selected as the most recognizable significantly more often than non-moving pedestrians (i.e., those who were standing). A notable difference between orientations was that in side orientation, walking and running pedestrians were selected over standing pedestrians 100% of the time at every distance in both high and low beams. This strong effect may be attributable to the characteristics of the standing pedestrian, who conveys little form information and no biological motion when side-oriented. This result is consistent with previous studies which have found that standing pedestrians are identified at much shorter distances than walking pedestrians (Balk et al., 2007, 2008; Moberly & Langham, 2002; Tyrrell et al., 2009). Likewise, presenting PLWs in static rather than a dynamic fashion has also been shown to impair observers' ability to recognize them (Pavlova, Krägeloh-Mann, Sokolov, & Birbaumer, 2001).

Running vs. walking pedestrians. A significant distance x beam interaction was observed for walking vs. running decisions in the side orientation. At the closer distances of 80 m and 160 m, the probability of selecting running over walking was greater in low beams than high beams. Observers may rely on speed cues to a greater extent in impoverished visual conditions, particularly because low beams differentially illuminate the lower half of the pedestrians' body (Olson & Farber, 2003). The revealing power of low beams is quite limited at 240 m and this may explain why the probability of selecting running over walking was greater in high beams.

While the probability of selecting running over walking was impacted by an interaction between the beam and distance variables for the side orientation, no such effect was found for the back orientation. In the back orientation, more reflective material is oriented towards the observer, which means that pedestrians in the least ideal condition (240 m, low beams) may not have been as difficult to discern when back-oriented, as they were when side-oriented. Although no specific hypotheses were made about how distance and beam would impact decisions, these results suggest that their impact may be different for each pedestrian orientation.

Despite an interaction in the side orientation, running was selected significantly more often than walking at every observation point. Although runners were selected as most recognizable more often than walkers, the magnitude of this effect was smaller than it was for decisions between moving (i.e., walking, running) and standing pedestrians. From past research, we know that animate motion captures visual attention to a greater extent than inanimate and no motion (Pratt, Radulescu, Guo, & Abrams, 2010), however both walking and running pedestrians are animate, which may explain why the magnitude of the result for running vs. walking decisions is smaller than moving (i.e., walking, running) vs. standing decisions.

Based on a systematic and thorough search of the literature, this is the first study to show that increasing speed of motion impacts the recognisability of pedestrians. Previously speed has been investigated in perceptual studies of biological motion using point light walkers (PLWs). Neri, Morrone, & Burr (1998) found that the detection and direction discrimination of PLWs improved as exposure times increased. However, unlike sensitivity to other kinds of motion (e.g., translational motion), sensitivity to biological motion was impacted by speed. When exposure times are short, more gait cycles can be observed for PLWs who move quickly than those who move more slowly. This may also explain the results of the current study because running pedestrians conveyed more gait cycles than walking pedestrians.

4.2 Orientation

Part of the 2AFC was designed to test how pedestrian orientation impacted the frequency with which a pedestrian was selected as being most recognizable as a person. This was assessed for all three levels of pedestrian motion (i.e., standing, walking, running). Table 4.2 provides a summary of the results for orientation decisions. As predicted, standing pedestrians in the back orientation were selected as most recognizable significantly more often than when they were in the side orientation. The back orientation reflects more light back to the observer and also conveys human form to a greater extent than the side orientation. In the absence of motion, these two factors likely contributed to the back orientation being selected with greater frequency than the side orientation. When walking, the impact of orientation was less clear. It was hypothesized that side-oriented pedestrians would be selected significantly more than those who were back-oriented because it better conveys the pendular motion of the extremities. There was partial support for this hypothesis as side-oriented walkers were selected significantly more than back-oriented walkers at three of the six observation points (80 m LB, 160 m LB, 160 HB). No significant differences were found between the orientations at 80 m and 240 m in high beams or at 240 m in low beams. This resulted in a greater probability of selecting the side orientation at 160 m than at 80 m or 240 m.

