https://doi.org/10.2352/EI.2025.37.11.HVEI-199

Impact of Camera height and Field-of-View on distance judgement and gap selection in digital rear-view mirrors in vehicles

Felix Thulinsson[a,b], Niclas Söderlund[a,b], Shirin Rafiei[a,d], Bo Schenkman[a,c], Anders Djupsjöbacka[a], Börje Andrén[a] and Kjell Brunnström[a,d]
[a]Department of Industrial Systems, RISE Research Institutes of Sweden, Kista, Sweden,
[b]Faculty of Science and Technology, Uppsala University, Uppsala, Sweden,
[c]Department of Speech, Music and Hearing, KTH Royal Institute of Technology, Stockholm, Sweden,
[d]Department of Computer and Electrical Engineering (DET), Mid Sweden University, Sundsvall, Sweden

Abstract

This study investigates how different camera perspectives presented in digital rear-view mirrors in vehicles, also known as Camera Monitor Systems, impact drivers' distance judgment and decision-making in dynamic driving scenarios. The study examines (1) the effects of field of view and (2) camera height on drivers' ability to judge distances to rearward vehicles and to select safe gaps in potentially hazardous situations. A controlled lab-based video experiment was conducted, involving 27 participants who performed distance estimations and last safe gap selections using a simulated side-view mirror display. Participants viewed pre-recorded driving scenarios with varying combinations of field of view (40°, 76°, 112°) and camera heights (1 meter, 2.3 meter). No significant effects were found for camera height, but wider field of views led to more accurate distance estimations. However, the use of a wider field of view also increased the risk of potentially dangerous overestimations of distance, as evidenced by the last safe gap results. This suggests that a wider field of view leads to the selection of smaller and potentially risky gaps. Conversely, narrow field of views resulted in underestimations of distance, potentially leading to overly cautious and less efficient driving decisions. These findings inform Camera Monitor Systems design guidelines on how to improve driver perception and road safety, to reduce accidents from vehicle distance misjudgments.

Introduction

Camera monitor systems (CMS) or digital rear-view mirrors is a technology that has the potential of enhancing road safety by eliminating blind spots and reducing the risk of accidents. It also has the potential of reducing CO_2 emissions through improved vehicle aerodynamics, which has become a prioritized vehicle design parameter due to larger geopolitical trends and policies [1]. The general idea of the CMS is to replace conventional side rear view mirrors in vehicles with cameras that live stream video of the rear and side view to display monitors inside the coupe [1].

Being aware of one's surroundings is crucial for informed decision making and safe driving. For example, in Germany, it is assumed that about 9,500 serious road accidents are caused annually by motorists who are not sufficiently aware of the traffic behind them in lane changing situations [1].

There are several practices and tools commonly leveraged by drivers to gather information about their surroundings in different traffic situations, to avoid accidents. Checking the rearview side mirror for approaching cars before changing lanes is one step; turning your head to check the blind spot before lane changing is another. The rearview mirror provides the driver with indirect vision. The driver can gather information about the surroundings which would otherwise be outside of the driver's field of view (FOV). By implementing a CMS, the indirect vision of drivers can be optimized and expanded, allowing for greater flexibility in adjusting FOV and camera height compared to conventional mirrors [1].

Beyond the promises of potential benefits offered by a new technology such as CMS, several questions arise. Mirrors and displays are fundamentally dissimilar and interact with human perception very differently. The flat, two-dimensional nature of digital displays can distort spatial relationships and does not necessarily provide the same depth information as mirrors. Binocular vision is not available when using displays and some authors [1, 2] points out that depth perception of the environment behind the car plays an integral role in several common traffic situations, such as parking, making a stop, lane change, merging into traffic and overtaking.

Some of these situations have a higher risk for fatal consequences, particularly those involving vehicles at higher speeds, such as lane changes occurring when merging into traffic or overtaking other vehicles. Any maneuvers when traveling at higher speeds are potentially dangerous, as poor decisions may result in hazardous situations. A parameter which could influence depth perception is perspective [3, 4]. Hence, more research is motivated to understand how different perspectives provided by automobile manufacturers, such as camera height and field of view (FOV), could affect depth perception in CMS. FOV and camera height could result in depth perception and distance judgment potentially leading to dangerous driver decisions with fatal consequences [5].

