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THE GEOMETRIC FIELD OF VIEW AND SPEED PERCEPTION IN A DRIVING SIMULATOR

Richard Goodenough
Clemson University, reevegoodenough@gmail.com

THE GEOMETRIC FIELD OF VIEW AND SPEED PERCEPTION IN A DRIVING SIMULATOR

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Richard Goodenough
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Dr. Johnell Brooks, Committee Chair
Dr. Leo Gugerty
Dr. Chris Pagano

ABSTRACT

Particularly in the health and rehabilitation sector where cost and space are constraints, practitioners need smaller driving simulators. Because these small-footprint driving simulators have a limited projected field of view (PFOV) it is desirable to extend the virtual or geometric field of view (GFOV) beyond that natively afforded by the PFOV. Changing the PFOV/GFOV ratio has been shown to alter perceived speed. In order for driving simulation to produce realistic experiences, drivers' perception of speed should correspond with real world experiences. The purpose of the current research was to better understand the relationship between speed perception and the GFOV/PFOV ratio in a way that would be useful to simulation practitioners using a small-footprint driving simulator. Using the DS-250, a small-footprint simulator, participants performed a speed matching task using six different GFOV conditions while the PFOV was held constant. Target speeds were presented in three appropriate simulated environments: 25mph in a residential area, 45mph in a commercial area, and 65mph on a freeway. In general, perceived speed was found to decrease with larger GFOVs. However, no GFOV tested produced accurate speed perception; on average, all participants underestimated their speeds using all GFOVs. A regression was used to estimate at which GFOV average error in speed production would approach zero. Subjective data regarding participant strategy, perceived accuracy, and their awareness of different GFOV conditions were also collected.

DEDICATION

This work is dedicated to my parents, Linda and Richard, my sister, Anna, and my niece, Iris.

ACKNOWLEDGMENTS

I express my gratitude to my advisor and mentor Dr. Johnell O. Brooks for her guidance both before and during the completion of my thesis. I thank Douglas F. Evans for his insight and assistance, as well as my committee members Dr. Christopher Pagano and Dr. Leo Gugerty for their feedback.

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INTRODUCTION

Although high-fidelity driving simulators are optimal for reproducing realistic driving experiences, they are often too expensive and require too much space to be practical outside of research environments. Particularly in the health and rehabilitation sector where cost and space are constraints, practitioners need smaller driving simulators. These smaller simulators must maintain the ability to reproduce rather complex driving scenarios while consuming a smaller footprint. However, there are some constraints inherent to using a smaller simulator, such as the reduced display dimensions, compared to those used in larger driving simulators offering a 360^{o} field of view (FOV).

The DS-250 (DriveSafety, Inc.) was designed to occupy a smaller footprint while maintaining the ability to produce useful driving simulations. The DS-250 forward display configuration consists of three 19” LCD screens. The left and right screens are each 30^{o} off-plane from the center screen such that the center of each screen is equidistant from the driver’s eyes and orthogonal to the driver’s line of sight (see Appendix A). This produces a display measuring 49” horizontally, which yields a horizontal projected field of view (PFOV) of 65^{o}. However, there are many driving situations that would require a horizontal FOV greater than 65^{o}, such as intersection negotiation, making sharp turns, or merging. Therefore, to replicate some of these driving situations in a useful way with this display, increasing the FOV of the virtual world, the geometric FOV (GFOV), is necessary.

However, increasing the GFOV while holding the PFOV constant has been shown to increase drivers’ perception of speed (Adetiloye, Wu, & Mourant, 2005; Mourant, Ahmad, Jaeger, & Lin, 2007; Diels & Parkes, 2009). In general, drivers underestimate their speed and produce higher driving speeds than intended when the veridical GFOV (GFOV/PFOV = 1.00) is displayed. This underestimate tends to decrease with increasing GFOV/PFOV ratios (GFOV/PFOV > 1.00), leading to smaller overproductions of speed, to a point at which the driver begins to overestimate their speed and produce lower driving speeds than intended.

In order for driving simulation to produce realistic experiences, drivers' perception of speed should correspond with real world experiences. If drivers are not able to perceive speed accurately, the behavior of the simulated vehicle is unlikely to match drivers' expectations. That is, if drivers are driving faster or slower than they perceive, the simulated vehicle may react in unexpected ways. For example, a driver underestimating their speed may unknowingly enter a turn at an inappropriately high speed and subsequently lose control. Because drivers' perception of speed increases as the GFOV/PFOV ratio increases, an understanding of this relationship is necessary for a simulator to provide accurate driving experiences in a small-footprint driving simulator. The purpose of the current research was to better understand the relationship between speed perception and the GFOV/PFOV ratio as well as determine at which GFOV/PFOV ratio speed perception would be most accurate using a small-footprint simulator such as the DS-250.

In order to increase the GFOV/PFOV ratio beyond the veridical 1.00, a technique known as *scene minification* is used. Scene minification involves mathematically, in this case rectilinearly, compressing the visual scene afforded by

GFOVs larger than the PFOV such that they can be presented in the same PFOV. In the case of the DS-250, scene minification includes taking the visual scene afforded by GFOVs greater than 65^o and compressing it to be presented on the same display with a PFOV of 65^o.

Recently, a usability study was conducted investigating driver comfort with using GFOV/PFOV ratios beyond and including the veridical ratio of 1.00 in the DS-250 (Brooks, Goodenough, Evans, & Duckworth, unpublished). Twenty-four licensed drivers drove through several different environments such as neighborhoods, rural roads, commercial areas, and freeways using the DS-250. Each drove through the driving environments using four different GFOVs (65^o, 80^o, 95^o, and $110^{o)}$, while the PFOV was held constant, yielding GFOV/PFOV ratios of 1.00, 1.23, 1.46, and 1.69, respectively. For a majority of the drivers 110^o (GFOV/PFOV = 1.69) was the preferred GFOV of the four tested. This finding was surprising because it was hypothesized that few drivers would be comfortable with a 110^o GFOV compressed to subtend the PFOV of 65^o. While not looking at speed perception per se, the researchers did find drivers commenting that speed did not ‘look right’ in some GFOV conditions. Specifically, with smaller GFOVs drivers felt as if they were travelling slower than the speedometer indicated. This was especially true when travelling at low speeds. As the GFOV increased, drivers tended to report a more realistic sense of speed as well as a more satisfactory driving experience. These anecdotal comments inspired the current research to investigate changes in speed perception with changes in the GFOV while holding the PFOV constant.

It has been suggested that speed of self-motion through a given environment is specified, perceptually, by the velocity of optic flow (Lee, 1974; Gibson, 1979). Specifically, there are two components of optic flow velocity specifying the speed of self-motion through a virtual environment: global optical flow rate and optical edge-rate (Larish & Flach, 1990). Global optical flow rate is defined as the ground speed divided by the observer's eye-height, and is thus an intrinsic, 'body-scaled' unit of velocity (Lee, 1974; Larish & Flach, 1990). Optical edge rate can be defined as the number of texture edges crossing a given reference point in the observer's FOV, with higher edge rates specifying greater velocities of self-motion (Larish & Flach, 1990; Diels & Parkes, 2009).

Manipulations of both global optical flow rate and optical edge rate have been shown to affect perceived speed in a virtual environment, with the latter generally having a stronger effect (Larish & Flach, 1990; Warren & Hannon, 1988). In addition, global optical flow rate is independent of changes in texture density, whereas optical edge rate is dependent on both texture density and ground speed, and independent of eye-height (Lee, 1974; Larish & Flach, 1990). Increases in texture density will result in increases in the gain of optical edge rate relative to ground speed, and therefore an increase in the observer's perceived speed.

Perceptually, increasing the GFOV/PFOV ratio has the effect of increasing the texture density in the virtual scene (see Appendices B – D). This increase in texture density inherently increases the gain of optical edge rate in the virtual scene relative to longitudinal velocity. That is, increases in longitudinal velocity incur larger increases in optical edge rate. This difference between the increase in longitudinal velocity and the increase in optical edge rate becomes greater as the GFOV/PFOV ratio increases. This increase in optical edge rate should, in turn, increase the observer's perceived speed.

In a 2007 study by Mourant et al., speed perception was affected by GFOV changes while the PFOV was held constant. Two driving environments were created to produce either low or high optic flow. The low optic flow environment consisted of a straight, two-lane road with a dashed centerline and no other objects (trees, buildings, traffic, etc.). The high optic flow environment was the same as the low optic flow environment except that trees were added to either side of the roadway. Drivers were given the task of matching a target speed of either 30mph or 60mph without feedback from a speedometer. The driving simulator consisted of a display with a 45^o horizontal PFOV. The GFOV levels chosen were 25^o, 55^o, and 85^o, which correspond to GFOV/PFOV ratios of 0.56, 1.22, and 1.89, respectively. Each participant drove each of the 12 (target speed / GFOV) conditions twice and the mean of their selected speeds was used for analyses. Optic flow environment type significantly affected participants' selected speed, with higher speeds being selected in the low optic flow environment. However, the size of this effect was small; selected speeds differed by only 2.4mph between low (without trees) and high (with trees) optic flow environments. The effect of GFOV on selected speeds was also significant. Collapsed across optic flow environment and target speed, participants' selected speeds were found to decrease with increases in GFOV, suggesting that larger GFOVs increase participants' perceived speed. A significant interaction effect of target speed and GFOV was also revealed in which selected speeds decreased at a faster rate with increases in the GFOV/PFOV ratio when the target speed was 60mph compared to when the target speed was 30mph.