Table 4.2

Summary of Results for Orientation Decisions

Decision		Distance effect	Beam effect	Distance x Beam	Selection Result
Standing	Side vs. Back 	X	X	X	B > S*
Walking	Side vs. Back 	✓ Probability of selecting Side > at 160 m than 80 m and 240 m	X	X	S > B* ns at 80 m HB, 240 m HB & LB
Running	Side vs. Back 	✓ Probability of selecting Side > at 160 m than 80 m and 240 m	X	X	S > B*

Note. S = Side orientation; B = Back Orientation; X = non-significant; ✓ or * = significant ($p < .05$)

The distance effect for the orientation decisions of walking pedestrians is interesting. At 160 m, side orientation was selected significantly more than back orientation. This pattern of results was only found in low beams at 80 m, and was not observed at 240 m. The non-significant findings at 240 m may have arisen because this distance is quite far from the observer and as a result, the amount of light that is reflected back from each orientation may be more important (see Figure 2.3 in Chapter 2). This may have influenced observers to choose the back orientation, which reflects more light than the side orientation, to a greater extent than they did at the closer distance of 160 m. At the more optimal high beam viewing condition of 80 m, both pedestrians are close to the observer and ideally illuminated making it easy to see pedestrians in either orientation as most recognizable as a person. This may have contributed to why a significant difference was only observed at 80 m when low beams were used.

This result is interesting because other studies that examined response differences between orientations found mixed results. Luoma and Penttinen (1998) found that side-oriented walking pedestrians were detected at greater distances (M = 230 m) than frontal oriented pedestrians (M = 189 m). In contrast, Balk et al. (2007) reported the opposite result with greater detection distances when pedestrians faced oncoming drivers (M = 114.02 m) than when the pedestrians faced to the side (M = 65.28 m). Another investigation by Wood et al. (2014b) reported no effect of pedestrian orientation at all. It is possible that previous studies have found conflicting results because the use of different test tracks generate considerably different mean response distances. The main effect of distance observed for orientation decisions in the current study suggests that the distance a response is made may be an important factor when determining which orientation makes pedestrians more recognizable.

Side-oriented running pedestrians were hypothesized to be selected as significantly more recognizable than back-oriented running pedestrians because the lateral motion of the extremities is more apparent in the side orientation. Support for this hypothesis was found at every distance examined in both high and low beams. Interestingly, a main effect of distance was observed such that the probability of selecting the side over back orientation was greater at 160 m than at 80 m or 240 m. This distance effect is similar to the one observed for walking pedestrians. However unlike the effect for walking, side orientation was selected significantly more often than back orientation at every distance in both beam settings for running. More lateral movement of the extremities may be needed for the side orientation to be consistently selected over the back orientation.

4.3 Post-Task Questionnaire

Participants' responses to the speed and orientation questions in the post-task questionnaire aligned with the pattern of results in the 2AFC task. Participants reported selecting the faster moving pedestrian to a greater extent in the side orientation than the back orientation. Walking and running pedestrians were selected over standing pedestrians 100% of the time in side orientation trials of the 2AFC task. Participants also reported that they found side-oriented pedestrians more recognizable as people to a greater extent when pedestrians were running than when they were walking or standing, which was the same pattern of results as the 2AFC task. The purpose of the post-task questionnaire was to act as an experimental check and the intention was not to correlate the results with the 2AFC. However, the alignment between the results of the post-task questionnaire and the 2AFC task suggests that participants are aware on some level of how they made their decisions and can retrospectively recall this information.

4.4 Limitations

In the current study, participants observed videos of two pedestrians presented side-by-side in a laboratory and decided which one looked most recognizable as a person. This kind of task is different than searching for and responding to pedestrians while driving at night. Drivers must search for hazards, including pedestrians, and control the speed and lane positioning of their vehicle with changes in the environment and roadway. Participants in the current study could focus exclusively on deciding which pedestrian met their decision criteria without the same vehicle and contextual demands. However, effects are generally stronger under conditions of divided attention, so while the results of the current study cannot be generalized to driving, there is reason to believe they may be equally or more pronounced under the divided attention conditions of driving.

It is also important to note that driving requires the simultaneous use of focal and peripheral vision (Leibowitz & Owens, 1986), but in the current study all pedestrians were presented in the central field of view. This is important because in real life driving situations, pedestrians may appear in the drivers' periphery. While accurate biological motion perception is possible in the periphery, it is slower and more sensitive to masking effects than perception in the fovea (Thompson, Hansen, Hess, & Troje, 2007).