This study examines how the visual perspective, specifically camera height and FOV may influence driver depth perception and decision-making in dynamic driving situations. The following research questions were formulated:

- How do FOV and camera height in CMS influence drivers' distance judgement with regard to rearward vehicles?
- How do FOV and camera height in CMS influence drivers' gap selection in potentially dangerous driving situations?

This paper is based on the M.Sc. thesis by Thulinsson and Söderlund (2024) [6]: For further details see the thesis report.

Method

Experimental design

An exploratory within-subject study was designed to investigate the research questions empirically. To address the research questions, visual perspective was broken down into a combination of two parameters: camera height and field of view (FOV). A controlled lab-based video experiment explored the perspective parameters. This method was chosen in favor of a virtual rendered environment. The primary reason was that video resembles real world CMS applications more accurately, since CMS is live-streamed video from an external camera. The previous studies by Bernhard et al. [3, 7, 8] have yielded somewhat contradictory results, highlighting the complexity of the human-machine interaction at play. The experiments by Bernhard and Hecht (2021) [7] have evolved to become increasingly ecological, closely resembling a real-world driving experience. It was thus decided that an experiment with an actual CMS-style video would be relevant, of interest, and would increase the validity of the study.

Two sessions

The empirical study consisted of two different sessions, both focused on CMS as indirect vision in lane changing situations, with one session focusing on distance estimation and one session focusing on last safe gap (LSG) selection. This was done to address both research questions, depth perception and decision making. An action based LSG task was considered more ecologically valid when reviewing previous research (Bernhard et al. [3, 8]). The session focused on distance estimation will be referred to as session **Dist**, while the session focused on last safe gap selection will be referred to as session **LSG**. The order in which the participants completed the two different sessions was alternated, with 13 participants starting with Dist and 14 starting with LSG. Within each session, the order in which the sequences with different CMS perspectives were displayed was randomized. Both sessions followed a repeated measures design. Each participant was exposed to all combinations of the independent variables in each session once.

Independent variables

Camera height

The independent categorical variable *camera height* had two levels, the first being "high" which was recorded with the camera located at a height of 2.3 meters from the ground, the second being "conventional" which was recorded with the camera located at a height of 1 meter from the ground. The *camera height* of 2.3 meters was the maximum height achievable with the truck used for the experiment, while 1 meter was chosen as a reference of a regular passenger car. Since previous studies that had investigated small vertical displacements without reaching statistical significance, our decision was intended to increase the chances of detecting any significant effects of *camera height*. The values for the independent categorical variable *camera height* were the same for both session **Dist** and session **LSG** in the experiment.

Camera field of view

The independent categorical variable *FOV* had three horizontal levels, 112 degrees, 76 degrees and 40 degrees. A maximum *FOV* of 112 degrees for the CMS was chosen as this would be enough to eliminate the blind spot and still provide a reference of the driver's vehicle. A traditional rearview mirror offers a FOV of approximately 15–20 degrees from the average driver's position, but it also allows the driver to expand the FOV by moving the head. The minimum *FOV* for the CMS in the experiment was set to 40 degrees, since the *FOV* is fixed with CMS and cannot be increased with head movement. The *FOV* of 76 degrees was chosen as it lies in the middle between 112 and 40 degrees. The values for the independent categorical variable *FOV* were the same for both session **Dist** and session **LSG** in the experiment.

Perspectives

The two independent categorical variables *FOV* and *camera height* were combined to create six unique perspectives, namely [high112, high76, high40, low112, low76, low40].

