The Heads-Down Display:
Autonomous Cars that Project Messages on the Ground Behind Them While Reversing Make Elderly Pedestrians Safer

by

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Table of Contents

Acknowledgements ii

List of Tables vi

List of Figures vii

Abstract ix

Chapter 1: Problem 1

Chapter 2: Design Process 4

2.1 Brief 4

2.2 Provocation 5

Chapter 3: Prior Work 8

3.1 Vehicle-to-Pedestrian Communication 8

3.1.1 Autonomous Vehicle to Pedestrian Communication 8

3.1.2 Automotive Lighting 10

3.1.3 Materials 11

3.1.4 Audio Channel 13

3.1.5 The Elderly Pedestrian 15

3.1.6 Parking Lots and Elderly Pedestrians 17

Chapter 4: Survey 19

4.1 Participants 19

4.2 Measures 20

4.2.1 Demographics 20

4.2.2 Behaviors 20

4.2.3 Message Interpretation 21

4.2.4 Design Preference...23

4.2.4.1 Visual Style 24

4.2.4.2 Messaging Concept 25

4.2.5 Selecting a Design for "Pedestrian Instruction" 26

4.2.6 Selecting a Design for "Vehicle Intent" 28

4.3 Survey Discussion 29

4.4 Limitations...31

Chapter 5: VR Simulation 32

5.1 Simulation Method 32

5.1.1 Participants 32

5.1.2 Measures 33

5.1.3 Materials 33

5.1.4 Procedure 37

5.2 Results 39

5.2.1 Detection...39

5.2.2 Reaction 40

Chapter 6: Discussion...42

6.1 Design Recommendation..42

6.2 Limitations..43

6.3 Future Work...44

6.4 Implications for V2P Communication...45

Appendix 46

References 47

List of Tables

Table 1: Summary of Participants for VR Simulator 33

Table 2: List of Parking Lot Videos and Properties Thereof 36

Table 3: VR Simulator Sample...39

Table 4: Projection vs No Projection Detection 40

Table 5: Stop Signs vs Reversing Arrow Detection...40

Table 6: Mean and Standard Deviations of Reaction time by projection type.............................41

List of Figures

Figure 1-1: Zoox Robotaxi [1] 1

Figure 1-2: Lincoln Welcome Lighting [2] 2

Figure 2-1: MDAS.ai Autonomous Shuttle [4] 4

Figure 2-2: Concept Sketch of Autonomous Ice Cream Truck by Brian Mason for MDAS.ai. (A) A “halo” lighting system attached to the roof for long-distance visual communication. (B) Projection on ground next to vending for queueing and menu information. (C) Front and rear light bars that could sense and “follow” nearby pedestrians. (D) Projected “safe zone” around vehicle 5

Figure 2-3: AV Projection Concepts by Brian Mason for MDAS.ai 6

Figure 2-4: Optical illusion chalk art by 3D Artist Chris Carlson [5]..7

Figure 3-1: Six initial interaction concepts from a 2019 study of V2P interaction concepts in virtual reality [9]...9

Figure 3-2: Overdriving Your Headlights [11] 11

Figure 3-3: OSRAM EVIYOS Lamp set up for testing 12

Figure 3-4: The process for EVIYOS projector hardware transforming the input (far left, hollow octagon) to the far right...12

Figure 3-5: A University of Michigan student demonstrates the EVIYOS projector array from a position on the A-pillar of the MDAS.ai shuttle. An image of a white octagon is projected onto the ground in front of the shuttle. 13

Figure 3-6: A parked group of Uber's self-driving Volvos in Pittsburgh [12].............................15

Figure 3-7: Representation of the CBVA measurement method [14] 16

Figure 4-1: Pie Chart of Age Groups of Survey Participants..20

Figure 4-2: Survey Question: When deciding to cross a street an at intersection, do you:...........21

Figure 4-3: Survey Question: Message Orientation - Stop 1 22

Figure 4-4: Survey Question: Message Orientation - Stop 2 22

Figure 4-5: Survey Question: Message Orientation - Stop 3 23

Figure 4-6: Survey Answers: Which projected graphic do you think communicates this best? A) Curved vs Straight Lines, B) Sold vs Dotted Lines, C) Words vs Signage, and D) Single vs Double 24

Figure 4-7: Survey Answers: Which projected graphic do you think communicates this best? A) Single Words vs Double Words, B) Shape vs Signage, C) Lines vs No Lines, D) Red Yield vs Yellow Yield...25

Figure 4-8: Survey Results - Vehicle Intent vs. Pedestrian Instruction (Arrows).........................26

Figure 4-9: Survey Answers: Pedestrian Intent Design Finalists...28

Figure 4-10: Survey Answers - Vehicle Intent Design Finalists...29

Figure 4-11: Projected graphic representing "Pedestrian Instruction" hereafter referred to as "Stop Signs" 30

Figure 4-12: Projected graphic representing "Vehicle Intent" hereafter referred to as "Reversing Arrow"...31

Figure 5-1: Example Time Lapse of Simulator Video with Projected Message 35

Figure 5-2: Projected Messages in Simulator Video: A) Brake Light Only, B) Stop Signs (Pedestrian Instruction), C) Reversing Arrows (Vehicle Intent)...............................37

Figure 5-3: Experiment Room in Pittsfield Senior Center 38

Figure 5-4: Experiment Room in Freedom Village Senior Living Center 38

Figure 6-1: Projected Image Final Design Recommendation 43

Abstract

Communication between driver and pedestrian is important in cross walks, parking lots, and other areas where knowledge of vehicle intent is important to pedestrian safety. With the development of autonomous vehicles, the human driver will be removed, and with it, the exchange that often occurs between vehicle operators and pedestrians (e.g., head nods, hand gestures). Designers and manufacturers are researching how to replace the communication that these interactions provide with cues emitted from the vehicle. One possible technology solution for doing so is using high intensity LEDs to project messages on the ground around the vehicle to communicate with pedestrians.

The population of specific interest is the elderly due to slower reaction time and in many cases hearing impairment. Older pedestrians are at particular risk of being struck by reversing cars in parking lots. This research draws a link between the downward gaze of the elderly pedestrian, the increased likelihood of the elderly pedestrian to be struck by a reversing, parking lot safety, and the potential for V2P messages on the ground plane. It proposes a solution where a parked autonomous car could use advanced lighting technology to project an image on the ground behind it when shifted into reverse.

The study found that elderly pedestrians are significantly more likely to detect a projected message on the ground than detect the existing brake light when walking in a parking lot. By increasing detection of and decreasing reaction time to reversing cars, elderly pedestrians can be safer in parking lots.

Chapter 1: Problem

Drivers communicate vehicle intent with various signals (e.g., turn signals, brake lights, high beams) and, in certain scenarios, by looking at pedestrians. Autonomous vehicles will need to communicate their intent without the benefit of the visual social contract between driver and pedestrian. AVs are not visually recognizable as legacy cars and pedestrians will need to learn new mental models to understand how they communicate without driver intercession. (Figure 1-1)

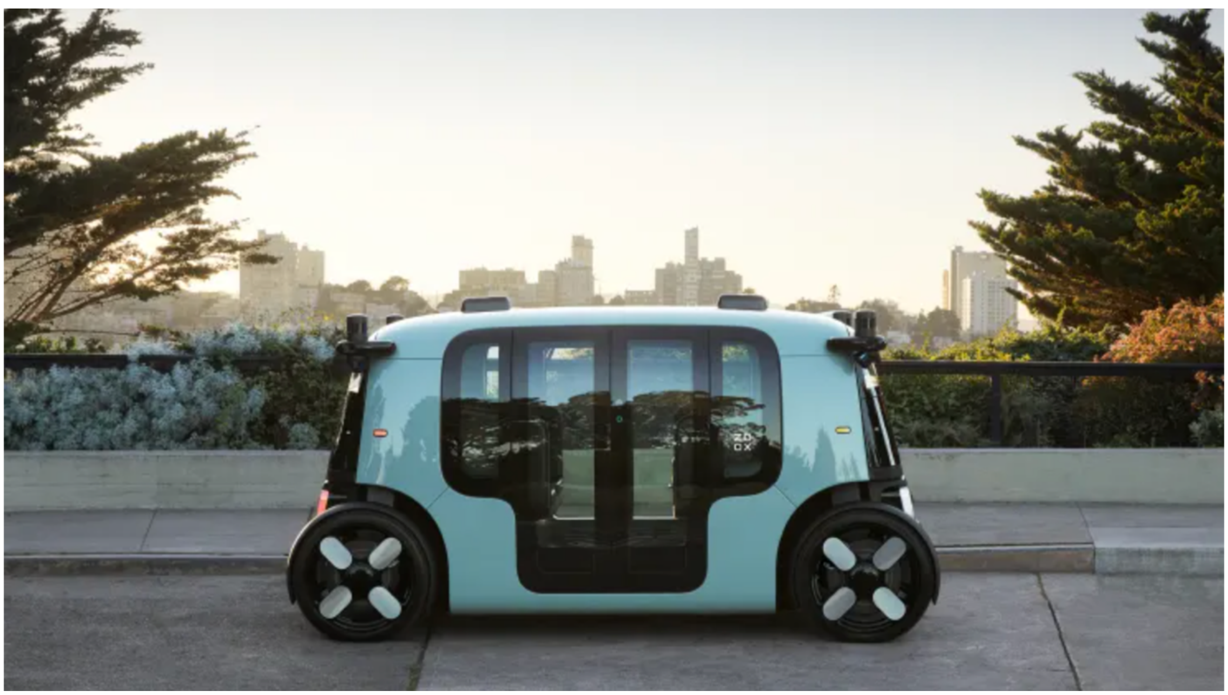

Figure 1-1: Zoox Robotaxi [1]

One potential place for V2P messaging is the ground around the car, which is primarily used for branding now (as in Figure 1-2). As lighting technology rapidly improves, using an exterior lighting apparatus to project messages on the ground around it becomes increasingly viable.

Figure 1-2: Lincoln Welcome Lighting [2]

Elderly pedestrians, who are already are in particular danger in parking lots, may be particularly suited to detect and understand V2P messaging due to the stooped posture and downward gaze that frequently come with aging. This experiment proposes a projector light attached to the back of the vehicle that projects on the ground behind it when the car shifts into reverse (when they are more likely to strike an elderly pedestrian [3]). The intent is to alert (particularly elderly) pedestrians walking behind the reversing car. Even a small improvement in reaction time could have sizeable benefits: for a vehicle traveling at 5 mph, a half second faster pedestrian reaction pedestrian would result in an extra 3.65’ between them and the car.

The experiment sets out to discover if the addition of a rear projection to the existing vehicle reverse signaling will decrease reversing vehicle detection time and subsequently, what is the best projection design.