The results of the Mourant et al. (2007) study suggest that a relationship between GFOV and drivers' speed perception exists. However, the study included only three levels of GFOV (25^o, 55^o, and 85^o) and only two levels of target speed (30mph and 60mph). While these manipulations were able to produce changes in speed perception, a wider range of GFOV levels and target speeds would likely provide a clearer, more detailed description of the relationship. In addition, the smallest GFOV tested was 25^o (GFOV/PFOV = 0.56), and the largest GFOV tested was 85^o (GFOV/PFOV = 1.89). While decreasing the GFOV below the PFOV for a GFOV/PFOV ratio of less than 1.00 is an interesting manipulation from a basic research perspective, in practice, it is generally desirable to increase the GFOV beyond the limited PFOV in order for maneuvers such as merging, intersection negotiation, and cornering to be possible. In the same vein, in the Brooks et al. usability study (unpublished), a GFOV of 85^o was reported to be too narrow for drivers to comfortably perform such maneuvers. It would also be of interest to investigate whether the interaction between GFOV and target speed extends beyond the GFOV/PFOV ratio of 1.89. The researchers also chose not to include the veridical GFOV of 45^o (GFOV/PFOV = 1.00). Including this GFOV would have allowed speed perception to be evaluated when neither minification nor magnification of the virtual scene are present.

Diels and Parkes (2009) conducted a similar study investigating the effects of GFOV on speed perception. Using a large simulator with a 210^o PFOV, participants were to match a target speed (20mph, 30mph, 50mph, and 70mph) within four GFOV/PFOV ratios (0.83, 1.00, 1.17, and 1.33) without any feedback from a speedometer. Target speeds of 20mph and 30mph were presented in an urban environment, while target speeds 50mph and 70mph were presented in rural environment. The urban environment consisted of generic urban scenery (buildings, street lights, sidewalks, etc.), and the scenery in the rural environment consisted of fields and trees. Participants matched each target speed twice, and the mean of these two selected speeds were used in analysis. In order to compare across target speed conditions Diels and Parkes transformed the selected speeds into a ratio of selected to target speed.

Similar to the results reported by Mourant et al. (2007), selected speeds decreased with increases in GFOV. Participants tended to underestimate their speeds at lower GFOV/PFOV ratios and overestimate their speeds at higher GFOV/PFOV ratios. Unlike the results from Mourant et al. (2007), however, no interaction effect of target speed and GFOV on selected speed was revealed. It is possible the lack of an interaction effect is due to the limited range of GFOV/PFOV ratios tested, from 0.83 to 1.33, whereas in the Mourant et al. (2007) study the range of tested GFOV/PFOV ratios was from 0.56 to 1.89. From the pattern of selected speed data presented in Diels and Parkes (2009; see Appendix E), it appears the interaction of GFOV and target speed on perceived speed may have become significant had the GFOV/PFOV ratios extended beyond 1.33.

It should be mentioned that while the roadway in the urban environment was straight throughout the drive, the rural environment consisted of several “gentle curves requiring the driver to maintain active steering and speed control” (Diels & Parkes, 2009,

p. 2). Because the participant may have received feedback regarding their speed from vehicle stability, these curves may have produced unwanted influences on the participants' perception of speed. That is, rather than basing their selected speed on only the visual information participants may have limited their driving speed due to feedback from vehicle performance. Therefore, to limit feedback from roadway characteristics the current research included only straight roadway environments.

In order to better describe the effect of GFOV on perceived speed, the current research included six GFOV levels including the veridical GFOV of 65^o. Increasing by 15^o from the veridical, GFOVs included 65^o, 80^o, 95^o, 110^o, 125^o, and 140^o. These correspond to GFOV/PFOV ratios of 1.00, 1.23, 1.46, 1.69, 1.92, and 2.15, respectively. In addition, the current research included three target speeds of 25mph, 45mph, and 65mph which correspond to a residential, commercial, and freeway driving environments, respectively. A similar effect of GFOV on speed perception as seen in both Mourant et al. (2007) and Diels and Parkes (2009) was expected. It was hypothesized that as the ratio of GFOV/PFOV increases, perceived speed will also increase. Therefore, using a target speed matching paradigm, as the GFOV/PFOV ratio increases drivers' selected speeds were expected to decrease.

Although the interaction between target speed and GFOV had a significant effect on selected speeds in Mourant et al. (2007), this interaction effect was not present in Diels and Parkes (2009). This lack of an interaction effect is believed to be due to the limited range of GFOV/PFOV ratios tested in Diels and Parkes (2009). Because the current research included GFOV/PFOV ratios up to and including 2.15, nearly twice the highest ratio present in Diels & Parkes (2009), it was further hypothesized that this interaction will be revealed. Specifically, it was expected that the decreases in selected speeds with increases in GFOV/PFOV ratio would be greater when the target speed was 65mph compared to 45mph, and greater when the target speed was 45mph compared to 25mph.

METHOD

Participants

Participants included 24 licensed drivers (11 males, mean age = 19.4, SD = 1.47) with a minimum of 2 years of driving experience (mean years driving = 4, SD = 1.62). Each participant was screened to ensure a minimum of 20/40 high contrast visual acuity. Participants received class credit for participation.

Driving Simulators

The DS-250 consists of a partial cab with a three-screen forward display (see Appendix A). The left and right screens are 30^{o} off-plane from the center screen such that the center of each screen is equidistant from the driver's eyes and orthogonal to their line of sight. This produces a display measuring 49" horizontally, which yields a horizontal projected field of view (PFOV) of 65^{o}. The partial cab includes the driver's seat, dashboard, and full center console and is a reduction of the cab found in the larger DS-600. The participant controlled the vehicle using the steering wheel, accelerator, and brake. During the experimental driving sessions, the instrument cluster was covered with black felt such that participants were not able to receive feedback from the speedometer.

Because practicing on the DS-250 would require a GFOV setting to be used, there was a possibility for speed estimations to be biased toward this GFOV should it be regarded by the participant as the baseline GFOV. Therefore, participants practiced driving on a straight, two-lane rural road using the DS-600 driving simulator. The DS-600 consists of a full cab surrounded by five large screens encompassing 270^o of view. Along with two side-view mirrors and a rearview mirror, the DS-600 provides a 360^o driving PFOV (see Appendix F). The DS-600 requires no visual scene compression.

Target Speed Levels and Driving Environments

Each target speed was presented in a distinct driving environment appropriate for that target speed. Target speeds included 25, 45, and 65 miles per hour. Target speed levels were chosen for their suitability to three distinct driving environments: residential (25mph), commercial (45mph), and freeway (65mph). The target speed of 25mph was presented in a residential environment consisting of a straight, two-lane roadway lined with houses, driveways, and horticulture typically found in a residential setting (see Appendix B). The 45mph target speed was presented in a commercial environment, consisting of a straight, two-lane road lined with multilevel buildings, parking lots, and their entrances (see Appendix C). The target speed of 65mph was presented in a freeway driving environment, consisting of a 6-lane, divided road, lined intermittently with trees and shrubbery (see Appendix D). Each of the roadway environments selected conforms to the Manual on Uniform Traffic Control Devices (MUTCD) standards; this was confirmed by a civil engineering PhD student. The residential and commercial roadways were delineated by a dashed line to the left and a solid line to the right of the driving lane, while the freeway was delineated by dashed lines on either side of the center driving lane. No other traffic or pedestrians were present in any of the driving environments.

Participants could have used a 'landmark strategy' in order to judge when they had reached the target speed. That is, if a participant felt they had reached the target speed when they passed, for example, a particular building in the environment, they may use this landmark then to make speed judgments in subsequent drives in the same environment. To ensure participants would not be able to successfully use this strategy, three different starting locations were created within each driving environment. The participants were briefed on the 'landmark strategy' and it was explained why it would be an unsuccessful strategy due to these different starting locations.

Geometric Field of Views

The GFOVs selected increased from the nominal FOV of 65^o in 15^o increments up to 140^o, yielding a total of six GFOV levels (65^o, 80^o, 95^o, 110^o, 125^o, and 140^o). These correspond to GFOV/PFOV ratios of 1.00, 1.23, 1.46, 1.69, 1.92, and 2.15, respectively.

Field of View and Target Speed Level Driving Trials

The six GFOV/PFOV ratios and three target speed levels yielded 18 experimental conditions. Each of the 18 conditions was presented to the participant three times, producing a total of 54 driving sessions per participant.

The order in which GFOV/PFOV ratio conditions were presented was randomized. In attempt to reduce simulator sickness, participants were presented with all target speeds (25, 45, and 65 mph) within each GFOV/PFOV ratio condition such that the GFOV/PFOV ratio was changed only five times during an experimental session. The target speeds were counterbalanced between participants.

Optic Flow Rate

Measurements were taken regarding the rate at which a textual element passes across the rightmost screen at each target speed using each GFOV/PFOV ratio. A driving scene was created consisting of a straight driving path with a Fiduciary square placed exactly five lateral meters from the center of the simulated vehicle's driving path (see Figure 1 below). The points at which the center of the Fiduciary square crossed the inside edge and outside edge of the rightmost screen were obtained visually by the experimenter and marked using the simulator's coordinate system (mark A and mark B, respectively). The simulator was programmed to travel at a specified constant speed, start a timer when it crossed mark A, and stop the timer when it crossed mark B. This was repeated at each target speed using each GFOV/PFOV ratio. Thus, the time for a textual element to cross the 16.125" horizontal of the rightmost screen for each condition was determined. The times were approximately identical using the leftmost screen. From this, the rate at which a textual element passed across the screen, in horizontal inches of screen per second, was determined.