Important visual functions such as visual acuity, contrast sensitivity and other abilities mediated by the central retina are negatively impacted by low levels of illumination (Leibowitz & Owens, 1977). Although filming was conducted with a broadcast quality camera and presented at high resolution, the stimuli in current study were degraded even further due to filming. Important contrast, luminance, depth and contour information is lost when three-dimensional stimuli are filmed and presented on a flat screen. These limitations may have affected the results of the study, particularly with regard to viewing distance and beam variables. However, most depth cues are degraded or completely absent at night and this would be the case on an otherwise non-illuminated roadway. Depth information is available in the beam path, but efforts were made to control contrast levels through the use of a field monitor.

Another important difference between the current investigation and previous pedestrian search conspicuity studies is the manipulation of orientation. Previous studies typically have pedestrians face the observer, while the pedestrians in the current study had their back to observer. These orientations are comparable in how they highlight the human shape and how much light they reflect, however whether the results would be similar for a frontal orientation seems likely, but remains unknown. Additionally, pedestrians in the current study were seen on a treadmill that elevated them six inches from the ground.

This was necessary to maintain pedestrian speed but did change the pattern of illumination on the pedestrian's body.

Another limitation of this study is the forced-choice nature of the task. Participants were forced to choose between two pedestrians that may have been equally recognizable. Because there was no 'equivalent' option, their responses may have been inconsistent until internal criteria could be formed. For example, the running pedestrian may have been chosen over the walking pedestrian even though the participant found them equally recognizable. As a result of being forced to choose and completing a number of trials, participants may have decided that choosing the runner was more logical even if it was perceived similarly as the walker. Despite these potential limitations, the results of the speed of motion and orientation decisions made in the current study are similar to previous studies that used different methods. In order to be externally valid, pedestrian conspicuity needs to be investigated in a real world setting, however, laboratory investigations such as the current study may be helpful in guiding the direction of this research.

4.5 Future Research

Future research should address how pedestrian speed of motion impacts pedestrian recognition in the field where the demands of nighttime driving impose additional limitations on the driver. For example, drivers could be required to search for pedestrians who may be running or walking along the roadway. Driver responses, including evasive manoeuvres, could be quantified in terms of distance to the pedestrian. Whether participants identified runners at greater distances than walkers would provide additional insight into the impact of pedestrian motion and form information. The results of the current study revealed that the pedestrian orientation selected as most recognizable depended on pedestrian speed. Therefore, future studies should investigate responses to walking and running pedestrians in both orientations. It would be worthwhile to investigate these responses in different age groups, as older drivers have greater difficulty under low light conditions (Leibowitz, Owens, & Tyrrell, 1998). Lastly, wearing full biomo clothing is not always convenient or practical. While some research has found that ankle and wrist configurations may be a suitable alternative (Balk et al., 2008; Luoma & Penttinen, 1998; Luoma et al., 1996; Tyrrell et al., 2009), more creative alternatives are needed, particularly for pedestrians who live in hot climates. It is similarly important that to develop strategies to increase the public's willingness to wear retro-reflective material. Working directly with major clothing manufacturers is important because people may be more likely to buy retro-reflective clothing if produced by companies that they already trust and find stylish, or if the clothing is promoted by celebrities or athletes that they admire.

It would also be worthwhile to investigate the impact of biological motion retro-reflectors for animals. Pet owners, particularly dog owners find themselves outside around sunset or in dark conditions. While people are not always willing to wear safety apparel themselves, they may be willing to use retro-reflectors on their pets. This could provide conspicuity advantages for the pet, but may also encourage drivers to search for an owner, who may or may not be wearing retro-reflectors. Identifying the ideal configuration of retro-reflective material for dogs and an easy way to fasten the material on the animal are interesting areas for future investigation.

4.6 Practical Applications

The current study can help inform pedestrians about how their behaviour impacts their recognisability at night. The results confirm prior findings that moving while wearing retro-reflective clothing has positive implications for being recognized by observers. Furthermore, the standing side-oriented pedestrian was never selected as the most recognizable in the current study. This suggests that retro-reflectively outfitted pedestrians who must stand on the side of the road (e.g., construction workers, police officers) may be better served to orient their front to oncoming traffic. Pending validation of these results in a field setting, this information could be used in nighttime safety training programs for first responders, construction workers and pedestrians.

The results of the current study reinforce the importance of motion for nighttime pedestrian recognition. Provided pedestrians are not moving into the path of the vehicle, moving on the spot or in a path clear of the vehicle should make pedestrians more recognizable than if they stand. Unfortunately, many pedestrians who are surprised by a vehicle will freeze up, stop moving and expect to still be recognized. When it comes to educating the public about the benefits of retro-reflectors, it is important to explain how pedestrian behaviour when wearing retro-reflectors can impact their recognisability.