Chapter 2: Design Process

2.1 Brief

The genesis of this work was the donation of an autonomous shuttle (Figure 2-1) to the MDAS.ai program at the University of Michigan-Dearborn for the purpose of researching the complexities of autonomous driving and shared mobility in a low-speed, pedestrian-rich environment (the campus). While Professor Lakshmanan and his team were developing the shuttle's self-driving capabilities, there was a parallel workstream around V2P (vehicle to pedestrian) messaging. The goal was to communicate awareness, intent, and safety — anything to increase the level of trust that pedestrians have for AVs. Design concepts were ideated around three themes: *approachable autonomy* (how might an AV draw in pedestrians rather than repel them?), *mutual understanding* (how might an AV show pedestrian understanding?), and *student-friendliness* (how might an AV survive the rigors of a college campus?).

Figure 2-1: MDAS.ai Autonomous Shuttle [4]

2.2 Provocation

The design process resulted in a what amounts to an autonomous ice cream truck, which fulfilled the addressed the themes mentioned prior and could build human trust in autonomous technology from safely outside the vehicle. Pedestrians interacted with the ice cream truck while it was stationary, so any adverse event would be less damaging. Its autonomy was approachable, as the lure of ice cream and the positive associations thereof could create a reason for pedestrians to come around it. It could create mutual understanding by using the various messaging channels to show that the vehicle sensed the state of its surroundings in a stationary environment and allow for a sense of play. It would also be student friendly by using rugged materials that could handle a degree of youthful hijinks and that would be easily configurable and repairable as students passed through their programs and worked with the vehicle. It could also create future work as an autonomous platform for a mobile, refrigerated vending machine with other collegiate applications.

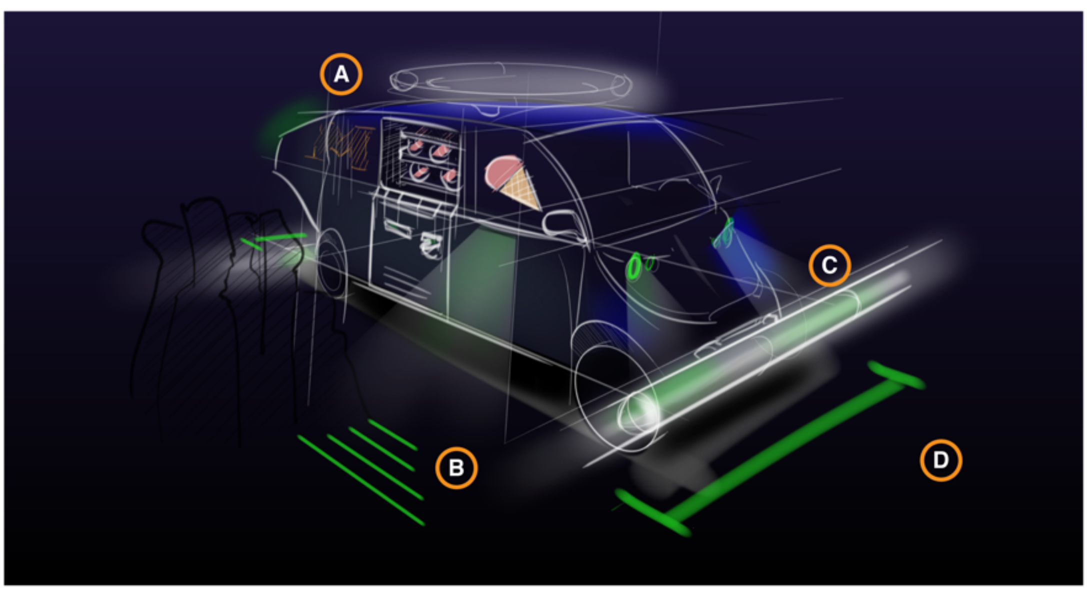

Figure 2-2: Concept Sketch of Autonomous Ice Cream Truck by Brian Mason for MDAS.ai. (A) A “halo” lighting system attached to the roof for long-distance visual communication. (B) Projection on ground next to vending for queueing and menu information. (C) Front and rear light bars that could sense and “follow” nearby pedestrians. (D) Projected “safe zone” around vehicle

The music that ice cream trucks play is an immediately recognizable type of audio V2P that is audible from long distance and provokes an equally immediate reaction. The concept of the ice cream truck raised another question: what types of messaging presentations were more effective at different distances? One of the more fruitful V2P concepts that was raised was a vehicle projection onto the ground plane (as in Figure 2-3): particularly an optical illusion (as in Figure 2-4) that appeared to be a stop sign-shaped hole on the ground. It raised the questions: would a V2P message on the ground plane be viable, and, if so, could the design provoke a desired reaction?

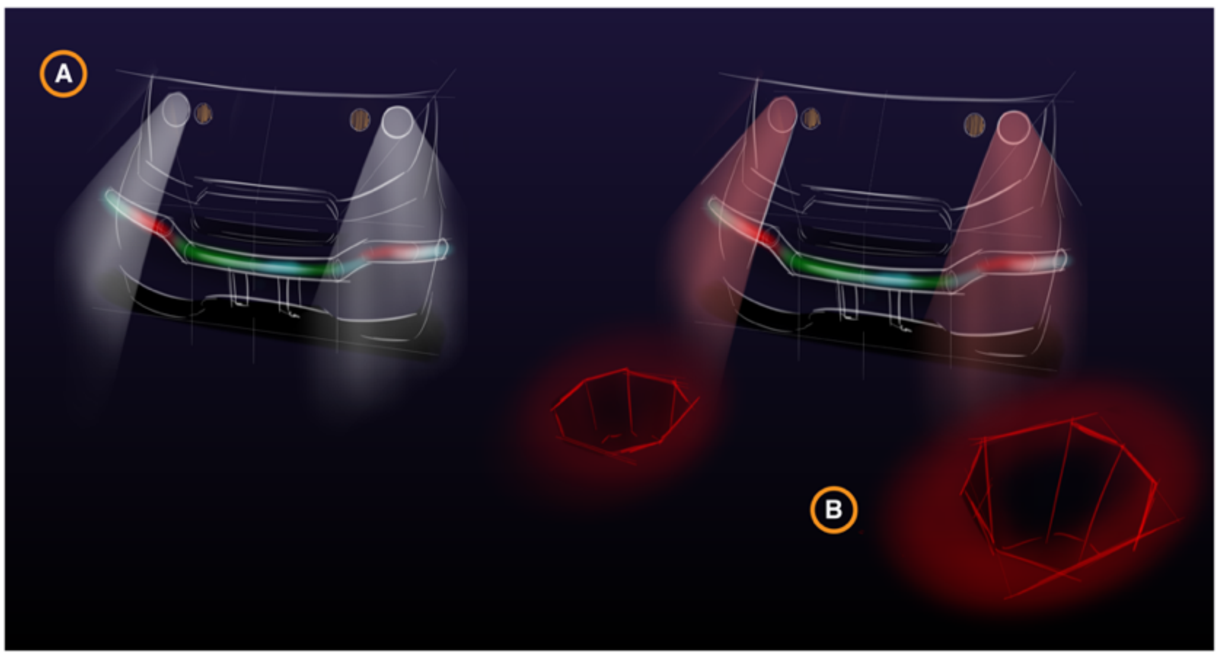

Figure 2-3: AV Projection Concepts by Brian Mason for MDAS.ai

Figure 2-4: Optical illusion chalk art by 3D Artist Chris Carlson [5]

Chapter 3: Prior Work

3.1 Vehicle-to-Pedestrian Communication

In his book *Turn Signals are the Facial Expressions of Automobiles*, Don Norman writes: "Social interaction is enhanced when the participants know not only what is happening at the moment, but what will happen. Of all the signals of the automobile, only the turn signals announce intentions." [6] There already exist unambiguous signals to pedestrians that their movement can cause danger to themselves. Exterior visual signals (brake lights, reverse light, high beams, and the aforementioned turn signals) on non-autonomous personal vehicles communicate to both pedestrians and motorists but rely on the viewer to infer what to do with the knowledge of the vehicle's action.

Specialty vehicles have more specialized messages: school buses have stop signs that deploy when school children are exiting the vehicle. The stop sign commands other vehicles and, to a lesser extent, informs the school children that it is safe to cross the street. Passenger buses feature vital V2P messaging about identification and route coexisting with less vital messaging about which products to buy. This is not a command to the pedestrians, but it is meant to be consumed by them to make choices about their movement.

3.1.1 Autonomous Vehicle to Pedestrian Communication

There are two broad categories of research regarding autonomous vehicle communication: driver-centered and pedestrian-centered. Pedestrian-centered research is the less explored of the two types, and the work that has been done around it primarily involves understanding the informal communication channels between driver and pedestrian. Broadly, interfaces can reside on the vehicle, the street infrastructure, the pedestrian, or some combination thereof and that explicitly communicating vehicular awareness and intent helps pedestrians make crossing decisions. This can be achieved through visual (iconography, text), physical (motion, haptics), and auditory (chimes, instructions) modalities. [7]

One pedestrian-centered V2P study explores the building of trust between college campus pedestrians and an autonomous shuttle. Mean comfort with shuttle-pedestrian interaction increased when a signal was provided by the shuttle when approaching a crosswalk. Participants were more comfortable with lighting a pathway, flashing headlights, obvious slowdown, or a computer voice. [8] Another VR study suggested projecting crosswalks on the ground in front of a stopped AV instructing pedestrians to start walking on the prescribed path. In a within-subject VR experiment where different V2P communication systems were tested against each other, [9], participants expressed a desire for a combination of designs (d) F015 and (f) Smart Road concepts (Figure 3-1).

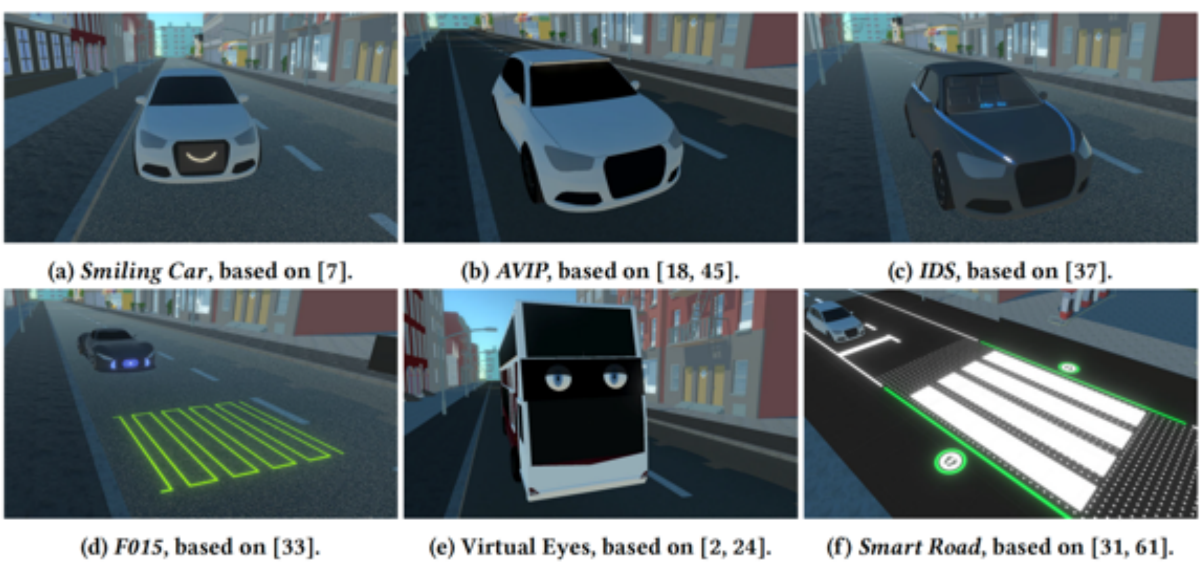

Figure 3-1: Six initial interaction concepts from a 2019 study of V2P interaction concepts in virtual reality [9]

In the same study (Figure 3-1), designs meant to approximate the human element of facial expression (a), and eye contact (e) were less successful. Designs that try to duplicate human faces inevitably do not test well, as they ask the pedestrian to infer what the car wants them to do with the added complexity of deciphering the abstraction of the graphics that lack the micro expressions that humans have been trained on for a lifetime.