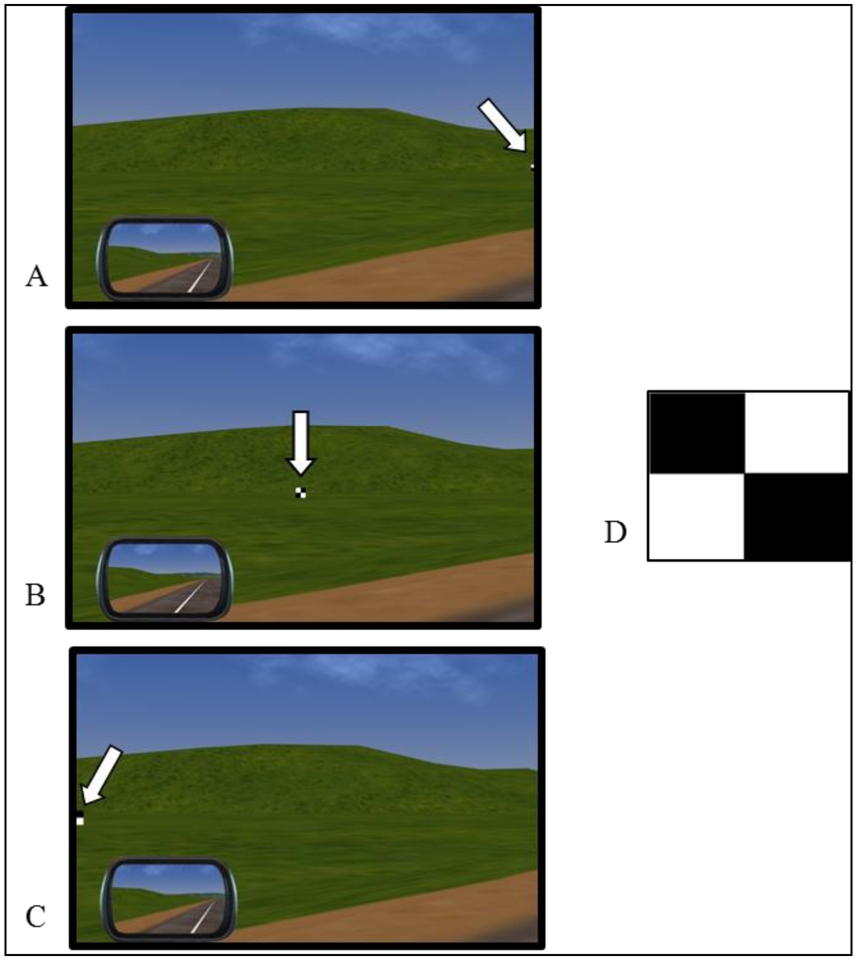


Figure 1. Screen captures from the left display of (A) the point at which the timer would start, (B) the Fiduciary square as it passes the center of the screen, (C) the point at which the timer would stop, and (D) an example of the Fiduciary square used. Note: Arrows added here for visibility.

The relationship between speed, GFOV, PFOV, and optic flow rate was found to be linear (see Figure 2, given by the equation: rate = 0.820 + 0.205(speed * (GFOV/PFOV)), where speed is the longitudinal speed of the simulated vehicle in miles per hour. This model accounts for 99.6% of the variance in optic flow rate.

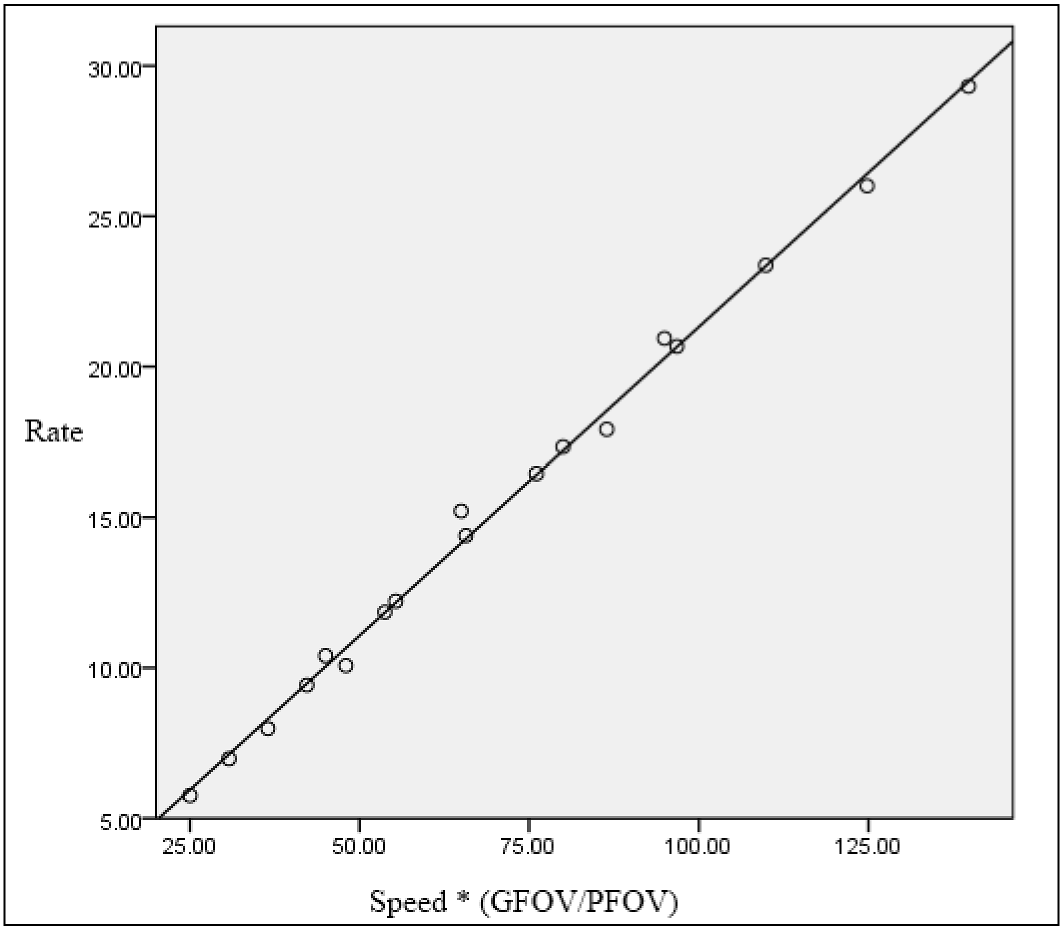


Figure 2. Linear relationship between speed*(GFOV/PFOV) and optic flow rate.

Procedure

After providing consent, each participant was screened for a history of migraines or motion sickness, and asked a series of motion sickness questions from an adapted version of the Motion Sickness Assessment Questionnaire (Brooks et al., in press). To ensure the well-being of the participant, he or she was asked this same set of motion sickness questions following each GFOV/PFOV ratio condition and was required to get out of the simulator for a minimum of 1 minute.

The participant first practiced driving in a simulator using the DS-600 until they were both comfortable driving in a simulator and able to stay in their lane while driving over 65mph for 30 seconds, after which the participant was asked to press one of the two steering wheel buttons. The vehicle then began to decelerate and the message, “Your driving session will now end,” appeared in the center of the forward screen and the driving session ended after three seconds. This is the same message the participant received at the end of each experimental driving session. The participant then moved to the DS-250. After the participant adjusted the seat to the preferred position, the display was moved toward or away from the participant so that the display was 44” from their eyes.

For each of the 54 driving sessions the participant’s task was to match a given target speed. The target speed was told to the participant prior to each driving session as well as presented on the center screen overlaid on the hood of the simulated vehicle during driving sessions (see Appendices B – D). Each driving session began with the vehicle stopped in the center of the driving lane. Participants were encouraged to accelerate and/or decelerate until satisfied they had matched the target speed. Once the participant felt they were travelling at the target speed, they were to press either one of two buttons located on the steering wheel, saving their current speed. Each driving session lasted less than one minute. Following completion of all 54 driving sessions, the participant was asked the following three questions: (1) “Did you notice any changes in the simulation at any time during the experiment?”; (2) “What strategies did you use to complete the speed matching task?”; and (3) “How accurate do you think you were in performing the task on a one to ten scale, one being ‘extremely inaccurate’ and ten being ‘extremely accurate’?” The experiment lasted approximately one hour and thirty minutes.

Prior to driving the first driving session in the DS-250, the participant received the following instructions: “Today you will complete a speed-matching task in this simulator. Before each driving session, I will give you a target speed, which will also be presented on the “hood” of your vehicle in the bottom of the center display. You will try to match three target speeds of 25, 45, and 65 miles per hour. Each target speed will be presented in a different environment. The target speed of 25 will always be presented in a residential environment, 45 in a commercial environment, and 65 on a freeway. Your goal is to match the target speed. It is important to know that you will be starting at different points along the roadway within each environment for each drive. This means that using landmarks to judge when you have reached the target speed will be unsuccessful. For example, if you were trying to match the target speed of 25, and you felt that you were travelling at 25 when you passed a particular house, you may not be travelling at 25 the next time you pass the same house because you started at a different point along the roadway. Please feel free to accelerate or decelerate as much as you like until you are satisfied you have matched the target speed. When you feel you are travelling at the target speed, please press either one of the two red buttons located on the steering wheel. Once you press the button your vehicle will begin to decelerate and you will receive a message reading, ‘Your driving session will now end,’ similar to the message you saw in your practice drive. If you have any questions, please ask them at any time."