Session Dist

In session **Dist** the vehicle showing the test participants point of view, is travelling at a constant speed of 90 km/h in the right lane of a two-lane highway. In the left rearview mirror, a car is seen trailing at a constant distance. The vehicle showing the point of view of the participant will from now on be referred to as the "ego vehicle". The participants were informed that the trailing vehicle was at a constant distance throughout the sequence, but the participant was not informed about at which speed their own and the trailing vehicle was travelling at. The participants were instructed to position the vehicle within the lane as appropriately as possible using the steering wheel, as if they were driving the car. Participants were informed that the steering wheel did not affect the movement of the vehicle in the simulation and that it did not register any data. Session **Dist** was designed to explore how well the participants could estimate distances using different perspectives. A total of three real distances were tested, 16, 31 and 39 meters. The independent variables *FOV* and *camera height* in combination with the *Real Tested Distances* amounted to a total of 18 distance estimation data points collected in session **Dist**. The data points collected were used to compute the dependent variables *absolute distance estimation error (meter)* and *relative distance estimation error (%)* used later in the analysis. The dependent variable *absolute distance estimation error* was of interest to us, as this measurement had been explored in the studies by Bernhard et al. [3, 8]). However, apart from the comparability of *absolute distance estimation error*, *relative distance estimation error was preferred. Absolute distance estimation error is* less comprehensible due to longer tested distances being correlated with greater variance. *The relative distance estimation error* provides a more comprehensible and fair straightforward comparison between the different FOVs and the dependent variable. This decision is also in line with the psychophysical Weber- Fechner law. Weber's law states that the just noticeable difference is a constant proportion of the original stimulus intensity. Fechner's Law suggests that perceived intensity grows logarithmically with the actual stimulus intensity, reinforcing the idea that perception is more sensitive to proportional changes than absolute ones. Thus, when experiments involve measurements that vary greatly in magnitude, relative error provides a more meaningful measurement with higher accuracy. It shows how significant an error is relative to the actual value, since our perception of stimulus changes is proportional to the initial stimulus level [2].

Session LSG

In Session **LSG** the ego vehicle is travelling at constant speed in the right lane of a two-lane highway with a car approaching from the rear. The participants were not informed of the speed at which their own, or the overtaking vehicles, were traveling. Each participant was instructed to position the vehicle within the lane as appropriately as possible using the steering wheel, as if he/she was driving the car. In case the participants asked, they were informed that the steering wheel did not gather any movement data. The task for the participant was to indicate the last moment at which he or she deemed it safe to switch lanes and turn out in front of the approaching car. This task is known as last safe gap [8]. The **LSG** judgement was indicated by pressing a paddle shifter on the steering wheel, which automatically stored the time frame in a data file. The paddle resembles the action of pressing the turn signal lever, thereby increasing the ecological validity of the experiment.

A total of three recorded unique traffic scenarios were used for this session of the experiment. As the tasks in session **LSG** were based on recordings of three unique traffic scenarios, an additional independent control variable alongside the perspective variables was introduced. This variable was named *environment*. Each *environment* was edited to make composites of each unique perspective which resulted in 18 different composite LSG sequences being displayed to the participants (*environment * camera height * FOV* = 3*2*3 = 18). The independent variable *environment* was introduced to control for any effect that the depicted traffic scenario might have on the decisions of the participants. The data points for LSG collected in this session were used to compute *time to contact (TTC)*, which was the independent variable in the analysis. The *TTC* refers to the time in seconds until the front of the overtaking vehicle reaches the back of the ego vehicle.

Participants

A total of 27 participants (18 males and 9 females) were recruited as test persons for the main study. The age range was between 23 to 64 years with a mean age of 38 years and a median of 29. The participants were found by recruiting acquaintances and through advertising at the platform Accindi, a platform for finding persons volunteering as test persons for studies [9]. The test participants were informed that each of them would receive a gift certificate for their participation, with the value of 100 SEK. All participants had a valid driver's license. Demographic and driving experience data was collected on participants' age, annual kilometers driven, gender and license time. The time of holding a license varied from one year to 46 years, with a mean of 18 and a median of 9.5. The yearly distances driven by the participants, were estimated by ten persons to be between 0 – 5000 km, seven to be between 5000 – 10000 km, nine to be between 10000 – 20000 km and one to above 20000 km.

Materials and video preparation

Equipment and software for video preparation

For the recording of the rear-view videos with different camera heights two GoPro Hero 12 Black were used, which were mounted at different heights and recorded simultaneously. The videos were recorded in 4K (3840 x 2160 pixels) with 60 frames per second (FPS) and a FOV of 112 degrees. The different FOVs were produced by cropping. The front view was recorded with a GoPro Hero 8 in HD resolution, i.e., 1920 x 1080 pixels in 60 FPS and 120 degrees FOV. 38 different videos for the experiment were prepared by using Adobe After Effects.