SAE J3134 -ADS Lighting guidelines recommend a signal on the front of the vehicle to inform pedestrians that an advanced driving system is active. The autonomy indicator light was recommended to be viewable by those close to the vehicle in daytime and nighttime and account for a range of mounting heights [10]. The task force proposed to mount the light at the top of the front windshield (mostly a function of a dearth of other options) that emitted a unique blue-green hue (to avoid confusion with other signals).

3.1.2 Automotive Lighting

Any use of a projected image like above would need to have a constant surface on which to project (the ground). In addition, for the projected image to be useful to pedestrians, the AV would need to be traveling at low speeds. The pedestrian would need sufficient time to detect the projected message, determine what it means, and react to it. Even in an idealized future state, a vehicle-mounted light is only effective for a limited distance before the image quality deteriorates. For this reason, some potential applications of the projector require a relatively static vehicle.

A projector array can only throw an image so far (even in an idealized future state), and thus would give an inattentive pedestrian an extremely short, if not impossible, time to react to the oncoming car. This phenomenon is similar to “overdriving your headlights”: when a car driving at night (or in low visibility) is moving so fast that the distance required to stop is beyond the driver's visibility (Figure 3-2).

Figure 3-2: Overdriving Your Headlights [11]

3.1.3 Materials

The concepts around ground plane projection led to an exploration of enabling technologies, which in turn led to a donated piece of technology: the OSRAM EVIYOS lighting system (Figure 3-3), which is a configurable grid array of 1024 high intensity LEDs. The designs can be configured by using a simple spreadsheet of 1's and 0's (Figure 3-4), which in turn reconfigures the design into a projectable pattern (Figure 3-5).

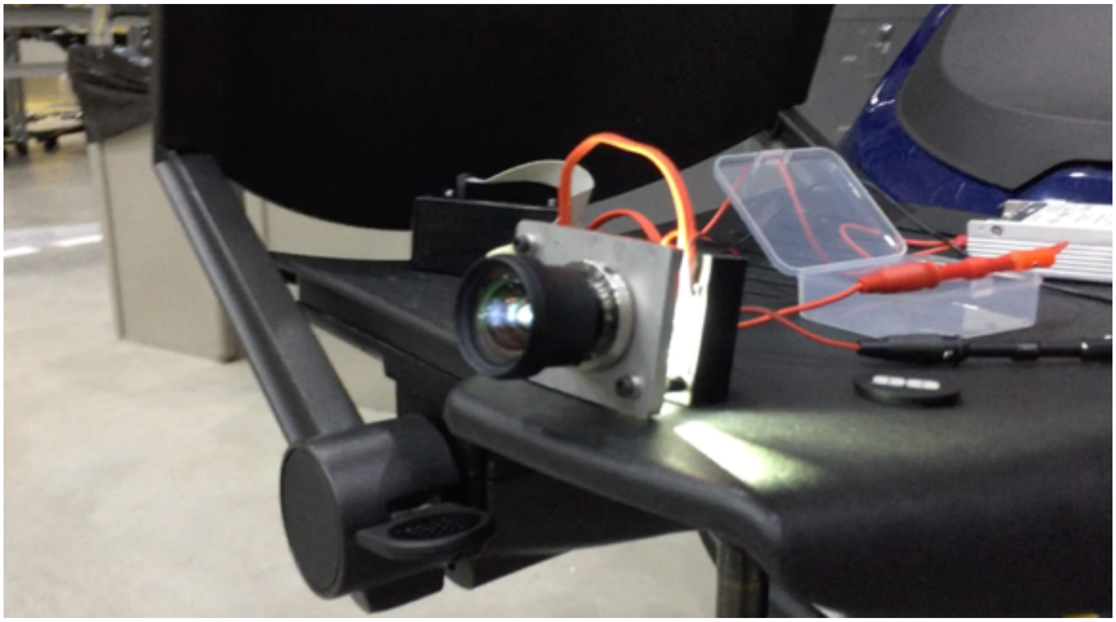

Figure 3-3: OSRAM EVIYOS Lamp set up for testing

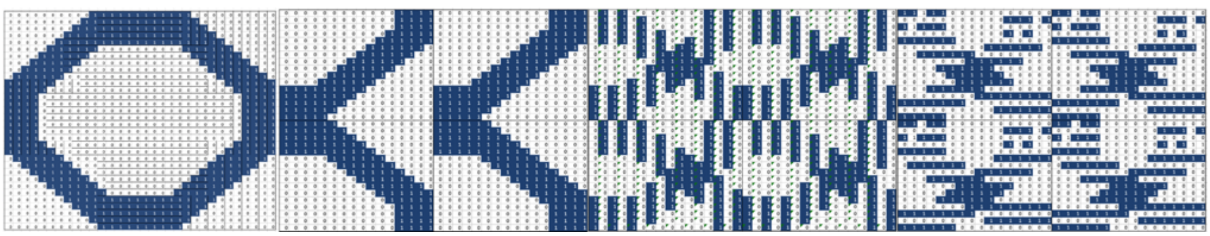

Figure 3-4: The process for EVIYOS projector hardware transforming the input (far left, hollow octagon) to the far right

Figure 3-5: A University of Michigan student demonstrates the EVIYOS projector array from a position on the A-pillar of the MDAS.ai shuttle. An image of a white octagon is projected onto the ground in front of the shuttle.

After confirming that, with an existing technology, a legible image could be projected from a vehicle onto the ground around it, further research was conducted into the parameters of the problem and the viability of the solution.

3.1.4 Audio Channel

Audio channels of V2P will remain important, particularly as silent electric vehicles increase in popularity and the telltale rumble of a car approaching from behind vanishes. The slam of a door or the rev of an engine can be a signal to pedestrians to take caution. However, V2P communication for AVs may require more information but also have drawbacks.

Another study around communicating V2P awareness to pedestrians found that several participants independently mentioned that a voice originating from the vehicle provided clear instructions to them would be a positive addition. [7] Audio feedback is generally very effective, as in the case of reverse beeps in large trucks or slamming doors and engine noise in a parking lot can both indicate a reversing (or soon-to-be reversing) vehicle but should be used as one of many communication modalities to pedestrians to guide them safely. Participants from the same study noted that some cues should be reserved for emergency situations (emergency vehicles, law enforcement, etc.), and that in a future where many AVs may be clustered together, they made need to coordinate or mute themselves for the sake of clarity. In addition, auditory modalities of communication may be less effective in urban environments with a higher incidence of noise pollution.

Figure 3-6: A parked group of Uber's self-driving Volvos in Pittsburgh [12]

3.1.5 The Elderly Pedestrian

Aging has many potential effects on the elderly: stooped posture, irregular gait, and downward gaze. Osteopenia and osteoporosis, or decreased bone density, are a result of the decreased hormone levels that come with natural aging. This decreases the structural support bone supplies to the skeleton. Another cause of spine issues is the hardening of the normally soft, shock-absorbing intervertebral discs. Sarcopenia, or decreased muscle mass, decreases muscular support for the spine. These three conditions can lead to hyperkyphosis.

Kyphosis is the normal posterior convex curvature of the spine in the thoracic (upper back) and sacral (hip) regions. In contrast, lordosis describes the normal anterior convex curvature of the cervical (neck) and lumbar (lower back) spine. Hyperkyphosis occurs when the angle of posterior spinal curvature is beyond healthy ranges [13]. One adverse health effect of the cervical spine issues brought about by aging is an increased chin-brow to vertical angle [14], which can force the gaze downward as shown in Figure 3-7. Another adverse health effect of cervical hyperkyphosis is a forward shift in the center of gravity [15] which can cause or exacerbate balance issues which can lead to falling and a fear thereof. Falls are a known and prioritized risk in the elderly, particularly as they relate to hip fractures. Hip fractures are difficult to recover from and may decrease subsequent quality of life. The focus required to pay attention to surrounding reversing vehicles can be redirected to make micro-corrections to shifting balance caused by an unusual gait.

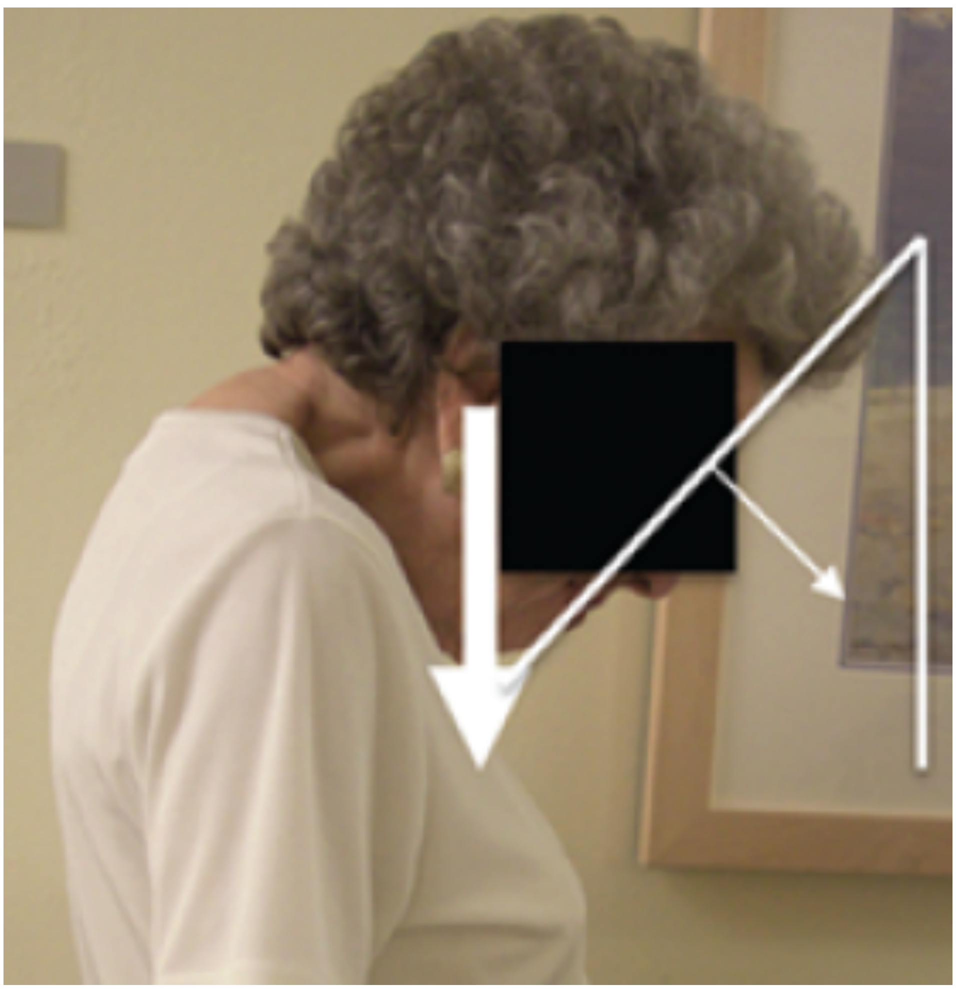

Figure 3-7: Representation of the CBVA measurement method [14]

3.1.6 Parking Lots and Elderly Pedestrians

The bulk of concepts and studies around V2X messaging has been in the context of an AV approaching a pedestrian at a crosswalk, but the arena of vehicle to pedestrian messaging in parking lots has gone largely unresearched. NHTSA does not keep track of pedestrian crashes in parking lots, which may contribute to this imbalance. Most pedestrian catastrophes occur in urban environments rather than rural areas [16], which aligns with the existing research focus. However most (73%) pedestrian catastrophes occur on the open road rather than at intersections (18%) where much existing signaling and social norms are established. The focus on autonomous V2X at intersections does not align with practical traffic issues but appears to be more centered around duplicating and understanding the social contract between driver and pedestrian.