RESULTS

Speed Estimate Error

Mean selected speeds for each target speed condition as a function of GFOV/PFOV ratio can be seen in Figure 3.

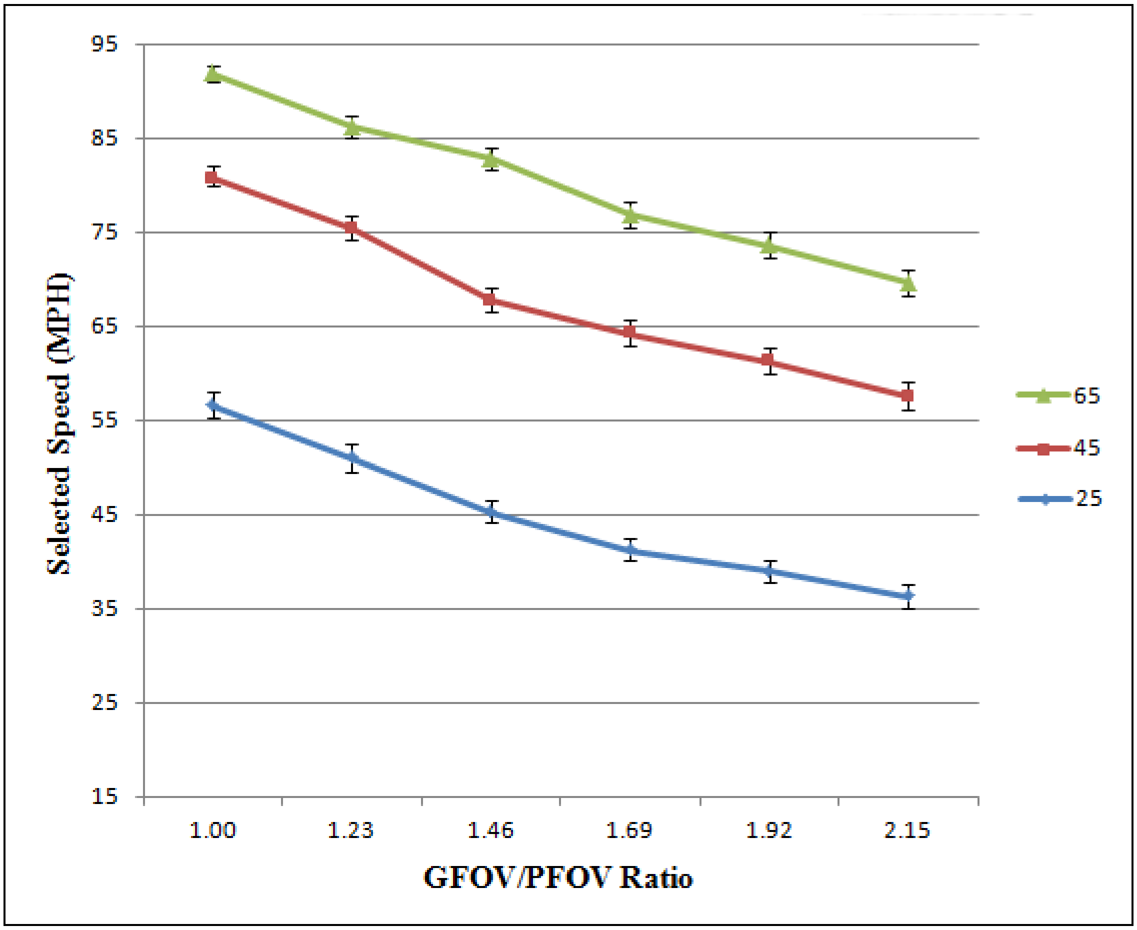


Figure 3. Mean selected speeds within each target speed condition as a function of GFOV/PFOV ratio.

In preparation for analyses, each selected speed was subtracted from its respective target speed, yielding a total of 1,296 participant speed estimate error (SEE) values (54 per participant). Positive SEE values indicate an overestimation of speed, and negative values an underestimation of speed. For example, if the target speed were 25 mph and a participant pressed the button when traveling 55 mph, the SEE would be -30 mph. These 1,296 SEE values were used for only outlier analysis. The SEE data were divided into their respective target speed and GFOV conditions. Z-scores were calculated within each target speed / GFOV condition. No outliers were found using this method.

For all other analyses, each participant's SEE values within a target speed / GFOV condition were averaged, yielding a total of 432 mean SEE (MSEE) values (18 per participant). Mean MSEE values for each target speed condition as a function of GFOV/PFOV ratio can be seen in Figure 4. All mean MSEE values are underestimations of speed, meaning the drivers were traveling faster than the target speed.

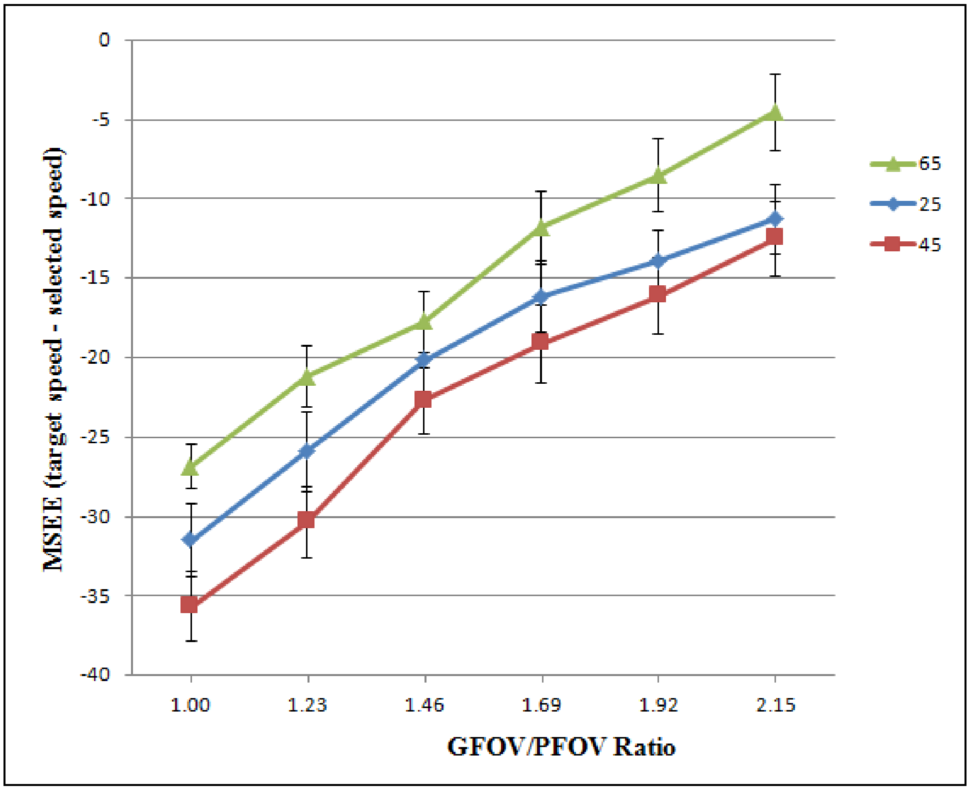


Figure 4. Mean MSEE values within each target speed condition as a function of GFOV/PFOV ratio.

Effect of GFOV/PFOV Ratio and Target Speed on MSEE

Mauchly's test showed the assumption of sphericity was not met within both factors GFOV/PFOV ratio and target speed (X^2 (14) = 27.096, p = 0.019; and X^2 (2) = 7.093, p = 0.029, respectively). Therefore, Greenhouse-Geisser degrees of freedom corrections were applied to estimates of the effects of both GFOV/PFOV ratio and target speed.

A 3 x 6 (target speed x GFOV/PFOV ratio) repeated measures ANOVA revealed MSEE values were significantly affected by both GFOV/PFOV ratio, F(3.976, 91.452) = 71.552; $\eta_p 2$ = 0.757 and target speed, F(1.662, 38.236) = 20.162; η_p^2 = 0.467. The interaction between target speed and GFOV/PFOV ratio was not significant (p = 0.457), indicating that the effect of the GFOV/PFOV ratio was unaffected by changes in the target speed, and vice-versa.

Paired *t*-tests with Bonferroni corrections comparing each GFOV/PFOV ratio condition indicated that, in general, as the GFOV/PFOV ratio increased MSEE values became more positive (see Table 1 and Figure 5). That is, as the GFOV/PFOV ratio increased, selected speeds decreased toward the target speed. All increases in the GFOV/PFOV ratio from 1.00 (M = -31.352) to 2.15 (M = -9.439) yielded positive increases in MSEE values. Except the ratio of 1.92 (M = -12.854), which did not differ from the ratio below of 1.69 (M = -15.707, p = 0.282) or the ratio above of 2.15 (M = -9.439, p = 0.171), MSEE values significantly differed between all other GFOV/PFOV ratios (remaining $p \leq 0.30$; see Table 1).

Table 1

Results of paired t-tests comparing mean MSEE differences between each GFOV/PFOV ratio condition (Bonferroni corrections applied).