4.7 Conclusions

Speed of motion and orientation impact the recognisability of pedestrians. Observers choose moving pedestrians (i.e., those who are walking or running) in biomo retro-reflectors as more recognizable as people than pedestrians who stand. Furthermore, running pedestrians are chosen over walking pedestrians as being the most recognizable. This pattern of results was found whether pedestrians were oriented with the side or back of their body facing the observer. The pedestrian orientation considered most recognizable was dependent on pedestrian speed. When standing, pedestrians in the back orientation were selected more often, while the side orientation was selected as the most recognizable when pedestrians were running and at half of the observation points for walking.

References

Alberta Ministry of Transport. (2007). *Painted Lane Width for Alberta Highways.* Design Bulletin #23/2007. Retrieved from: http://www.transportation.alberta.ca/Content/docType233/-Production/DesignBulletin43.pdf

Balk, S. A., Graving, J. S., Chanko, R. G., & Tyrrell, R. A. (2007). Effects of retroreflector placement on the nighttime conspicuity of pedestrians: An open-road study. *Proceedings of the Human Factors and Ergonomics Society 51st Annual Meeting*, 1565–1568. doi:10.1177/154193120705102411

Balk, S. A., Tyrrell, R. A., Brooks, J. O., & Carpenter, T. L. (2008). Highlighting human form and motion information enhances the conspicuity of pedestrians at night. *Perception*, *37*, 1276–1284. doi:10.1068/p6017

Bhagavathula, R., & Gibbons, R. B. (2013). Role of Expectancy, Motion and Overhead Lighting on Nighttime Visibility. *Proceedings of the Human Factors and Ergonomics Society 57th Annual Meeting*, *57*, 1963–1967. doi:10.1177/1541931213571438

Blomberg, R. D., Hale, A., & Preusser, D. F. (1986). Experimental evaluation of alternative conspicuity-enhancement techniques for pedestrians and bicyclists. *Journal of Safety Research*, *17*, 1–12. doi:10.1016/0022-4375(86)90002-2

Borowsky, A., & Oron-Gilad, T. (2013). Exploring the effects of driving experience on hazard awareness and risk perception via real-time hazard identification, hazard classification, and rating tasks. *Accident Analysis & Prevention*, *59*, 548–565. doi:10.1016/j.aap.2013.07.008

CCMTA. (2013). *Determining Driver Fitness in Canada: CCMTA Medical Standard for Drivers.* Retrieved from: http://ccmta.ca/images/publications/pdf//Determining-Driver-Fitness-In-Canada-Final.pdf

Cardinal, M., Crain, J., Do, M. T., Fréchette, M., McFaull, S., Skinner, R., Thompson, W. (2012). Report summary - injury in review, 2012 edition: spotlight on road and transport safety. *Chronic Diseases and Injuries in Canada, 32*, 229-230. Retrieved from: http://europepmc.org/abstract/med/23046806

Ghisletta, P., & Spini, D. (2004). An Introduction to Generalized Estimating Equations and an Application to Assess Selectivity Effects in a Longitudinal Study on Very Old Individuals. *Journal of Educational and Behavioral Statistics*, *29*, 421–437. doi:10.3102/10769986029004421

Google Maps. (2015). [Fire Training Academy Test Track, Calgary, Alberta]. Retrieved from:https://www.google.ca/maps/place/5727+23+Ave+SE,+Calgary,+AB+T2B+1M2/@51.0322591,113.9527917,626m/data=!3m2!1e3!4b1!4m2!3m1!1s0x53717b0577ff9631:0xb51afa3c19f076d3!6m1!1e1

Griswold, J., Fishbain, B., Washington, S., & Ragland, D. (2011). Visual assessment of pedestrian crashes. *Accident Analysis & Prevention*, *43*, 301–306. doi:10.1016/j.aap.2010.08.028

International Traffic Safety Data and Analysis Group. (2011). Road Safety Annual Report 2011. Retrieved from http://www.internationaltransportforum.org/Irtadpublic/pdf/11IrtadReport.pdf

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics*, *14*, 201–211. doi: 10.3758/BF03212378