Parking lots are particularly dangerous places for pedestrians, particularly the elderly, who have a slower detection and reaction time. [17] They are more likely than pedestrians of other age groups to be struck by a car in a parking lot, and when they are, they are significantly more likely to sustain a debilitating or catastrophic injury than pedestrians in other age groups [3]. In 2009, adults older than 65 comprise approximately 13% of the Floridian population but accounted for 18% of all pedestrian catastrophes [18], the highest of any other age group. In 2009, American adults over 75 comprised approximately 9% of the population but accounted for a disproportionate 26% of back-over catastrophes (in and out of traffic) and 18% of injuries. [19]

Scenarios involving cars striking pedestrian are extremely sensitive to the level of ambient lighting, as catastrophic pedestrian crashes are three to four times more likely in the dark than in the daytime. [20]. For pedestrians outside of parking lots, the dark is particularly dangerous, as 75% of catastrophic pedestrian incident occur in the dark and 21% occur in daylight, and 2% at dusk. For the parking lot pedestrian, parking lot crashes were most likely between 12:00PM and 6:00PM, when most commercial businesses are open [3].

Older pedestrians are particularly vulnerable to being backed over by cars, which is a contributing factor to the location of the proposed projection system in the rear of the vehicle. Pedestrians age 75+ years are roughly twice as likely to be hit by a vehicle traveling in reverse than forward. The opposite is true for pedestrians aged 14 and younger. [3] Although the elderly are particularly vulnerable, so are the youth. The rate of crashes per 1000 population is highest for pedestrians between 15 and 19 years of age. The crash rate then slowly declines until pedestrians reach 75 years old, where it spikes sharply. [3] In addition children under 5 are at the highest risk for injury or catastrophe from a reversing car. [19]

Chapter 4: Survey

Having posited that a projected message on the ground plane behind a reversing car would help elderly pedestrians, to move toward an ideal design (one that was more detectable and offered a quicker response time) for a projected message, a survey was conducted to better understand elderly pedestrians' behaviors, attitudes and V2P messaging preferences. The results will be used to decide which graphics, wording, and metaphors pedestrians responded to best so that they could be cogently combined into two designs. The two designs will be tested against each other in a VR simulator to determine which pedestrians detect more and react faster to. One design will fall under the concept "Vehicle Intent." The other will fall under the concept "Pedestrian Instruction." Participants had one hour to respond to 70 questions. Data was collected over two weeks.

4.1 Participants

480 American residents over the age of 55 were recruited through Amazon mTurk to participate in the survey. Participants were 62.53% female, and 37.47% male and residents were primarily between ages 55-64 (54.68%) and 65-74 (40.43%).

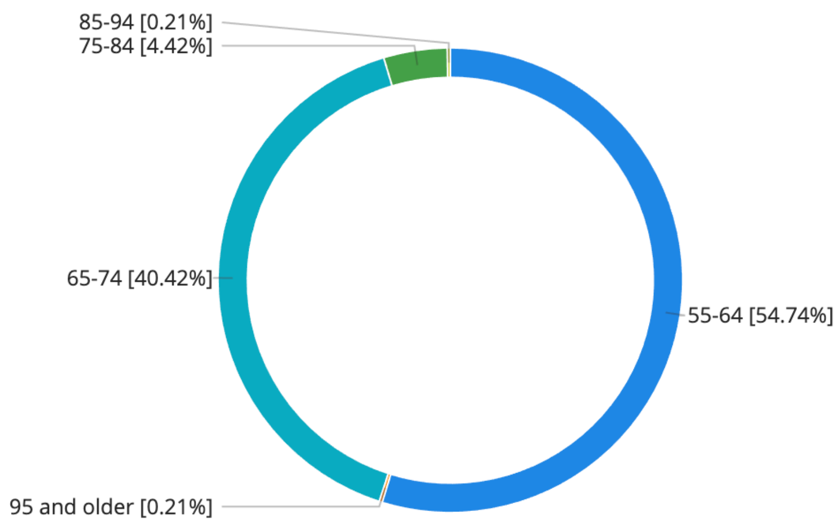

Figure 4-1: Pie Chart of Age Groups of Survey Participants

4.2 Measures

Participants were asked 70 (primarily multiple choice) questions divided into four parts: Demographic, Behaviors, Message Interpretation, and Design Preference. There were additional free response questions when elaboration was necessary or additional comments were solicited.

4.2.1 Demographics

A number of (41.06%) participants reported having difficulty seeing without glasses, with most reporting that they do wear corrective glasses. A much smaller 5.27% reported hearing issues. 18.09% of participants reported having difficulties walking to and from their car due to mobility issues. 11.7% reported using a walker, which was the most frequently used mobility assistance device. Only 21.05% lived in a rural area, with the rest living in either suburban/exurban areas (42.53%) or urban areas (34.95%).

4.2.2 Behaviors

Participants were asked questions about their attitudes as pedestrians. Most participants (65.12%) said that they wait for the walk sign when deciding to cross the intersection. Similarly, most participants (66.38%) said that they wait for oncoming cars to come to a complete stop at a stop sign before crossing the street (Figure 4-8).

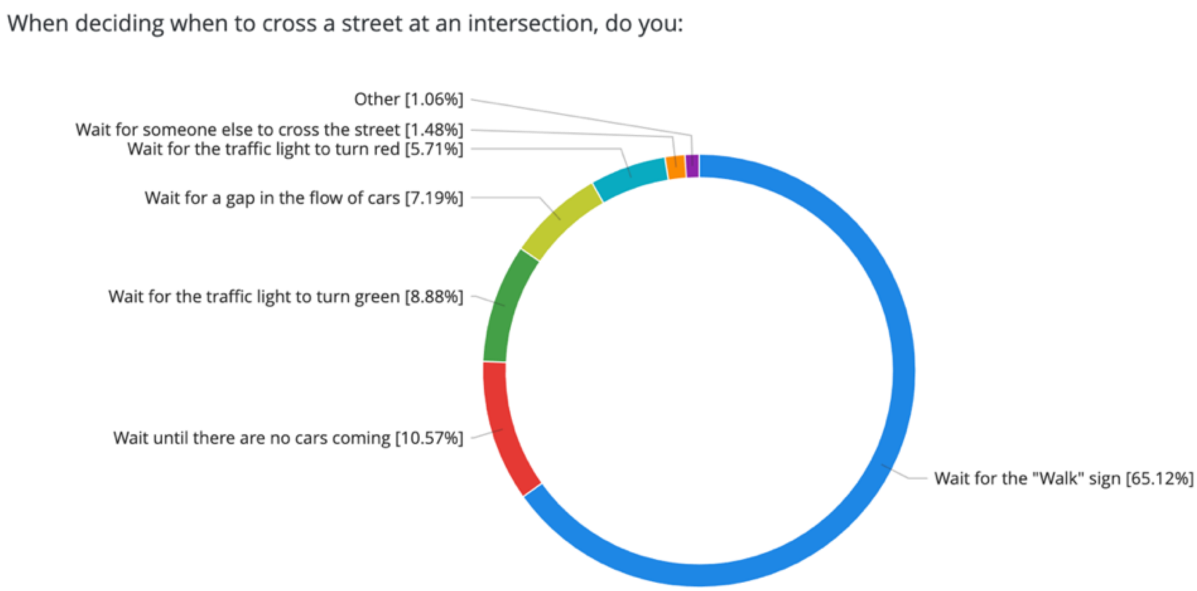

Figure 4-2: Survey Question: When deciding to cross a street an at intersection, do you:

Participants were provided with a scenario that described walking down a row of parked cars in a parking lot when one of the parked cars begins reversing out of its space. Most (58.14%) participants said they would stop completely until the car is out of their path, and almost a quarter (22.39%) said they would continue walking but reroute to a safe area.

4.2.3 Message Interpretation

This section was devoted to how pedestrians and drivers would interpret a symbol on the ground behind a vehicle. To that end, a series of questions was posed where participants were given variations on a projected message asked to answer what they though it meant. It was emphasized to participants that there were no wrong answers.

Six such questions ask: “You are a pedestrian walking through a parking lot. An autonomous car is projecting this graphic behind it. What does the graphic mean to you?” and present an image of a projected message behind a parked AV such as in Figure 4-3, Figure 4-4, and Figure 4-5. Three featured stop signs and three featured yield signs.