GFOV/PFOV Ratio		Mean Difference (MPH)	Std. Error	p
1.00	**1.23**	-5.533*	1.374	**.008**
	1.46	-11.138*	1.461	**.000**
	1.69	-15.644*	1.399	**.000**
	1.92	-18.498*	1.691	**.000**
	2.15	-21.913*	1.893	**.000**
1.23	**1.00**	5.533*	1.374	**.008**
	1.46	-5.605*	1.109	**.001**
	1.69	-10.112*	1.194	**.000**
	1.92	-12.965*	1.097	**.000**
	2.15	-16.380*	1.513	**.000**
1.46	**1.00**	11.138*	1.461	**.000**
	1.23	5.605*	1.109	**.001**
	1.69	-4.506*	.969	**.002**
	1.92	-7.359*	.937	**.000**
	2.15	-10.775*	1.446	**.000**
1.69	**1.00**	15.644*	1.399	**.000**
	1.23	10.112*	1.194	**.000**
	1.46	4.506*	.969	**.002**
	1.92	-2.853	1.129	.282
	2.15	-6.268*	1.799	**.030**
1.92	**1.00**	18.498*	1.691	**.000**
	1.23	12.965*	1.097	**.000**
	1.46	7.359*	.937	**.000**
	1.69	2.853	1.129	.282
	2.15	-3.415	1.241	.171
2.15	**1.00**	21.913*	1.893	**.000**
	1.23	16.380*	1.513	**.000**
	1.46	10.775*	1.446	**.000**
	1.69	6.268*	1.799	**.030**
	1.92	3.415	1.241	.171

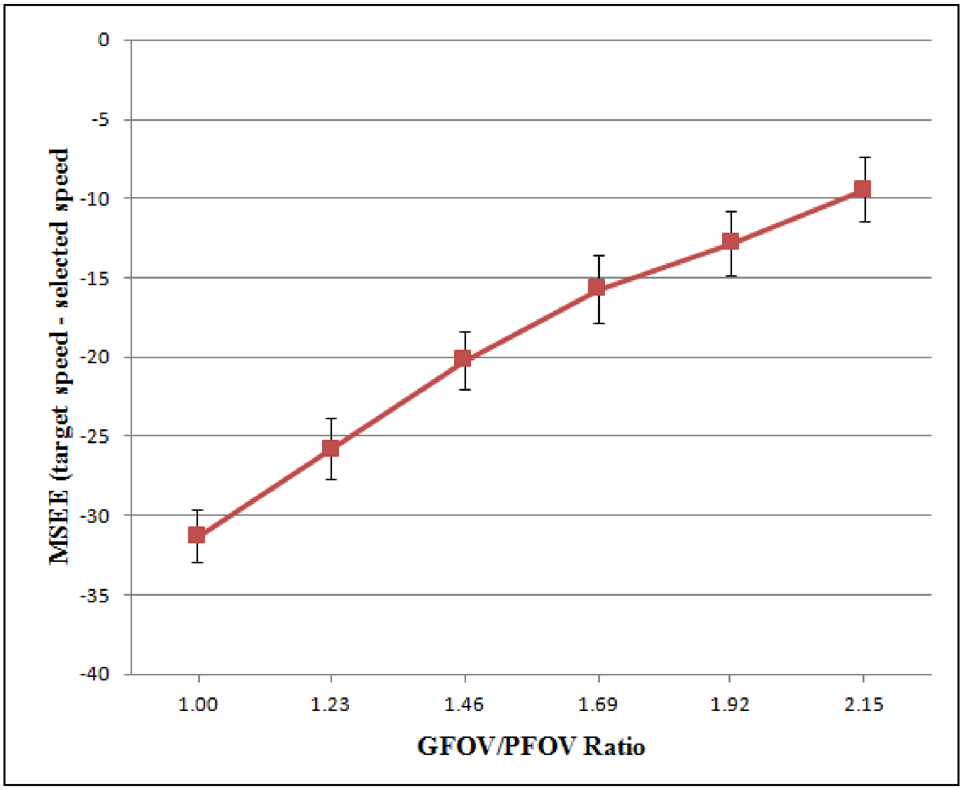


Figure 5. Mean MSEE values as a function of GFOV/PFOV ratio.

Paired *t*-tests with Bonferroni corrections were used to compare target speed conditions (see Table 2 and Figure 6). When the target speed was 65mph, MSEE values were closest to zero (M = -15.112). MSEE values with the target speed of 65 mph were significantly different than MSEE values when the target speed was either 25mph (M = -19.835, p = 0.007) or 45mph (M = -22.746, p ≤ 0.0001). MSEE values were not significantly different between the 25mph condition and 45mph condition (p = 0.126).

Table 2

Results of paired t-tests comparing mean MSEE differences between each target speed condition (Bonferroni corrections applied).

Target Speed (MPH)		Mean Difference (MPH)	Std. Error	p
25	**45**	2.911	1.352	.126
	65	-4.723^{*}	1.374	**.007**
45	**25**	-2.911	1.352	.126
	65	-7.635^{*}	.837	**.000**
65	**25**	4.723^{*}	1.374	**.007**
	45	7.635^{*}	.837	**.000**

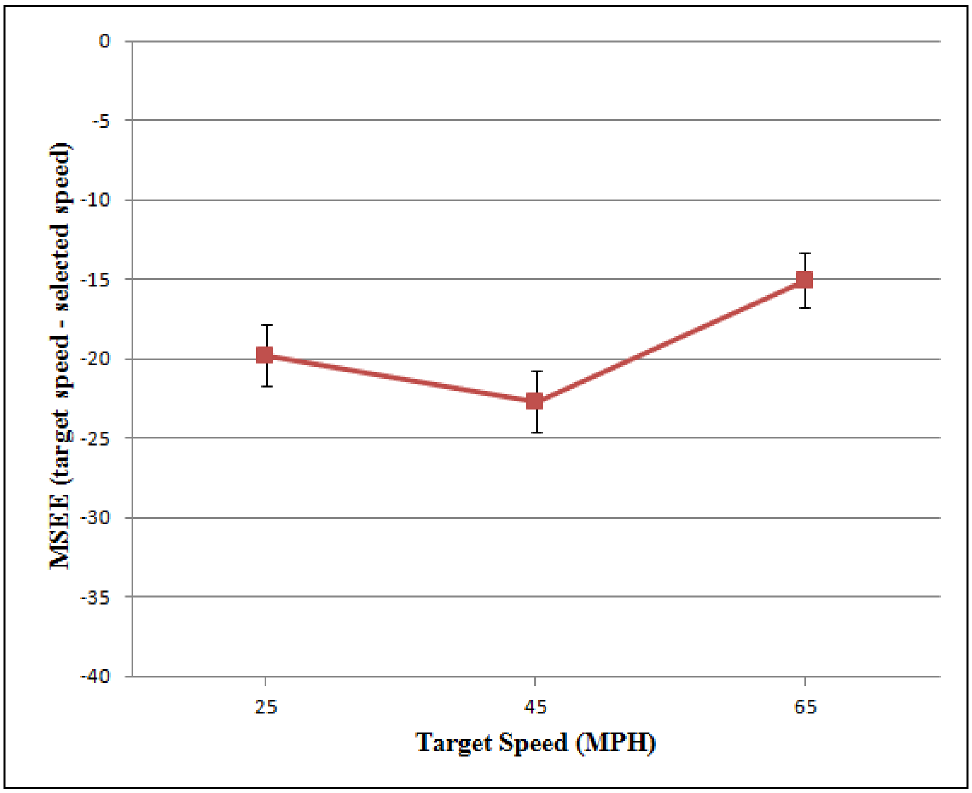


Figure 6. Mean MSEE values as a function of target speed.

Regression of GFOV/PFOV Ratio on MSEE

A linear regression of GFOV/PFOV ratio on MSEE values revealed that the GFOV/PFOV ratio is a significant predictor of MSEE values ($p \leq 0.0001$) and accounts for 31.3% of the variance in MSEE values. The linear model (see Figure 7) predicts that, on average, MSEE values would approach zero if the GFOV/PFOV ratio were 2.59. In the case of the DS-250, this would mean a GFOV of 168.35.