Ego vehicle

The vehicle from which the participants experienced the driving was called the ego vehicle [10]. We selected a light truck Iveco Daily, because it had a side profile that was high enough (> 2 meters i.e. 2.7 meters) almost vertical (slightly curved < 0.05 difference between lenses) with a flat surface. The interior space provided sufficient mounting solutions for the forward view camera.

Camera mounting

The conventional camera was mounted at a height 1 meter from the ground to the lens, as shown in Figure 1. This is the same as in a recent study prior to this project [3] and represents a common height for conventional mirrors in passenger cars. The high camera was mounted at a height of 2.3 meters from the ground, resulting in a vertical displacement of 1.3 meters between the two camera heights.

Figure 1: (left) Mounting of conventional (bottom) and high (top) camera heights. (right) Mounting for the conventional camera position, with the lens at a height of 1 meter from the ground.

While the camera at the conventional *camera height* was tilted slightly up, the camera at the high *camera height* was tilted slightly down to have the horizon at roughly the same ratio of the image. This alignment was made for keeping consistency in the visual information for both height settings. The cameras were adjusted to capture similar portions of the vehicle.

The interior camera was mounted to give a forward view, to resemble the viewpoint of a driver, Figure 2.

Figure 2: Mounting of interior camera for creating the forward view in experiments.

Video preparation

Making a composite sequence containing both forward and rearward views in one video frame was chosen, as it eliminates synchronizing challenges from using separate display monitors for the respective views. The footage had to go through significant stabilization as the built-in stabilization was disabled on the cameras. In order to fix the *FOV*, the stabilization in post-production utilized built-in tracking features of Adobe After Effects. The first step of stabilization was focused on maintaining the angle of the horizon. The second step was keeping the rearward vehicle stable.

Cropping enabled simulation of the different *FOVs*. When simulating the different *FOVs* the choice of what parts of the *FOV* to keep was set to maximize the amount of relevant information within the chosen *FOV*. A visible part of the ego vehicle was kept across the different *FOVs,* as previous research has indicated that this is valuable information for the drivers to orient themselves in the environment [7].

Given the slightly longer viewing distance (1.2 m) in the lab that the participant had in our experiment, as compared to for a driver in a car (0.9 m) the rearward view (CMS) was scaled down with 25%. This was done to maintain the same *FOV* as for CMS in a car. After scaling down the size of the CMS videos simulating the different *FOVs* in order to fit the composite sequence, all the different rearward view *FOV* simulations had a resolution exceeding the pixels per square centimeter of the 4K composite they were later displayed on. This means that there were no effective resolution differences between the different *FOVs* despite the cropping.

The videos for session **Dist** were rendered 600 frames long at 60 fps, the videos for session **LSG** were rendered 1656 frames long at 60 fps. Both videos had an audio signal 5 seconds into the clip, signaling that the participant should redirect their attention towards the rearward view, but continue to drive actively and use the steering wheel to follow the road. In session **Dist,** three different forward view sequences were used, these were all used one time each for each *real distance tested*, each forward view sequence was also used with each *FOV*camera height.* This design choice was made to balance any potential effect the forward view sequence might have on the dependent variable. In session **LSG** the overtaking car passed the ego vehicle (the participants vehicle) after 1200 frames, meaning that the remaining part of the video displayed the overtaking car transitioning from the rearward view into the front view and that the overtaking car continued its journey forward.

Figure 3 displays the same instance recorded with the two cameras at their respective *camera height* and *FOV*. This was made possible by cropping the *FOV* for each camera and by synchronizing the two cameras using the sound from the horn as a time reference marker. These pictures show the range of details that are included for the different perspectives and display how the rearview car differs in size, although being on the same distance.

Figure 3: Same instance snapshots recorded with the two cameras at their respective camera height and FOV, the first column (left) for high camera, the second column (right) for conventional. Rows show the different FOVs. First row (top) 40, second (middle) 76, and third (bottom) 112 degrees.

Procedure

Each participant was first given a written consent form to sign and a written background questionnaire where he or she provided demographic information about his or her age, gender, number of years holding a driving license and the number of kilometers they estimated they are driving in a typical year.