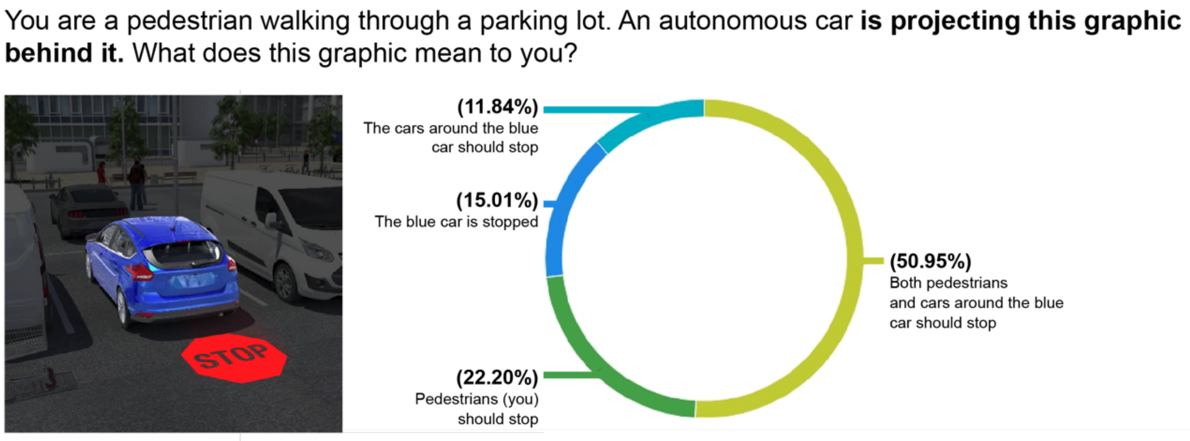

Figure 4-3: Survey Question: Message Orientation - Stop 1

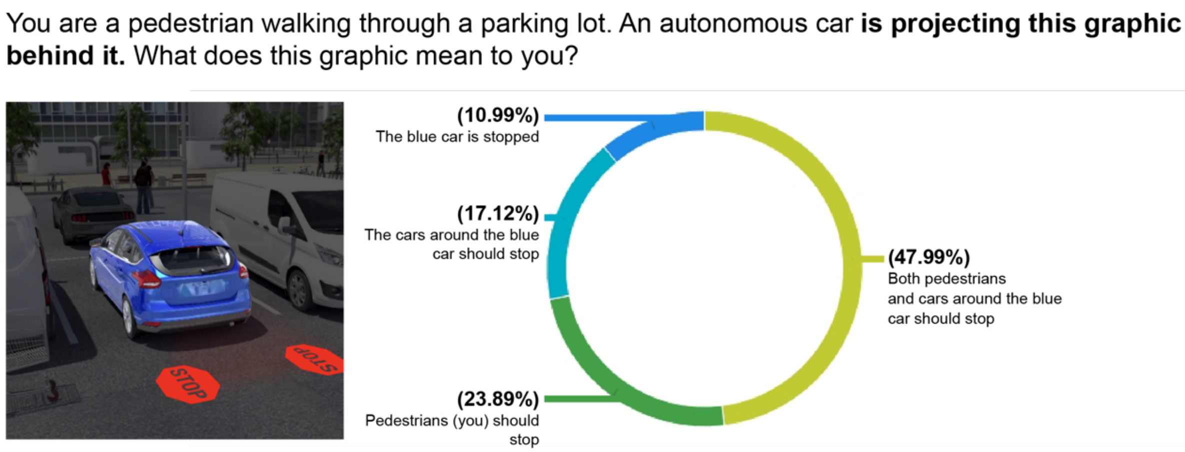

Figure 4-4: Survey Question: Message Orientation - Stop 2

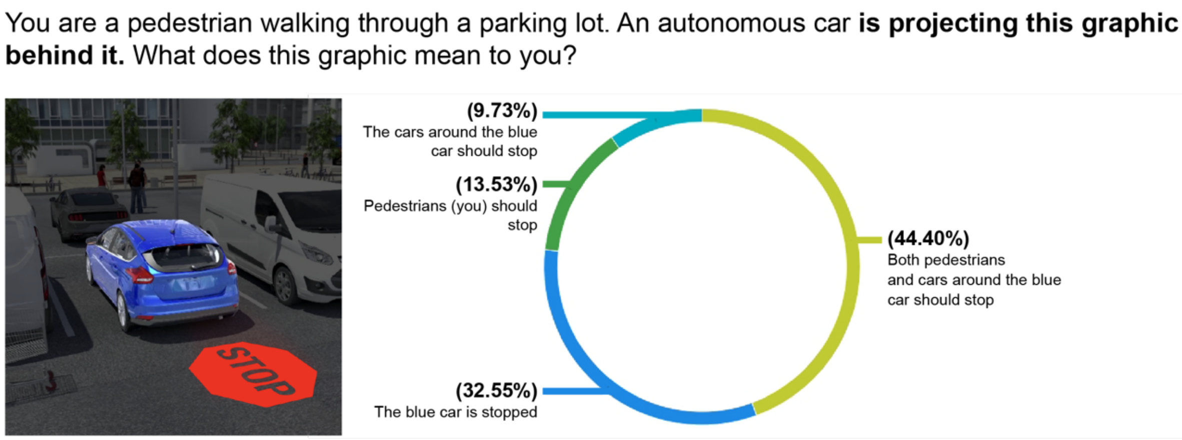

Figure 4-5: Survey Question: Message Orientation - Stop 3

In all six cases, regardless of orientation or signage, most participants believed the project message to mean "both pedestrians and cars around the blue car" should follow the projected signage. The second most frequent response for all six questions was "pedestrians should follow the signage," though "the cars around the blue car should follow the signage" came in a close third. The signs with text oriented parallel to the rear bumper (as in Figure 4-3) were thought to be describing the state of the car behind it. When the same series of six questions was posed with the participant taking on the role of a driver rather than pedestrian, most participants still believed that the signage was meant for both drivers and pedestrians. The phenomenon of the parallel signage continued in this case with "the blue car is stopped" at 30.98% and "the blue car is yielding" at 29.34%. When the participant was asked to imagine themselves as the pedestrian, they were more likely to believe the message was for pedestrians, and when asked to imagine themselves as a driver, they were more likely to believe that the message was for drivers.

4.2.4 Design Preference

Participants were then asked a series of A vs B questions about their preference in text choices and graphic cues. This information could be used to design future signage, but also to inform the process of synthesizing popular survey concepts into two final designs for comparison.

4.2.4.1 Visual Style

Participants were then asked "You are a pedestrian walking through a parking lot. A parked autonomous car has shifted into reverse. Which projected graphic do you think *communicates this best?*" Participants believed that straight lines (58.06%) communicated reversing better than curved lines; that dashed lines (54.19%) communicated better than solid lines, signs (75.05%) were preferable to words, and that two signals perpendicular to the bumper was better than one parallel to it for both symbols (72.96%) (Figure 4-6), and verbiage (60.3%) (Figure 4-7). They also felt that signs with words (92.36%) were preferable to the shape of the sign alone, and that a yellow yield sign (67.17%) was preferable to a red one.

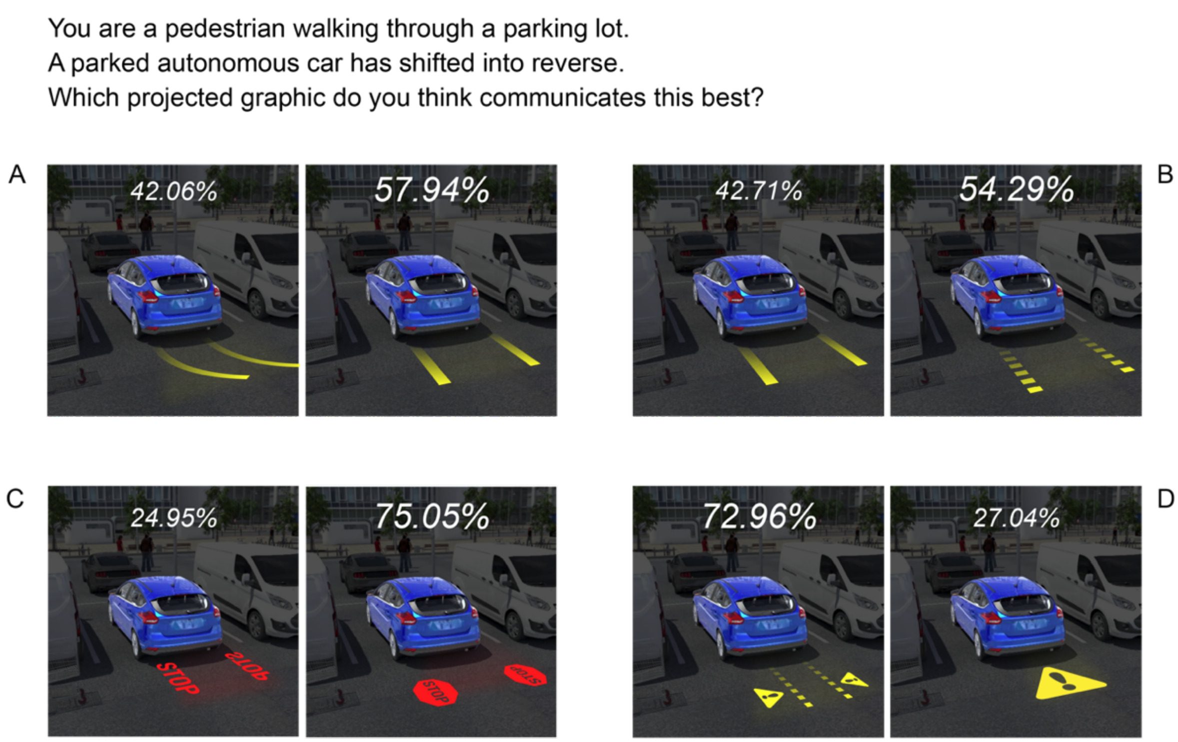

Figure 4-6: Survey Answers: Which projected graphic do you think communicates this best? A) Curved vs Straight Lines, B) Sold vs Dotted Lines, C) Words vs Signage, and D) Single vs Double

Figure 4-7: Survey Answers: Which projected graphic do you think communicates this best? A) Single Words vs Double Words, B) Shape vs Signage, C) Lines vs No Lines, D) Red Yield vs Yellow Yield

4.2.4.2 Messaging Concept

The primary goal of the survey was to determine which two designs (vehicle intent and pedestrian instruction) to test in the simulator. Although the design options were selected in a subsequent section of the essay, it was still relevant to ask participant opinion. They were asked: “You are a pedestrian in a parking lot. A parked autonomous car has shifted into reverse. *Which projected graphic would you prefer to see?*”. The design representing vehicle intent, (Figure 4-8) 9A (51.07%) narrowly edged out the design representing pedestrian instruction (9B) by 11 participants, which was not statistically significant. This pair was designed with the arrow in 9A representing the vehicle’s intent to reverse straight back along the path of the arrow. The arrows in 9B representing the desired pedestrian path (clearing left and right out of the way of the path of the car).

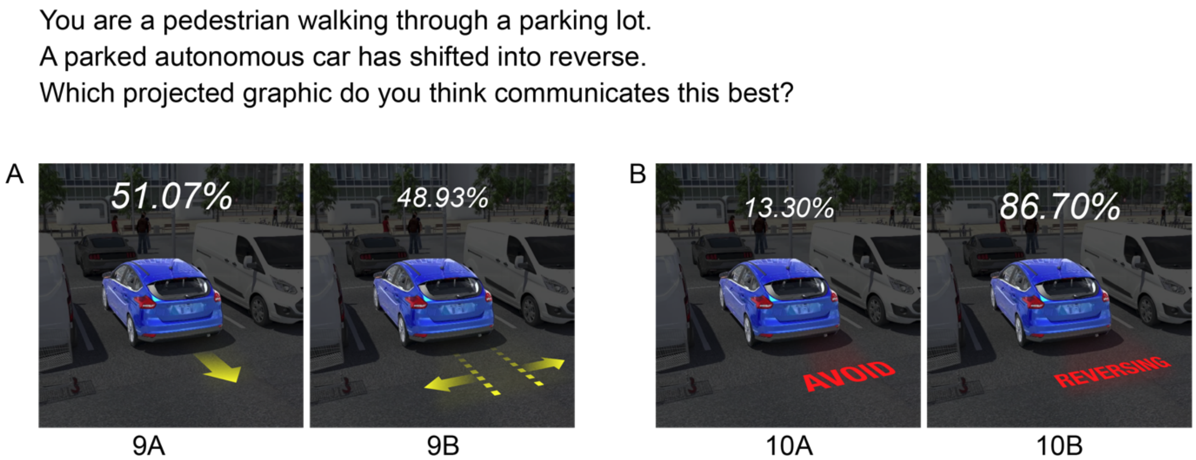

Figure 4-8: Survey Results - Vehicle Intent vs. Pedestrian Instruction (Arrows)

No associations were found between intent vs instruction preference and age (participants were divided into over and under 65), as the chi-squared statistic does not achieve statistical significance (X^2 (1) = 3.47, p = .06 . There was also no association between intent vs instruction preference and gender (X^2 (1) = 2.63, p = .10,. There was also no association between intent vs instruction preference and crossing behavior. (X^2 (1) = 0.069, p = .79 When the same question was asked of a pair of projected words ("avoid" suggesting pedestrian instruction and "reversing" suggesting vehicle intent), participants strongly preferred 10B (86.70%), the vehicle intent option.