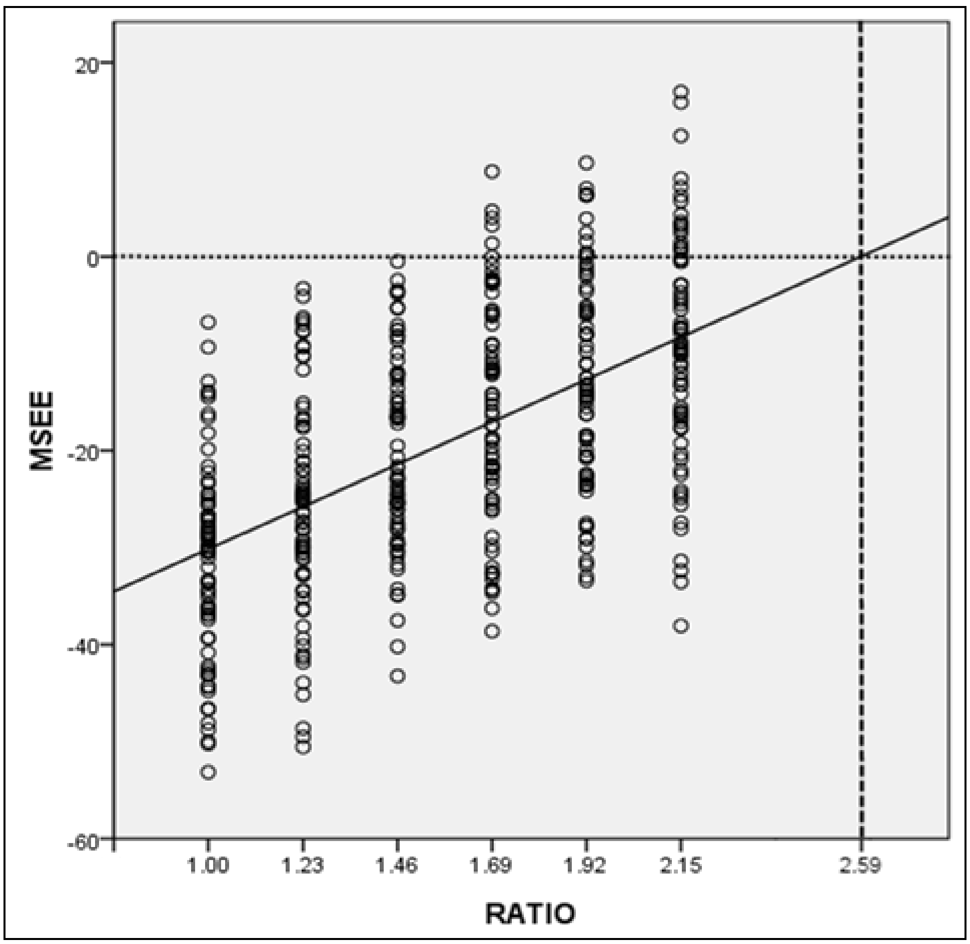


Figure 7. Linear model predicting MSEE from GFOV/PFOV ratio.

Changes in Simulation Cited by Participants

No participants conveyed they had directly noticed changes in the GFOV during the experiment. Of the 24 participants, nine (37.5%) cited no changes in the simulation during the experiment, 14 (58.3%) cited changes in the simulated vehicle's ability to accelerate, and one (4.2%) cited changes in the simulated engine sound.

Subjective Accuracy in Speed Matching Task

On average, participants reported their accuracy to be 5.5 (SD = 1.38) on a scale of one to ten, one being 'extremely inaccurate' and ten being 'extremely accurate'.

Strategies Used to Complete the Speed Matching Task

Participants tended to use one or more of three strategies: 1) 'using optic flow,' 2) 'using the simulated engine sound,' or 3) 'comparing to experience.' A participant's strategy was categorized as 'using optic flow' if he or she mentioned using the speed of the simulated environment passing by to judge speed. For example, 'I looked at how fast stuff went by,' or 'I watched how fast the lines in the road were passing' were categorized as 'using optic flow.' Participants' strategies that included the use of any aspect of the simulated engine sound, such as 'I listened to when the gears shifted' or 'I listened to the engine RPMs,' were categorized as 'using the simulated engine sound.' Any strategy that the participant described as involving a comparison to experience, such as 'I thought about how it feels to drive at the target speed,' were categorized as 'comparing to experience.' A complete list of the statements made by the participants and how these statements were categorized into the three strategies can be found in Table 3 below.

Of the 24 participants, 10 (41.6%) cited ‘using optic flow’ as their only strategy, 2 (8.3%) cited only ‘using the simulated engine sound,’ 2 (8.3%) cited only ‘comparing to experience,’ 5 (20.8%) cited a combination of ‘using optic flow’ and ‘using the simulated engine sound,’ and 5 (20.8%) cited a combination of ‘using optic flow’ and ‘comparing to experience.’

Selected Optic Flow Rates

Using the aforementioned linear model describing optic flow rate, the optic flow rate at the time a participant selected a speed as matching the target speed was calculated (see Figure 8). Mauchly’s test showed the assumption of sphericity was not met for either factors GFOV/PFOV ratio and target speed (X^2 (14) = 31.79, p = 0.019; and X^2 (2) = 7.66,

p = 0.029, respectively). Therefore, Greenhouse-Geisser degrees of freedom corrections were applied. These selected optic flow rates were included as the dependent variable in a 3 x 6 (target speed x GFOV/PFOV ratio) repeated measures ANOVA. Selected optic flow rate was significantly affected by both GFOV/PFOV ratio, F(3.26, 75.08) = 109.36; $\eta_p 2 = 0.826$; $p \leq 0.001$, and target speed, F(1.55, 35.54) = 445.17; $\eta_p^2 = 0.951$; $p \leq 0.001$. The interaction between target speed and GFOV/PFOV ratio was also significant, F(4.82, 110.85) = 31.17; $\eta_p^2 = 0.575$; $p \leq 0.0001$.

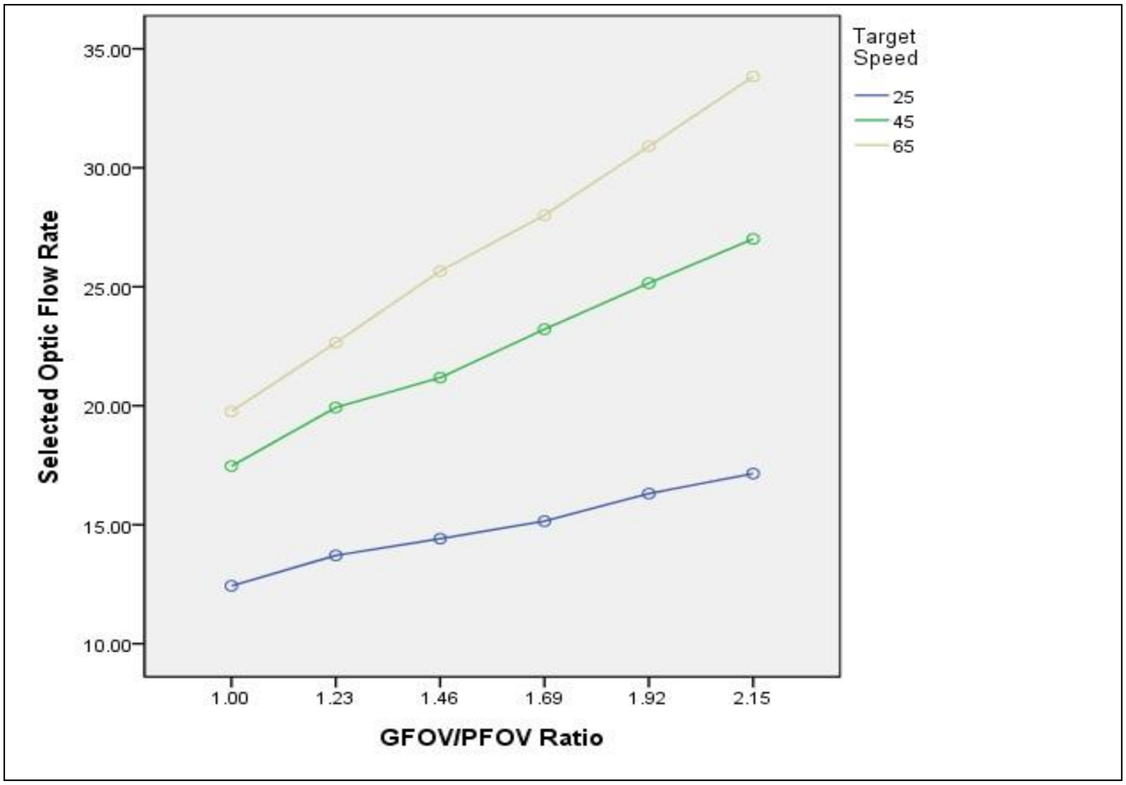


Figure 8. Selected optic flow rates as a function of GFOV/PFOV ratio and target speed.

Table 3
Categorization of statements made by participants regarding strategy.

P	Statement from participant	Categorized as
1	"I looked at how fast stuff was going by; lines and signs"	Using optic flow
2	"I looked at the lines in the 45 and 65; used the houses in the 25"	Using optic flow
3	"Watched stuff going by; listened to RPMs and shifting"	Using optic flow / using simulated engine sound
4	"Watched signs going by"	Using optic flow
5	"First I listened to the shifting, then started watching buildings"	Using optic flow / using simulated engine sound
6	"Intuition; what I was used to; watched lines going by"	Using optic flow / comparing to experience
7	"Used personal experience with how fast you should go in neighborhood, etc."	Comparing to experience
8	"How fast the lines went by"	Using optic flow
9	"Watched center line, light posts, and driveways"	Using optic flow
10	"Watched lines and trees"	Using optic flow
11	"Tried to remember how fast lines should move at different speeds"	Using optic flow / comparing to experience
12	"Used speed of objects and center line; compared to real world"	Using optic flow / comparing to experience
13	"Markers on side of road; stuff going by"	Using optic flow
14	"Speed of passing driveways; looked at lines on freeway"	Using optic flow
15	"How fast things went by; when it shifted gears"	Using optic flow / using simulated engine sound
16	"How fast peripheral stuff went by"	Using optic flow
17	"Listened to engine and shifting gears"	Using the simulated engine sound
18	"Watched points in the distance; engine sound"	Using optic flow / using simulated engine sound
19	"Watched lines on road and surroundings compared to real life"	Using optic flow / comparing to experience
20	"How fast lines and surroundings were going by"	Using optic flow
21	"Compared to real life; how stuff passes by"	Using optic flow / comparing to experience
22	"Thought about roads I knew with those speed limits"	Comparing to experience
23	"Listened to gears shifting"	Using the simulated engine sound
24	"Listened to gears changing; watched lines in mirrors"	Using optic flow / using simulated engine sound

DISCUSSION

As driving simulator markets are opening to clinical settings, it is necessary to minimize the footprint while maintaining functionality. A simulator such as the DriveSafety DS-250 has the benefit of occupying a smaller footprint, making it suitable for settings where space is a precious commodity. However, there are drawbacks inherent to using a small-footprint simulator, such as the reduced display size. In the case of the DS-250, the display provides a horizontal projected field of view (PFOV) of 65^o. With this reduced display size, it is necessary to expand the simulated field of view, or geometric field of view (GFOV) beyond the PFOV afforded by the physical characteristics of the display so that drivers can effectively negotiate roadway configurations such as corners and intersections.