Johansson, G. (1975). Visual motion perception. *Scientific American*, *232*, 76–88. doi:10.1038/scientificamerican0675-76

Knoblauch, R. L., Pietrucha, M. T., & Nitzburg, M. (1996). Field studies of pedestrian walking speed and start-up time. *Transportation Research Record: Journal of the Transportation Research Board*, *1538*, 27-38. doi:10.3141/1538-04

Langham, M., & Moberly, N. (2003). Pedestrian conspicuity research: a review. *Ergonomics*, *46*, 345-363. doi:10.1080/00140130210000395574

Leibowitz, H., & Owens, D. (1977). Nighttime driving accidents and selective visual degradation. *Science, 197*, 422-423. doi:10.1126/science.197.4302.422-a

Leibowitz, H., & Owens, D. (1986). We Drive By Night- And when we do we often misjudge our visual abilities, courting disaster. *Psychology Today*. *20*, 54-58.

Leibowitz, H., Owens, D. A., & Tyrrell, R. A. (1998). The Assured Clear Distance Ahead Rule: Implications for Nighttime Traffic Safety and the Law. *Accident Analysis & Prevention*, *30*, 93–99. doi: 10.1016/S0001-4575(97)00067-5

Luoma, J., & Penttinen, M. (1998). Effects of experience with retroreflectors on recognition of nighttime pedestrians: comparison of driver performance in Finland and Michigan. *Transportation Research Part F: Traffic Psychology and Behaviour*, *1*, 47–58. doi:10.1016/S1369-8478(98)00006-0

Luoma, J., Schumann, J., & Traube, E. (1996). Effects of retroreflector positioning on nighttime recognition of pedestrians. *Accident Analysis & Prevention*, *1*, 47–58. doi:10.1016/00014575(96)00004-8

Moberly, N., & Langham, M. (2002). Pedestrian conspicuity at night: failure to observe a biological motion advantage in a high‐clutter environment. *Applied Cognitive Psychology*, *16*, 477–485. doi:10.1002/acp.808

Neri, P., Morrone, M. C., & Burr, D. C. (1998). Seeing biological motion. *Nature*, *395*(6705), 894–896. doi:10.1038/27661

Olson, P., & Farber, E. (2003). *Forensic Aspects of Driver Perception and Response* (2nd Ed). Tucson, AZ: Lawyers & Judges Publishing Company.

Owens, D. A., Antonoff, R. J., & Francis, E. L. (1994). Biological Motion and Nighttime Pedestrian Conspicuity. *Human Factors: The Journal of the Human Factors and Ergonomics Society* , *36* (4), 718–732. doi:10.1177/001872089403600411

Owens, D. A., Wood, J. M., & Owens, J. M. (2007). Effects of age and illumination on night driving: a road test. *Human Factors*, *49*(6), 1115–1131. doi:10.1518/001872007X249974

Pavlova, M., Krägeloh-Mann, I., Sokolov, A., & Birbaumer, N. (2001). Recognition of point-light biological motion displays by young children. *Perception*, *30*(8), 925–933. doi:10.1068/p3157

Pratt, J., Radulescu, P. V, Guo, R. M., & Abrams, R. a. (2010). It's alive! animate motion captures visual attention. *Psychological Science : A Journal of the American Psychological Society / APS*, *21*(11), 1724–1730. doi:10.1177/0956797610387440

Sayer, J. R., & Mefford, M. L. (2004). High visibility safety apparel and nighttime conspicuity of pedestrians in work zones. *Journal of Safety Research*, *35*(5), 537–46. doi:10.1016/j.jsr.2004.08.007

Sullivan, J. M., & Flannagan, M. J. (2002). The role of ambient light level in fatal crashes: inferences from daylight saving time transitions. *Accident Analysis & Prevention*, *34*, 487-498. doi:10.1016/S00014575(01)00046-X

Thompson, B., Hansen, B. C., Hess, R. F., & Troje, N. F. (2007). Peripheral vision: good for biological motion, bad for signal noise segregation? *Journal of Vision*, *7*, 1–7. doi: 10.1167/7.10.12

Transport Canada. (2011). *Canadian Motor Vehicle Traffic Collision Statistics 2011*. Retrieved from http://www.tc.gc.ca/media/documents/roadsafety/TrafficCollisionStatisitcs_2011.pdf