4.2.5 Selecting a Design for "Pedestrian Instruction"

To determine participant's preferred graphic to represent pedestrian instruction, they were asked to choose which projected message they preferred if an autonomous vehicle was "leaving a parking space" and was going to *guide them to safety*. The questions were worded in that way to as not to describe the vehicle intent (wanted to back up), but rather the state (leaving the parking space) of the vehicle and what it wanted to communicate to the pedestrian. There were first three questions that asked for the design preference within a category: 1) existing signage, 2) symbols, 3) and wording.

Participants first were asked to choose between a projected stop sign and a projected yield sign (Figure 4-9). More users (55.48%) preferred the stop sign to the yield sign, which is roughly consistent with the 58.14% of participants from Figure 4-2 that said they would stop completely for reversing vehicles in a parking lot. The second question asked participants to choose between a design with arrows suggesting the path of pedestrians away from the car and a triangular icon similar to the ISO 7010 general warning sign. More users (52.26%) preferred the warning sign to the arrows. The third question asked participants to choose which word (in a projected context) best communicated the vehicle's desire to guide them to safety: Yield, Stop, Back, or Avoid. More users (40%) preferred the Yield wording than Stop (22%), Back (22%) or Avoid (17%)

The participant's answers from the three questions were then compiled and then provided as the answers to another question (with the same wording): "You are a pedestrian walking through a parking lot. A parked autonomous car is leaving its parking space and wants to guide you to safety. Which projected graphic do you prefer?" The three previous questions gave their preference within each mode of message (existing signage, new icons, and text-only instructions), so the final combined question gives us the preferred mode and design. The top two responses representing Pedestrian Instruction were Figure 4-9A and Figure 4-9B.

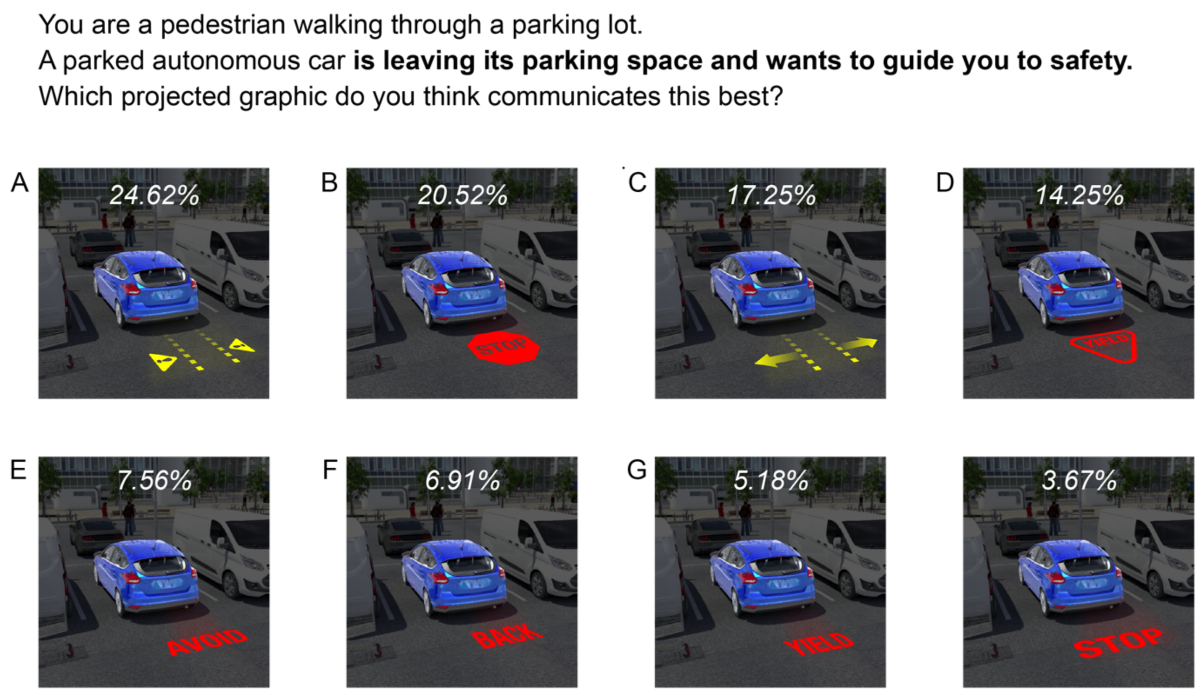

Figure 4-9: Survey Answers: Pedestrian Intent Design Finalists

4.2.6 Selecting a Design for "Vehicle Intent"

To determine participant's preferred graphic to represent vehicle intent, they were asked to choose which graphic they preferred if an autonomous vehicle "intends to pull out of its parking space" and wanted to communicate that. The question required less delicate wording than the pedestrian instruction, as the vehicle's intent to reverse was no secret. There were first two questions that asked for the design preference within a category: 1) verbiage, and 2) vectors.

The first question asked participants to choose which word (in a projected context) best communicated the vehicle's intent to reverse: "Reversing" (the soon-to-be state of the car), "Reverse" (the gear that the car was in), or "Back." More users (62.7%) preferred the Reversing wording than Reverse or Back. The second question asked participants to choose the best type of vector that suggests the intended path of the car. Most users (53%) preferred a single simple arrow rather than two lines suggesting the path of tires. Of the tire path treatments, tire tracks

(33%) were preferred to the solid (10%) or zigzag (4%) lines. The participant's answers were then compiled and then provided as the answers to the same question. The top two responses were Figure 4-10 A and Figure 4-10 B

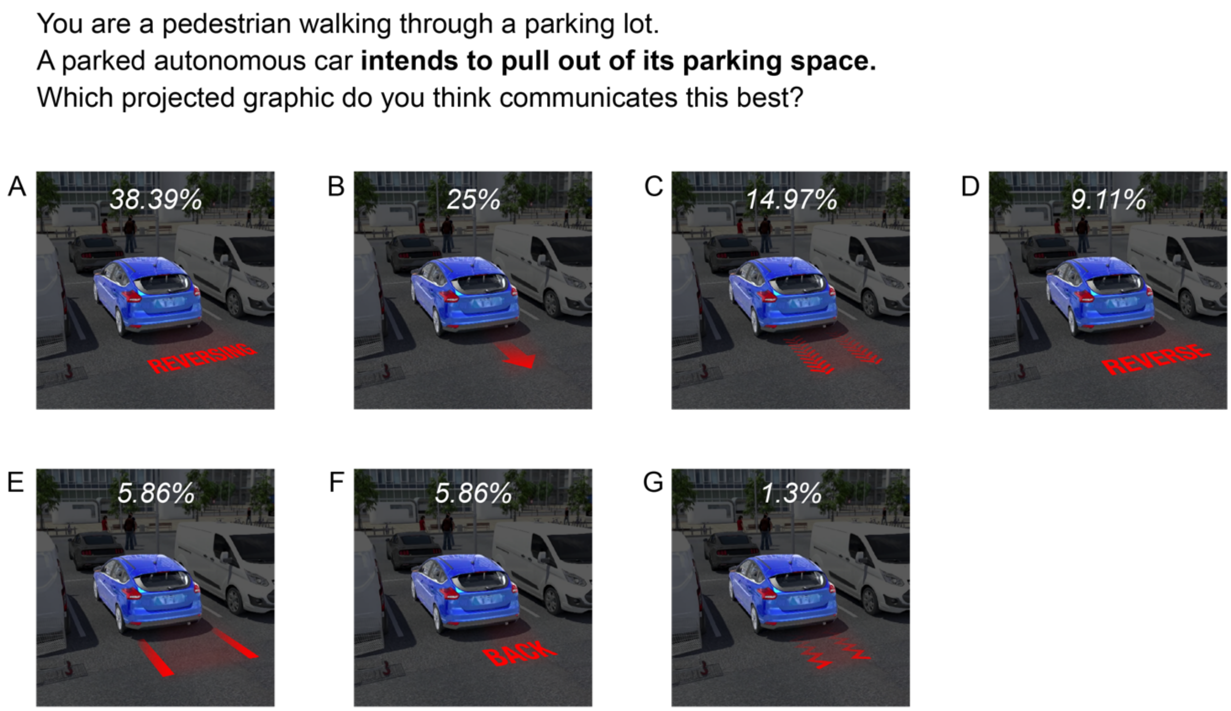

Figure 4-10: Survey Answers - Vehicle Intent Design Finalists

4.3 Survey Discussion

Participants showed a strong preference towards existing signage conventions and wording. Attempts to get clever, such as using "back" to suggest both vehicle and pedestrian should be moving back, were soundly rejected. There was a preference that graphics run perpendicular to the back of the car, as the messages were more clearly understood to be for pedestrians/motorists and not describing the state of the vehicle. Participants preferred that stop signs, the color red, and combinations of symbols and words. Armed with the participant preferences for the two messaging strategies and preference data from the survey, the design feedback was synthesized and turned into two messaging concepts to test against each other in the simulator test. Also of interest is the preference for the yellow yield sign over the red yield sign, as the US moved from yellow signs to red signs in 1971 [21]. The more elderly participant base may account for this response.

The Pedestrian Instruction projected message (Figure 4-11), called “Stop Signs,” combined the two highest vote getters from the survey into a single concept that incorporated both instructions (double stop), signage (stop signs with text), and the dashed lines (the area to be avoided) that survey participants preferred. The Vehicle Intent projected message (Figure 4-12), called “Reversing Arrow,” combined the two highest vote getters from the survey into a single concept that incorporated both vectors (the large arrow suggesting the path of the car), and verbal instruction (reversing). These would be the designs tested against each other in the VR simulator.