Early usability testing (Brooks et al., unpublished) indicated that senior participants were most comfortable and found speed to be most realistic using a GFOV of 110^o – a GFOV/PFOV ratio (110/65) of 1.69. This result was unexpected. In fact, the GFOV of 110^o was selected as the maximum GFOV tested because it was anticipated that participants would not be comfortable with this condition and would thus isolate a smaller GFOV setting.

The motivation for the current study was to explore the relationship between the GFOV/PFOV ratio and speed estimates in the DS-250 in a systematic manner. Specifically, the purpose of the present study was to investigate how drivers' speed estimates change with changes in the GFOV while the PFOV was held constant.

To this end, 24 university students were given a speed matching task in the DS-250. The task consisted of using the accelerator and/or brake to match the target speed of 25, 45, or 65 miles per hour presented in a residential, commercial, or freeway environment, respectively. These environments consisted of straight roadways with no hills, other traffic, pedestrians, or intersections. Different starting points were used along the roadways within each environment. Each target speed was presented three times using six different GFOV/PFOV ratios of 1.00, 1.23, 1.46, 1.69, 1.92 and 2.15, corresponding to GFOV values of 65^o, 80^o, 95^o, 110^o, 125^o, and 140^o, respectively, for a total of 54 drives per participant. Once the participant completed the drives, a short interview was completed during which he or she was asked to rate their accuracy, whether they had noticed anything change during the task, and what strategies they used to complete the task.

In order to make comparisons across target speed conditions, the participants' selected speeds were subtracted from the respective target speed to produce a speed estimate error for each participant for each drive. Negative values indicate an underestimation of speed, while positive values indicate an overestimation. For example, if the target speed was 25mph and the participant selected a speed of 35mph, the speed estimate error would be -10mph (25 – 35 = -10), signifying the participant underestimated their speed by 10mph. For analyses, these values were averaged across the three drives for each participant within each target speed and GFOV/PFOV ratio condition. This transformation yielded 18 (3 target speeds X 6 GFOV/PFOV ratios) mean speed estimate error (MSEE) values per participant.

Previous research used a different transformation on similar speed estimate data. Specifically, Diels and Parks (2009) transformed speed data by dividing the produced speed by the respective target speed, yielding a ratio of produced to target speed. While the transformation does allow for comparisons across target speed conditions, information regarding the absolute magnitude of the error in speed estimation was lost. This is not the case for the MSEE values used in the current study. To illustrate this point using the example above, the MSEE value for the participant selecting a speed of 35mph when the target speed was 25mph was -10mph and their ratio of produced to target speed would have been 1.40. If that same participant selected a speed of 91mph when the target speed was 65, their MSEE value would have been -26mph, but again their produced to target speed ratio would have been 1.40. From an applied perspective the difference between driving 10mph and 26mph over the intended speed is important.

In the current study, it was hypothesized that as the GFOV/PFOV ratio increased, participants' speed estimations would increase. This pattern of increases in selected speeds as the GFOV/PFOV ratio increased was observed in the current study from a ratio of 1.00 (M_{MSEE} = -31.352) to 2.15 (M_{MSEE} = -9.439), and is consistent with previous research (Mourant et al., 2007; Diels & Parks, 2009). However, participants' MSEE values were all negative within each of the GFOV/PFOV ratio conditions. These negative MSEE values indicate that participants underestimated their speed regardless of the GFOV/PFOV ratio used. That is, participants consistently selected speeds that were faster than the target speed. Overall, the magnitude of the underestimation was reduced with larger GFOV/PFOV ratios, though individual participants rarely correctly estimated or overestimated their speed. All GFOV/PFOV ratios significantly differed from one another except for when the GFOV/PFOV ratio of 1.92 was used (M_{MSEE} = -12.854); MSEE values did not differ from the ratio just below of 1.69 (M_{MSEE} = -15.707) or above of 2.15 (M_{MSEE} = -9.439). This suggests that the reduction in speed underestimation with increases in the GFOV/PFOV ratio may taper off as the GFOV becomes considerably larger than the PFOV. While increasing the GFOV/PFOV ratio can minimize speed underestimations, the strength of this modification may be reduced at higher GFOV/PFOV ratios.

When examining the three speed conditions, participants consistently underestimated their speed. Of the three conditions, the underestimation was the least when the target speed was 65mph (M_{MSEE} = -15.112). MSEE values when the target speed was 65mph were significantly different than MSEE values when the target speed was either 45mph (M_{MSEE} = -22.746) or 25mph (M_{MSEE} = -19.835). However, the difference in MSEE values between the 25mph and 45mph conditions was not significant. This difference in MSEE values between the target speed of 65 and the target speeds of both 25 and 45 may have been produced by the simulated vehicle dynamics. The average selected speed of 85.112mph (65 + $|MSEE_{65}|$) approaches the simulated vehicle's upper limit in velocity (approximately 95mph). At such velocities, the simulated vehicle's acceleration rate would have been substantially lowered to the point that it may appear to the driver that they were no longer accelerating. This subtle aspect of the simulated vehicle dynamics may have set an upper bound on the speeds participants selected in the 65mph condition. If the vehicle had accelerated at a constant rate, regardless of speed, participants' speed estimates may have been closer to those observed in the 25mph and 45mph conditions.

Further support for this explanation can be found in Mourant et al. (2007). While efforts were made in the current study to create environments with reasonably similar optic flow profiles without drastically changing the environments, the freeway environment used in the 65mph condition could still be said to have a lower density of objects along the roadway compared to the residential and commercial environments used for the 25mph and 45mph conditions, respectively. Therefore, it would be expected that participants select higher speeds in the freeway environment compared to both the residential and commercial environments. However, this was not the case. This suggests some factor other than the optic information was influencing participants' speed estimates; this factor may have been the simulated vehicle's acceleration rate.

It was further hypothesized that an interaction would be observed in which MSEE values would increase more quickly with increases in the GFOV/PFOV ratio when the target speed was 65 mph as compared to 45mph, and more quickly when the target speed was 45mph compared to 25mph. However, this was not observed. Changes in the target speed did not alter the effect of the GFOV/PFOV ratio on participants' speed estimates. This lack of an interaction conflicts with similar research by Mourant et al. (2007). The reason for these differing findings may be attributed to differences in the simulated driving environments used.

Using a similar protocol as the current study, Mourant et al. (2007) found that estimated speeds decreased more quickly at a higher target speed (60mph) with increases in the GFOV/PFOV ratio as compared to a low target (30mph) speed. Mourant et al. presented these two target speeds using three GFOV/PFOV ratios of 0.56, 1.22, and 1.89. The two simulated driving environments used by Mourant et al. were not very different, one environment consisting of a roadway with evenly spaced trees along the side and the other without these trees. However, unlike the current study, Mourant et al. presented both target speeds of 30mph and 60mph in both driving environments. Furthermore, the way in which experimental trials were ordered by Mourant et al. (2007) made it likely that participants would consecutively try to match the same target speed in the same environment using different GFOV/PFOV ratios. The procedure and driving environments used by Mourant et al. may have allowed participants to make direct comparisons of the changes in optic flow between GFOV/PFOV ratio conditions. Making the changes in the gain of optic flow rate relative to velocity more obvious potentially enhanced the interaction between GFOV/PFOV ratio and target speed.

In the current study, driving environments were selected based on their suitability to the target speeds in order to make the findings more useful to driving simulation practitioners. Each simulated environment was purposely created to be appropriate for each target speed based on MUTCD guidelines. Also, it was ensured that no participant was consecutively presented with the same environment at different GFOV/PFOV ratios.

The Diels and Parks (2009) protocol more closely matches that of the current study in which different target speeds were presented in context appropriate environments. Diels and Parks (2009) presented participants with four different target speeds. The target speeds of 30mph and 70mph were presented in a rural environment, while 20mph and 50mph were presented in an urban environment. Each of these target speeds was presented using GFOV/PFOV ratios of 0.83, 1.00, 1.17, and 1.33. The speed estimates presented in Diels and Parks appeared to be decreasing with increasing GFOV/PFOV ratios at a slightly faster rate in the higher target speed conditions compared to the lower target speed conditions. However, Diels and Parks did not find a significant interaction between target speed and GFOV/PFOV ratio. The significant interaction between target speed and GFOV/PFOV ratio was hypothesized in the current study due to this pattern of speed estimate presented in Diels and Parks. It appeared their lacking this interaction may have been due to limiting the range of GFOV/PFOV ratios used to 0.83 to 1.33, a difference of 0.50. It was assumed that if this pattern were to continue beyond the GFOV/PFOV ratio of 1.33, the interaction would have been significant. Because the range of GFOV/PFOV ratios used in the current study from 1.00 to 2.15 was considerably larger, a difference of 1.15, this interaction was expected to exist here. The lack of an interaction in the current study as well as in Diels and Parks, along with the significant interaction in the Mourant et al. (2007) may indicate that one can expect the changes in speed estimates due to changes in the GFOV/PFOV to remain relatively stable between various speeds so long as those speeds are presented in different driving environments.