Transport Canada. (2013). *Canadian Motor Vehicle Traffic Collision Statistics: 2013*. Retrieved from https://www.tc.gc.ca/media/documents/roadsafety/cmvtcs2013_eng.pdf

Tyrrell, R. A., Wood, J. M., & Carberry, T. P. (2004). On-road measures of pedestrians' estimates of their own nighttime conspicuity. *Journal of Safety Research*, *35*(5), 483–90. doi:10.1016/j.jsr.2004.06.004

Tyrrell, R. A., Wood, J. M., Chaparro, A., Carberry, T. P., Chu, B., & Marszalek, R. (2009). Seeing pedestrians at night: visual clutter does not mask biological motion. *Accident Analysis & Prevention*. doi: 10.1016/j.aap.2009.02.001

World Health Organization. (2013). *Pedestrian safety: A road safety manual for decision-makers and practitioners*. Retrieved from http://apps.who.int/iris/handle/10665/79753

Wood, J. M., Lacherez, P. F., & Tyrrell, R. A. (2014a). Seeing pedestrians at night: effect of driver age and visual abilities. *Ophthalmic and Physiological Optics*, *34*, 452–458. doi:10.1111/opo.12139

Wood, J. M., Marszalek, R., Lacherez, P., & Tyrrell, R. A. (2014b). Configuring retroreflective markings to enhance the night-time conspicuity of road workers. *Accident Analysis & Prevention*, *70*, 209–214. doi:10.1016/j.aap.2014.03.018

Wood, J. M., Tyrrell, R. A., & Carberry, T. P. (2005). Limitations in drivers' ability to recognize pedestrians at night. *Human Factors*, *47*, 644–653. doi:10.1518/001872005774859980

Wood, J. M., Tyrrell, R. A., Marszalek, R., Lacherez, P., Carberry, T., & Chu, B. S. (2012). Using reflective clothing to enhance the conspicuity of bicyclists at night. *Accident Analysis & Prevention*, *45*, 726–730. doi:10.1016/j.aap.2011.09.038

Wood, J. M., Tyrrell, R. A., Marszalek, R., Lacherez, P., Chaparro, A., & Britt, T. W. (2011). Using biological motion to enhance the conspicuity of roadway workers. *Accident Analysis & Prevention, 43,* 1036-1041. doi:10.1016/j.aap.2010.12.002

Zeger, S. L., & Liang, K. Y. (1986). Longitudinal data analysis for discrete and continuous outcomes. *Biometrics*, *42*, 121–130. doi:10.2307/2531248

Appendix A: Participant Recruitment Script

An investigation of nighttime visibility

As you have likely noticed from your own experiences, it is much harder to see at night than during the day. This reduction in visibility is particularly problematic for drivers who are expected to drive with the same skill and proficiency at night as they do during the day. The purpose of this study is to investigate nighttime visibility and the various factors that may affect the ability to see at night.

Should you agree to participate, your vision will be tested to ensure that you have normal or corrected-to-normal vision (you may wear glasses). Following vision testing, you will be seated in front of a computer screen. You will be shown videos of nighttime driving scenes and will be asked to make responses to certain stimuli by touching the screen. You will also be asked to complete questionnaires to gather information about your driving habits and demographics.

Should you agree to participate, you will be assigned a participant number by the researcher that will be used throughout data analysis. All of the information you provide will be handled confidentially. All data will be stored in a locked filing cabinet and on a laboratory computer that is only accessible by the research team.

Participants will receive bonus course credit toward a final grade.

This study has been approved by the Conjoint Faculties Research Ethics Board (CFREB) REB 14-0582

Appendix B: Driver Experience Questionnaire

Driver Experience Questionnaire

Instructions: The purpose of this questionnaire is to assess your driving experience and general background. Your personal identity will not be associated with any of your responses. As before, only a unique number will be recorded and will be used by the researchers.

Part I. Demographic Information

1. Are you? ☐ Male ☐ Female
2. Date of birth (YY/MM/DD): ___________________
3. Age______________________
4. Number of years of education: Primary-High School: _________(years)
   Post-Secondary:____________(years)
5. Are you right-handed or left-handed? Right ☐ Left ☐

Part II. Driving Experience

6. Do you have a valid driver's license? Yes ☐ No ☐

7. What class of license do you have? ________ (e.g. class 5, class 3)

__Clarification__: Class 5 is typical (2 axle vehicle)
If unsure, please ask researcher for clarification

8. On average, how many kilometers do you drive:
   Per week? _________ km/week (e.g. 950 km/week)
   Per month? ________ km/month (e.g. 4000 km/month)
   Per year? __________ km/year (e.g. 50 000 km/year)

9. On average, how many hours would spend driving:
   Per week? _________ hours/week (e.g. 20 hours/week)
   Per month? ________ hours/month (e.g. 100 hours/month

10. Assuming that there is no adverse traffic or weather, do you ever avoid nighttime driving?

    Yes ☐ No ☐

If yes, please explain why you avoid nighttime driving.