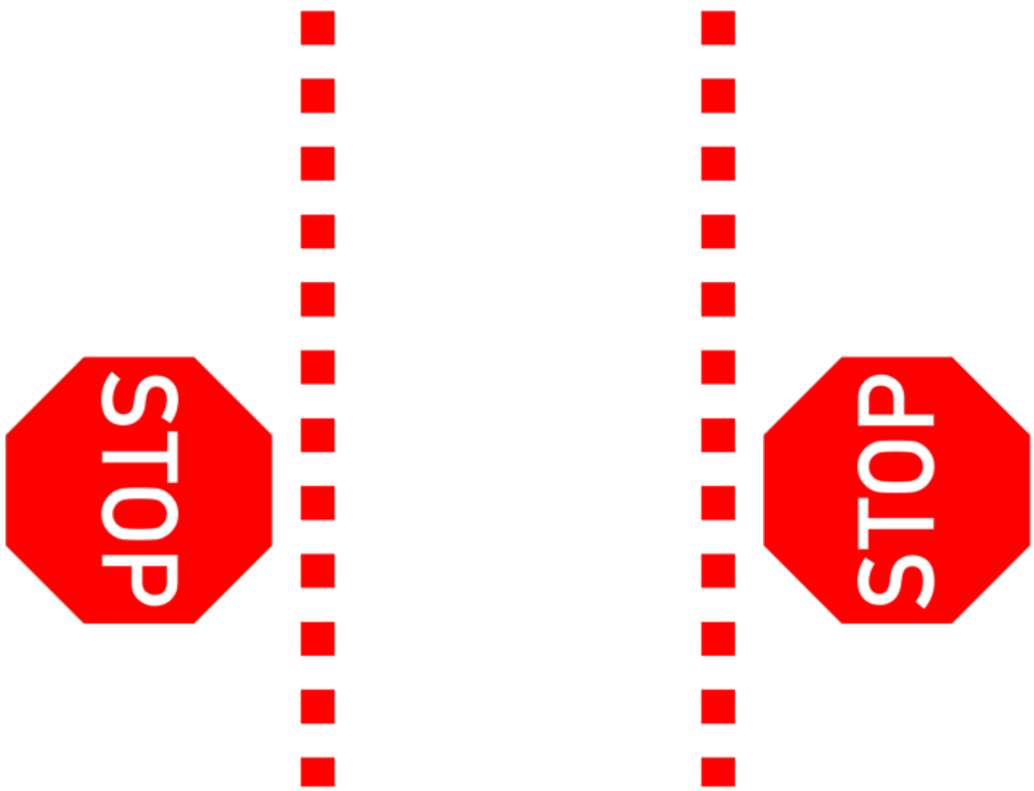

Figure 4-11: Projected graphic representing "Pedestrian Instruction" hereafter referred to as "Stop Signs"

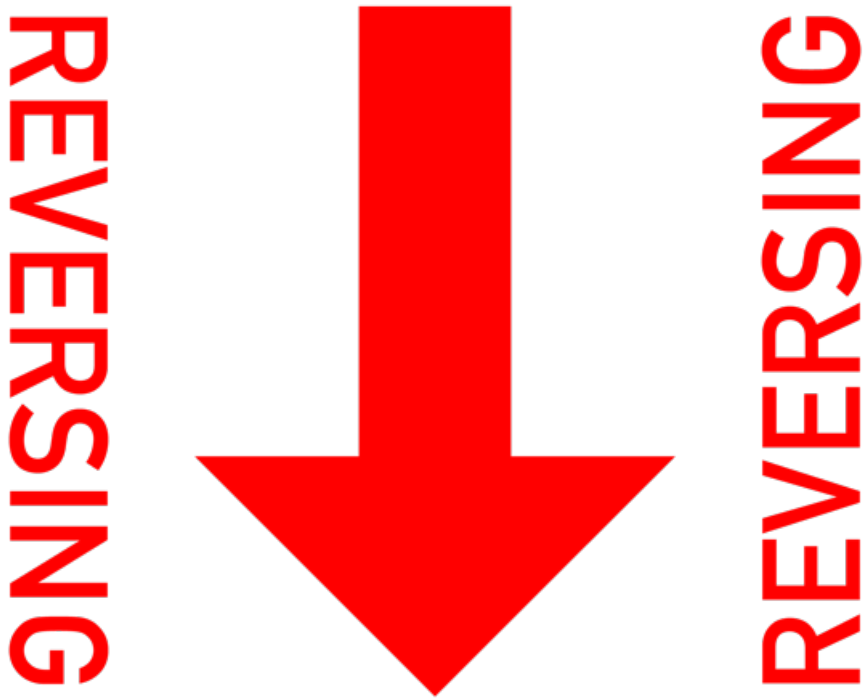

Figure 4-12: Projected graphic representing "Vehicle Intent" hereafter referred to as "Reversing Arrow"

4.4 Limitations

The survey sample was overall younger than the ideal targeted population, as the jump in peril for pedestrian peril occurs around 75 years of age. However, the generalizability of these findings is likely to be robust due to the relatively younger age of the study participants. Pedestrians of this age will likely experience close contact with AVs as their presence increases in the next 20 years.

Chapter 5: VR Simulation

5.1 Simulation Method

The goal of the VR Simulator experiment was to test elderly pedestrians' reaction time when a car shifted into reverse (without moving) while "walking" down a row of cars in a virtual parking lot. The experiment will discover if elderly pedestrians are more likely to detect, and quicker to react to, a projected message on the ground than the existing brake light assembly.

It will collect reaction times for the existing brake light assembly and the respective projected messages by asking subject to pause the simulator video when they notice a car in reverse.

5.1.1 Participants

Participants were recruited from Pittsfield Senior Center (5 participants) near Ann Arbor, MI, and Freedom Village Senior Living Community (29 participants). Recruitment was restricted to ambulatory participants 65 and older that had walked, with or without the help of a mobility device, in a parking lot within the last month. The original sample size was composed of 34 participants However, four had to be removed: Subject 668 (first subject, procedure was not explained properly and was updated after), Subject 263 (participating in bad faith and trying to "game" the experiment), Subject 555 (had to stop due to a vertigo spell), and Subject E (outside of age range for experiment). The final sample size (Table 1) was composed of 30 total participants: 18 female and 12 male.

Table 1: Summary of Participants for VR Simulator

Final Simulator Subjects Demographics							
	Female	Male	65-74	75-84	85-94	95+	Total
Count	18	12	6	9	14	1	30
Percent	60.00%	40.00%	20.00%	30.00%	46.67%	3.33%	

5.1.2 Measures

The participants are told to pause the video the moment they notice a car is reversing. The noted times in the video are: the moment the brakes are applied (brake lights on) and the moment the car shifts into reverse (reverse lights on). Times were recorded in hundredths of a second. From this we can calculate the reaction time to the respective projected message. Participants were also asked the questions from the survey pertaining to demographics and pedestrian behavior. A "projection only" configuration was never tested, as the ground plane projection would always be used in conjunction with other modalities.

5.1.3 Materials

The two best representations of the messaging strategies were determined by the survey so their respective noticeability and reaction times could be tested against each other (and the existing brake light assemblies. The simulator test used 30 videos with different projected messages and variables to best gather data. Each of 30 videos (Figure 5-2)would feature the first-person point of view of a pedestrian walking down a row of cars. One of the cars would, or would not shift into reverse and would, or would not project a graphic behind it. Variables were split up so that projected messages were equally distributed amongst the videos. Of the 30 videos shown to pedestrian one third featured the Stop Signs projection, another third featured the Reversing Arrows projection, and the final third used only the existing brake lights. One video for each direction and parking configuration (six in total) had no cars in reverse. Half of the videos featured the virtual pedestrian was walking north; the other half walking south. Half of the videos featured the mover on the far left; the other half featured the mover on the right, and so on (see Table 2). Six of the videos were mirror images of another.

A) Start of Video

B) 00:05 elapsed

C) 00:10 elapsed

D) 00:15 elapsed

B) 00:20 elapsed

B) 00:25 elapsed

B) 00:30 elapsed (End of Video)

Figure 5-1: Example Time Lapse of Simulator Video with Projected Message

Table 2: List of Parking Lot Videos and Properties Thereof

Video	Reverse Time (elapsed)	Mover Model	Mover Side	Mover Position	Projection	Direction	Video Template #
1	6.03	Camry	Right	Near	Stop	North	22
2	6.03	Camry	Right	Near	Arrow	North	22
3	19.19	Focus	Left	Far	Arrow	South	8
4	19.19	Focus	Left	Far	Stop	South	8
5	22.04	Camry	Left	Far	Arrow	North	16
6	22.04	Camry	Left	Far	Stop	North	16
7	22.1	Camry	Right	Far	Arrow	South	22
8		None				South	
9	22.1	Camry	Right	Far	Stop	South	22
10	19.19	Focus	Right	Far	Stop	South	16
11	19.19	Focus	Right	Far	Arrow	South	16
12	7.12	Focus	Right	Near	Arrow	South	17
13	7.12	Focus	Right	Near	Stop	South	17
14	6.03	Camry	Left	Near	Stop	North	18
15	6.03	Camry	Left	Near	Arrow	North	18
16		None				South	
17		None				North	
18		None				North	
19		None				North	
20	10.13	Focus	Left	Near	Arrow	North	19
21	10.13	Focus	Left	Near	Stop	North	19
22		None				South	
23	19.19	Focus	Left	Far	None	South	8
24	6.03	Camry	Right	Near	None	North	22
25	22.1	Camry	Right	Far	None	South	
26	22.04	Camry	Left	Far	None	North	16
27	10.13	Focus	Left	Near	None	North	19
28	6.03	Camry	Left	Near	None	North	18
29	7.12	Focus	Right	Near	None	South	17
30	19.19	Focus	Right	Far	None	South	16

The designs were digitally added to pedestrian POV videos to appear projected from behind a car (Figure 5-2). A parking lot/filming site with one-way aisles was selected to film the simulator videos, as not only are brake lights more visible than two-way aisles, but prior studies have no effect on crash frequency or severity [3]. When filming the simulator videos, the camera was positioned 60” above the ground, which is the mean standing eye height of 1532 mm / 60.31496 inches of Australian males 65 and older. Although American males and females are generally taller other populations worldwide, [22], there is no nationwide anthropometric data on Americans [23].

Figure 5-2: Projected Messages in Simulator Video: A) Brake Light Only, B) Stop Signs (Pedestrian Instruction), C) Reversing Arrows (Vehicle Intent)

The videos were made using Adobe AfterEffects 2020. A .png image containing the image was placed on a ground plane using a 3D tracker camera. The Layer Blending was set to "Color" at 100% Opacity, which "creates a result color with the luminance of the base color and hue and saturation of the blend color. This preserves the grey levels in the image and is useful for…tinting color images." [24] This was chosen to retain the integrity of the image, reflect the texture of the street below, and to give the projected message a realistic relationship with shadow. This approximates a more advanced, but plausibly performing, lighting system than what is currently available.

5.1.4 Procedure

The simulator experiments were conducted in a small multi-purpose room at the Pittsfield Senior Center and in resident's room at Freedom Village. Participants were first asked a series of questions (from the survey) regarding demographic information and pedestrian behaviors. They were then shown a sample video and pointed out the location of the reversing lamps and explained the concept of the ground plane projection. They were instructed to press pause (spacebar) on a keyboard in their lap when they noticed one of the cars shifted into reverse. Participants reacted to one sample video for practice and were informed they could quit at any time if they started to feel nauseous. The 30 videos were shown to the 30 participants.