Subjective data collected at the conclusion of the driving simulator task may help to clarify some of the findings as well as suggest ways to improve the methodology of the current study from a basic research perspective. The subjective data regarding whether or not participants noticed the changes in the GFOV/PFOV ratio during the experimental trials indicates that no participant directly identified these changes. This is likely due to the fact participants never consecutively drove through the same simulated environment using different GFOV/PFOV ratios, limiting their ability to easily make direct comparisons between GFOV/PFOV ratio conditions. Participants also began each drive at different points along the roadway. Because participants were made aware of these different starting points before beginning the experimental sessions, they may have attributed the changes they saw in the display to changes in their starting location. Referring to Appendices A - C it can be seen how it is plausible for a change in the scene due to a change in the GFOV to be mistakenly attributed to a change in one's location along the roadway.

Moreover, participants who reported they did notice something change credited the changes to differences in the simulated vehicle's ability to accelerate. This is what one would expect to find with changes in the gain of optic flow relative to simulated vehicle velocity. That is, the increase in the velocity of optic flow becomes larger compared to the increase in the simulated vehicle velocity as the GFOV/PFOV ratio increases. This gain in optic flow, therefore, provides illusory visual information that the simulated vehicle is accelerating at a faster rate at higher GFOV/PFOV ratios compared to lower ratios. This also suggests that participants were attending to the simulated vehicle's acceleration rates during the experiment. Additionally, the pattern of MSEE values between target speed conditions suggests participants' speed estimates may have been influenced by the simulated vehicle's acceleration rate. Specifically, the MSEE values when the target speed was 65mph ($M = -15.112$) were closer to zero as compared to when the target speed was either 25mph (M = -19.835) or 45mph (M = -22.746). One of the aforementioned reasons for this pattern is that at higher speeds it may have seemed as though the simulated vehicle was no longer accelerating. Along with the subjective data indicating participants were noting acceleration rates, this pattern suggests future studies may want to consider altering the simulated vehicle's dynamics such that acceleration rates were constant regardless of velocity. This may have helped to limit the speed information participants were able to receive through the simulated vehicle's dynamics rather than through only the optic flow. While this would have enhanced the current study's ability to answer basic research questions pertaining to how speed perception is affected by changes in the optic flow, it would also have altered the simulated vehicle characteristics to be entirely unrepresentative of how vehicles perform. That being said, it is important to remember one of the main goals of the current research was to provide useful information to driving simulation practitioners and changing the simulated vehicle dynamics in an unrealistic way would have limited the practical utility of the findings.

The strategies participants cited using to complete the speed matching task point out that optic flow is often consciously used to judge speed. However, it also appears it is not the only information used. While many participants (N = 10) cited using only the speed of the simulated environment passing by to judge their speed (later categorized as 'using optic flow'), others cited using the simulated sound of the engine (N = 2), comparing to experience (N = 2), or a combination of using optic flow and either the simulated engine sound (N = 5) or comparing to experience (N = 5). The fact that participants cited using the simulated engine sound as part of their strategy suggests that muting the sound would have also limited extraneous speed information. Eliminating audial information specifying speed would be beneficial from a basic research perspective, though from a practical perspective this creates a relatively unrealistic task. Modifying aspects of the simulation such as the simulated vehicle's acceleration rate and muting the simulated engine sound may have limited the speed information participants received, but it would have also limited the practical efficacy of the findings.

The participants' estimates regarding how accurate they were in the speed matching task emphasize some important characteristics of the task itself. The mean rating of 5.5 on a one to ten scale, one being 'extremely inaccurate' and ten 'extremely accurate,' suggests that participants were unsure how well they performed. This could be because participants received as little feedback as possible regarding the accuracy of their speed estimates. In addition, these subjective accuracy ratings highlight the general difficulty of estimating one's speed in a driving simulator (Hurwitz, Knodler, & Dulaski, 2005; Kemeny & Panerai, 2003).

A regression of GFOV/PFOV ratio on MSEE values was conducted to determine at what GFOV/PFOV ratio speed estimates would be most accurate. This linear model suggests that if one were to use a GFOV/PFOV ratio of 2.59, MSEE values would approach zero. That is, at this GFOV/PFOV ratio drivers are expected to, on average, estimate their speed with approximately zero error. In the case of the DS-250 this would mean using a GFOV of 168.35^{o}. Though this GFOV/PFOV ratio is predicted to produce the least amount of error in speed estimation, it is important to consider that the data used to produce the model were acquired using simulated environments that consisted of only straight roadways. These environments did not include hills, turns, intersections, traffic, pedestrians or other such complexities typically found in driving scenarios used by practitioners.

While the model suggests that speed estimation will be most accurate in the DS-250 using the rather large GFOV of 168.35^{o}, it does not include important information regarding other performance measures and drivers' comfort levels. Although the ability to accurately estimate one's speed is highly important in driving simulation, it is only one aspect of the multiple elements that make driving simulation useful to practitioners. Factors important to driving simulation practitioners including gap acceptance, braking performance, distance perception, lane keeping, and drivers' comfort levels may also be affected by changes to the GFOV/PFOV ratio.

It is also important to recall that when comparing speed estimates between GFOV/PFOV ratios, there were no differences in MSEE values between the ratio of 1.92 and the ratios of 1.69 or 2.15. This suggests there may be a limit to how effective increasing the GFOV/PFOV ratio will be in reducing speed estimate error, as the effect of reducing speed estimates may taper off beyond the ratio of 1.92. Therefore, future research should assess the efficacy of using a GFOV/PFOV ratio of 2.59 to minimize speed estimate error as well as investigate how other important aspects of simulated driving are affected by changes in the GFOV/PFOV ratio. Along with the findings presented in the current study, this would give practitioners as well as researchers a much clearer understanding of how changing the GFOV/PFOV ratio in a small-footprint driving simulator affects its practical viability.

APPENDICES

Appendix A

The DS-250 Display Configuration

Appendix B

Screen Captures from Each Screen in the 25mph Driving Environment at Each GFOV/PFOV Ratio

$65^{o}/65^{o} = 1.00$

$80^{o}/65^{o} = 1.23$

$95^{o}/65^{o} = 1.46$

$110^{o}/65^{o} = 1.69$

$125^o/65^o = 1.92$

$140^o/65^o = 2.15$

Appendix C

Screen Captures from Each Screen in the 45mph Driving Environment at Each GFOV/PFOV Ratio

$65^o/65^o = 1.00$

$80^o/65^o = 1.23$

$95^o/65^o = 1.46$

$110^o/65^o = 1.69$

$125^o/65^o = 1.92$

$140^{o}/65^{o} = 2.15$

Appendix D

Screen Captures from Each Screen in the 65mph Driving Environment at Each GFOV/PFOV Ratio

$65^{o}/65^{o} = 1.00$

$80^{o}/65^{o} = 1.23$

$95^{o}/65^{o} = 1.46$

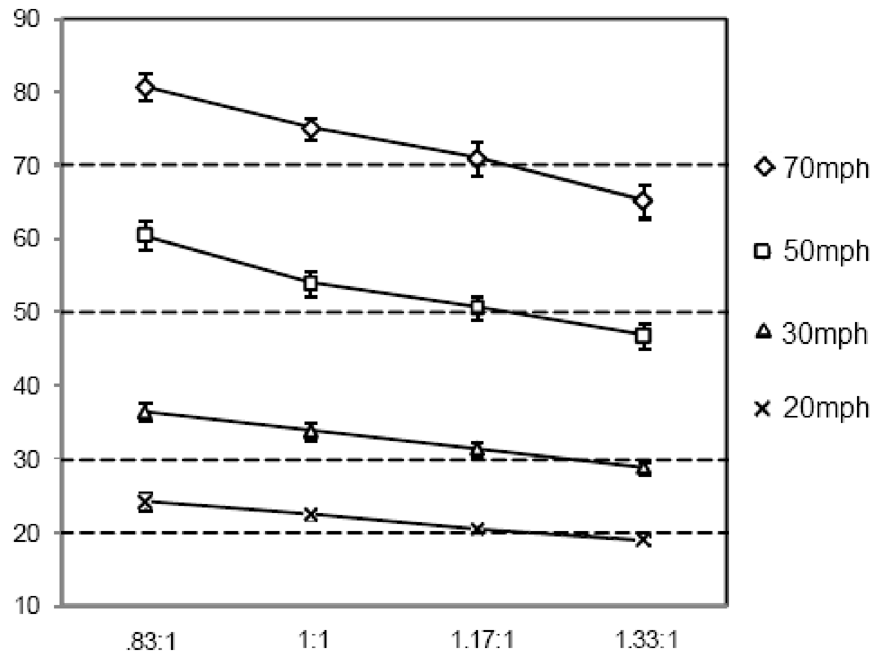
$110^{o}/65^{o} = 1.69$

$125^{o}/65^{o} = 1.92$

$140^{o}/65^{o} = 2.15$

Appendix E

Mean Selected Speed for Each Target Speed as a Function of GFOV/PFOV Ratio (from Diels & Parkes, 2009)



Appendix F

The DS-600 Display Configuration.

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