____
____
____

11. Have you ever been involved in a pedestrian collision? (either as the driver or pedestrian)

Yes ☐ No ☐

If yes, please specify whether you were the driver or pedestrian

____
____
____

Part III. Visual Information

12. Do you have any visual diseases or other diseases that degrade your vision? ☐ Yes ☐ No
    If yes, please specify each:____
    ____
    ____

13. Do you use glasses (or contact lenses) for distance? ☐ Yes ☐ No

14. Do you use glasses (or contact lenses) for reading? ☐ Yes ☐ No

15. Do you use bifocals, trifocals or progressive lenses? ☐ Yes ☐ No
    If yes, please specify any of the above you require: ______________________________

Appendix C: Consent Form

UNIVERSITY OF CALGARY

Name of Researcher, Faculty, Department, Telephone & Email:

Jasmine Mian

Faculty of Arts

Department of Psychology

Phone: 587-437-5299

Email: jmian@ucalgary.ca

Supervisor:

Dr. Jeff Caird
Faculty of Arts
Department of Psychology

Title of Project:
An investigation of nighttime visibility

Sponsor:
Social Sciences and Humanities Research Council (SSHRC)
AUTO21

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Faculties Research Ethics Board has approved this research study.

Purpose of the Study

As you may have experienced in your own life, it is much harder to see at night. This is particularly problematic for drivers who are expected to perform equally well at night despite a substantial reduction in visibility. The purpose of this study is to investigate various aspects of nighttime visibility. This study is being carried out as a thesis project to fulfill a requirement of the researcher's degree program.

What Will I Be Asked To Do?
In order to participate in this study, participants must meet certain visual requirements. In order to ensure that you meet the visual requirements, your vision will be tested. The tests will require you to read off a chart and sort objects by colour. Following vision testing, you will be seated in front of a computer screen. You will be shown videos of nighttime driving scenes and will be asked to make responses to different stimuli. You will also be asked to complete a questionnaire to report information such as your age, number of years you have been licensed as well as some of your driving habits (e.g., how many kilometers do you drive per week?). You are free to decline to answer any and all questions. Participation in this study will take approximately 1 hour of your time.

Your participation is entirely voluntary and you are free to discontinue the study at any time and for any reason. You may refuse to complete the entire study or certain portions without penalty, loss of compensation or loss of course credit. In addition, you are free to ask questions about your participation at any time in the study, before or after you sign this agreement.

What Type of Personal Information Will Be Collected?
You will be asked to provide basic demographic information and information about your driving habits, however none of this data will be linked to your identity. Should you agree to participate, you will be assigned a participant number by the researcher that will be used throughout data analysis. All of the information you provide will be handled confidentially.

Are there Risks or Benefits if I Participate?
There are no known physical risks that could result from your participation in this study. Your participation in the study will not directly benefit you in any way. Your involvement in the study, however, may help further the understanding of how retro-reflectively outfitted pedestrians are recognized at night

Participants recruited through SONA will receive 1 credit that may be assigned towards any registered psychology course, using the University of Calgary's SONA system.

What Happens to the Information I Provide?
In order to protect your identity, you will be assigned a participant number that will be used in all data analysis. The only identifying information that will be linked to this participant number is your date of birth and age at the time of data collection. All data will be stored in a locked filing cabinet and on a laboratory computer that is only accessible by the research team. Only group information will be summarized for any presentation or publication of results. Should you choose to withdraw part way through the study, your data will be erased or shredded. You may also withdraw your information from the study following data collection provided that the results have not already been published. The only way to identify your data following data collection is to provide the researcher with your date of birth and age at the time of data collection. Any data that matches your date of birth and age at the time of data collection will be erased or shredded. All data included in the study will be kept for five years after the completion of the study, at which time, electronic data will be erased and any hardcopies shredded.