Figure 5-3: Experiment Room in Pittsfield Senior Center

Figure 5-4: Experiment Room in Freedom Village Senior Living Center

The videos had no sound to isolate the visual component. The projector lens was positioned 143” from the wall, which led to a projected image 60” tall with a 122” diagonal as shown in Figure 5-3. The bottom of the projection was meant to be a close to the floor as possible to suggest ground level. Participants were allowed to be seated rather than the more realistic standing, as each test took roughly half an hour and that is a long time to ask elderly people to stand up. Participants were given a keyboard to either hold in their lap or rest on the desk in front of them

5.2 Results

The experiment was conducted on 30 participants, who each watched 30 videos of 30 second duration. However due to time restraints, some data (35 reaction times) was not collected. The videos (6) where no vehicles were in reverse were removed from the data set (180 reaction times). An additional 118 responses were removed for being outside the numerical area: if they were over ten seconds (the messages were only visible on the simulator for ten seconds at a time due to walking speed) and reactions prior to the vehicle’s shift to reverse (including those after the vehicle’s brakes were pressed). Table 3 shows that of the 900 intended data points, 567 were valid for analysis.

Table 3: VR Simulator Sample

Video #	1	4	6	9	10	13	14	21	2	3	5	7	11	12	15	20	23	24	25	26	27	28	29	30
Projected Design	Stop	Stop	Stop	Stop	Stop	Stop	Stop	Stop	Arrow	Arrow	Arrow	Arrow	Arrow	Arrow	Arrow	Arrow	None	None	None	None	None	None	None	None
# of Subjects	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
Sample Removed	3	14	3	6	8	1	1	2	0	10	7	3	13	3	3	2	9	2	3	6	3	2	4	10
Sample Not Taken	2	0	2	0	2	1	0	0	1	5	2	2	2	1	1	2	3	2	1	0	2	0	1	1
Responses	25	16	25	24	20	28	29	28	29	15	21	25	15	26	26	26	18	26	26	24	25	28	25	19
Detected	21	15	21	22	20	20	24	9	24	14	21	19	15	16	20	14	13	8	12	12	4	1	1	12
Not Detected	4	1	4	2	0	8	5	19	5	1	0	6	0	10	6	12	5	18	14	12	21	27	24	7

5.2.1 Detection

Participants detected the projected messages at a significantly higher (43.06%) rate than the existing brake light assembly, X^2 (1, N =569) =110.41, p = <0.001>.” The Stop Signs projected message and the Reversing Arrow projected message were detected at a similar rate, X^2 (1, N =378) = 0.002, p = <0.96>.”

Table 4: Projection vs No Projection Detection

Observed Detection of Projected Message			
	Hit	**Miss**	**Total**
Projection	295	83	378
No Projecton	63	128	191
Total	358	211	569
Projection	82.40%	39.34%	
No Projecton	17.60%	60.66%	
Chi Square p =	<0.01		

Table 5: Stop Signs vs Reversing Arrow Detection

Observed Detection of Projected Messages - Between			
	Detected	**Not Detected**	**Total**
Stop Signs	152	43	195
Reversing Arrow	143	40	183
Total	295	83	378
Stop Signs	50.93%	51.19%	
Reversing Arrow	49.07%	48.81%	
Chi Square p =	0.96		

5.2.2 Reaction

Upon detecting the vehicle in reverse, participants reacted slightly faster to projected messages ($M = 1.83$, $SD = 1.21$) than the existing brake light ($M = 2.38$, $SD = 1.47$)

configuration, *t* (25) = 1.72*, p*= .09. The effect of the addition of the projected messages on was small (Cohen's *d* =.38) but led to a mean decrease in reaction time of .55 seconds. Reaction times between the Stop Sign (*M* = 1.80, *SD* = .87) messages and the Reversing Arrow (*M* = 1.87, *SD* = 1.49) projections were not significant, *t* (28) = - 0.23, p= .81 or effective (Cohen's *d* = .06)

Table 6: Mean and Standard Deviations of Reaction time by projection type

	Message			
	Brake Light Only	**Stop Signs**	**Reversing Arrows**	**Stop + Arrows**
Mean Reaction Time	2.38	1.80	1.87	1.83
Standard Deviation	1.47	0.87	1.49	1.21

Chapter 6: Discussion

The addition of the rear projection to the existing messaging when the car is in reverse is an effective form of V2P communication and will keep elderly pedestrians in parking lots safer. Although the change to reaction time was relatively small, the large (42.47%) increase in signal detection will drastically increase safety and decrease the number of situations where an elderly pedestrian is forced to quickly take evasive action. It is inconclusive if elderly pedestrians react faster after detecting a projected message on the ground than they would after detecting the existing brake light system. It also inconclusive if the design of the projected messages effects detection or reaction time in a statistically significant way.

6.1 Design Recommendation

Although the test results showed that the difference between the two proposed designs was not statistically significant, if given the opportunity, a good message design is likely a combination of a linear directional element indicating the path of the vehicle and instructional road signs or verbiage. According to the survey, participants preferred the stop sign to the yield sign and reported to stop for reversing cars, but it leads to questions about the wisdom of a private vehicle commanding a pedestrian to stop. For that reason, something akin to Figure 6-1 would be recommended as the optimal projected message for a reversing AV. Any design within the parameters of what is currently recognizable road symbology will likely have a positive effect on safety.

Many participants said they looked for was motion when scanning a parking lot. It is likely that if the lines moved (perhaps following the intended path of the vehicle), that detection would increase. This should not be confused by a flashing projection, because while younger populations are more likely to notice a flashing light, the same is not true for the elderly [25].

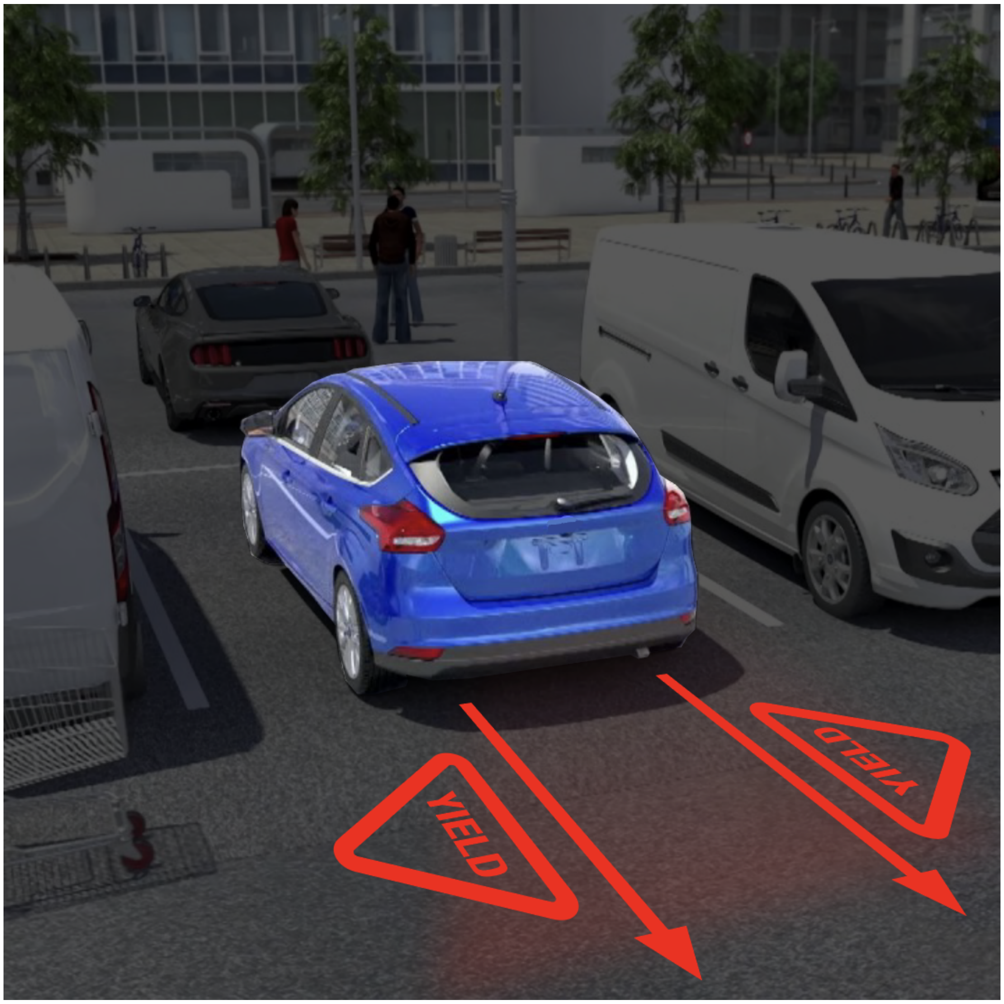

Figure 6-1: Projected Image Final Design Recommendation

6.2 Limitations

The largest limitation of this study is the simulator. There were significant safety concerns about setting up this type of experiment in a real parking lot with real (potentially) reversing vehicles. Accuracy could be increased by evolving the simulator or creating a prototype. An indoor, controlled prototype could be used to achieve accurate eye tracking and distance data, but the element of surprise and the context of a parking lot would be lost.

A more immersive VR-goggle experience could also present high risk to seniors due to VR motion sickness and balance issues.

6.3 Future Work

Future work could increase both the accuracy and scope of the experiment. As previously mentioned, eye tracking and gaze data could be of great benefit. However, testing the Heads-Down Display projected messages in other contexts (nighttime, wintertime, covered parking) and on other populations may prove fruitful. Testing projected messages on participants between 15 and 19 years of age, for whom the rate of pedestrian crashes in parking lots is highest for pedestrians between 15 and 19 years of age [3] could also greatly increase the safety of a vulnerable population. This could also be attempted with young children, for whom collisions result in the highest rate of catastrophe. The projector would also need to be tested on the front of the car, as other age groups are not as uniquely imperiled by back-over accidents.

Another use case of this projection is to grab the attention of a distracted pedestrian looking at their phone. Pedestrians that are texting on their phone are 3.9 times more likely to exhibit a dangerous crossing behavior than those that are not distracted [26]. The addition of a new graphic being displayed behind the phone could potentially grab attention from the phone to the environment.

There are also larger questions about the solution. Would ground plane projection perform better as part of the infrastructure rather than an AV? Would it lessen or exacerbate potential liability issues? In addition, does the level of autonomy, or perceived autonomy, of the vehicle, affect the detection and reaction of the projected messages?

6.4 Implications for V2P Communication

When walking in a parking lot, elderly pedestrians are significantly more likely to detect a projected message on the ground than detect the existing brake light configuration. Adding a projected message designed with a combination of vehicle intent and pedestrian instruction, we can increase detection of and decreasing reaction time to reversing vehicles and make elderly pedestrians can be safer.

Appendix

What follows is the link to the survey

https://umich.qualtrics.com/jfe/form/SV_8iEqBrCNmZCFZvE

What follows are links to samples of the videos watched by VR simulator subjects.

https://youtu.be/mjBl5mS96ww

https://youtu.be/DeK5yEainZI

https://youtu.be/m-5l2E74fbo

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