Signatures
Your signature on this form indicates that 1) you understand to your satisfaction the information provided to you about your participation in this research project, and 2) you agree to participate in the research project.
In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant's Name: (please print) ____

Participant's Signature: ____ Date: _______________

Researcher's Name: (please print) ____

Researcher's Signature: ____ Date: ________________

Questions/Concerns
If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Jasmine Mian
Department of Psychology, Social Sciences
T: 587-437-5299 E: jmian@ucalgary.ca
&
(Supervisor: Dr. Jeff Caird, Department of Psychology, Faculty of Social Sciences.)

If you have any concerns about the way you've been treated as a participant, please contact an Ethics Resource Officer, Research Services Office, University of Calgary at (403) 220-3782; email cfreb@ucalgary.ca.

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form

Appendix D: Debriefing Form

Nighttime Visibility Study Debriefing

Thank you for participating in this study. Seeing pedestrians at night can be very difficult—you may have experienced this in your own life and throughout the duration of this study. It is for this reason that understanding ways to maximize pedestrian conspicuity at night is of great interest to researchers and hopefully to you as a road user!

Wearing retro-reflective material at night can save your life. Past research has shown that highlighting the movable joints (e.g., wrists, elbows, shoulders, waist, knees and ankles) to show the form and motion of the human body helps pedestrians be detected at much greater distances.

The goal of this study is to investigate how the behaviour of pedestrians outfitted in retro-reflective clothing influences our ability to see them. Throughout the current study, you were shown films containing pedestrians that move in various ways (e.g., running, walking) and in different orientations (e.g., facing the observer, facing the roadway). Your participation in this study will help answer the following questions about pedestrian behaviour:

1) Does pedestrian motion (e.g., running) result in pedestrians being detected at earlier distances?
2) Does the orientation of the pedestrian (e.g., facing the observer) result in pedestrians being detected at earlier distances?
3) How does the way pedestrians move and their orientation to the observer work together to influence our ability to see them?

If you have any questions about the study or wish to contact us for the results, please feel to ask the researcher now or contact the researcher at a later date using the contact information provided below.

Thank you for your time,

Jasmine Mian
Masters Student
Department of Psychology
University Of Calgary
2500 University Drive N.W.
Calgary, AB T2N 1N4
Email: jmian@ucalgary.ca

Appendix E: Post-Task Questionnaire

Nighttime Visibility Study Post-Task Questionnaire

Thank you for completing the task!

Please read the following before answering the questions:

In the task, pedestrians were shown moving at three different speeds and in two orientations:

Three speeds: not moving at all, moving slowly, moving quickly

Two orientations:

Side

Back

To help us better understand how you made your judgments, please complete the following set of questions about how you decided which pedestrian was most recognizable as a person. If none of the statements seem adequate, please use the space below the statements to describe how you made your decisions.

Pedestrian Motion Questions

1) When both pedestrians on the screen were in SIDE orientation, how did pedestrian speed of motion impact your selection?

Please select 1 of the following:

a) I tended to pick the pedestrian that was not moving
b) I tended to pick the pedestrian that was moving, but not necessarily moving the fastest
c) I tended to pick the pedestrian that was moving fastest
d) None of the above, see description____
____
____
____

2) When both pedestrians on the screen were in BACK orientation, how did pedestrian speed of motion impact your selection?

Please select 1 of the following:

a) I tended to pick the pedestrian that was not moving
b) I tended to pick the pedestrian that was moving, but not necessarily moving the fastest
c) I tended to pick the pedestrian that was moving fastest
d) None of the above, see description____

Pedestrian Orientation Questions

1) When both pedestrians on the screen were not moving at all, how did pedestrian orientation impact your selections?

Please select 1 of the following:

a) I tended to pick the pedestrian in side orientation
b) I tended to pick the pedestrian in back orientation
c) None of the above, see description____

2) When both pedestrians on the screen were moving slowly, how did pedestrian orientation impact your selections?

Please select 1 of the following:

a) I tended to pick the pedestrian in side orientation
b) I tended to pick the pedestrian in back orientation
c) None of the above, see description____

3) When both pedestrians on the screen were moving quickly, how did pedestrian orientation impact your selections?

Please select 1 of the following:

a) I tended to pick the pedestrian in side orientation
b) I tended to pick the pedestrian in back orientation
c) None of the above, see description____
____
____
____