The visual acuity and color vision were evaluated by a Snellen chart from 3 meters and an Ishihara test [11], respectively. Two of the participants had color deficiencies, but all participants had normal or corrected to normal visual acuity.

Once each participant was seated (see Figure 4), they were provided with a written instruction to the experiment. The instructions first explained what CMS means and why it has the potential to replace conventional mirrors. For context, the participant was shown an example picture of a real CMS inside of a car. Then the set-up of the simulated CMS in the experiment, as in Figure 4 (right), was shown to the test participant.

Figure 4: (left) Set up of the test room with the fixed positioning of the participant. (right) Screenshot of a simulated front view (Swedish: framåtvy) and side view mirror/camera (Swedish: sidospegel) as presented in the experiments.

Half of the participants started with the distance judgements (session **Dist**) and the other half started with the LSG judgements (session **LSG**). This measure was made to balance potential order effects such as familiarization [12].

Each participant underwent two practice rounds before the two main sessions began, allowing them to familiarize themselves with the task and the equipment. One for each task and just before the task started. Questions were encouraged during the training sessions to avoid any misinterpretations of the written instructions.

Once the practice was completed, the experiment started, and the test leaders exited the room and closed the door. A brief break was offered and encouraged between the first and second sessions.

After completing both Dist and LSG parts of the experiment, the participants answered a written post experiment questionnaire. Lastly, the participants could voluntarily participate in a recorded interview which would take about 5 minutes.

Data analysis and results generation

Repeated measures Analysis of Variance (ANOVA) [13] was used for the statistical analysis. The assumptions of normality and sphericity, were controlled by using Shapiro-Wilk's [14] as well as Mauchly's test [15]. If the assumption of normality is met but sphericity is not, Greenhouse-Geisser correction would be applied [16].

The Estimated Marginal Means (EMMs) were calculated. They are used to estimate the mean response of a dependent variable for each level of an independent categorical variable. The marginal means can help to better understand the isolated effect of the independent variable on the predicted dependent variable in the model by accounting for the influence of other covariates or factors, thereby providing a picture of the predicted mean of the dependent continuous variable at different levels of the independent categorical variable.

As a post hoc test Tukey Honest Significant Difference (HSD) was applied to compare which specific combinations of the independent variables that had significant differences [17].

Ethical considerations

Each participant was provided with detailed information about the study's purpose and procedures before their involvement. Each participant was required to give written informed consent prior to participation, ensuring that they understood the nature of the research and their right to withdraw at any time without consequences. To maintain anonymity and confidentiality, participants' data were anonymized and securely stored.

Results

Session Dist - Relative distance estimation error

Normality testing was conducted with respect to the measurement points using Shapiro-Wilk's test. The null hypothesis of the sample being normally distributed was rejected for most of the measurement points, as $p < 0.05$. Mauchly's test showed that *camera height* was the only one of the independent variables fulfilling the assumption of sphericity. As the assumption of normality was not met, the Greenhouse-Geisser correction was not applied. However, multiple studies have suggested that the ANOVA method is robust and handles data which does not meet the assumption of normality well (see e.g. [18]).

The *FOV* significantly affects the *relative distance estimation error* ($F(1, 452) = 275.0$, $p < 0.001$, generalized $\eta 2 = 0.16$). The violin plots in Figure 5 display the distribution of *relative distance estimation errors* (%) for different *FOV* settings (40, 76, and 112 degrees). The black points and error bars represent the EMM and their 95% confidence intervals, respectively. The pink area represents the model distribution that was used to compute the EMMs. The black line outlines the raw data distribution.

A Tukey HSD post-hoc test showed significant differences between all the pairwise means of *relative distance estimation errors* ($p < 0.05$), see Figure 6.

The interaction between *FOV* and *real distance tested* on *relative distance estimation error* is indicated as significant ($F(1, 452) = 6.94$, $p < 0.05$, generalized $\eta 2 = 0.006$). The over- and underestimations of distances behaved differently for different distances and FOV. FOV 40 had the largest underestimations for all distances, but the estimation errors were very similar for all *real distance tested*. FOV 112 had the smallest underestimation and even overestimation, with a largest difference between the *real distance tested*.

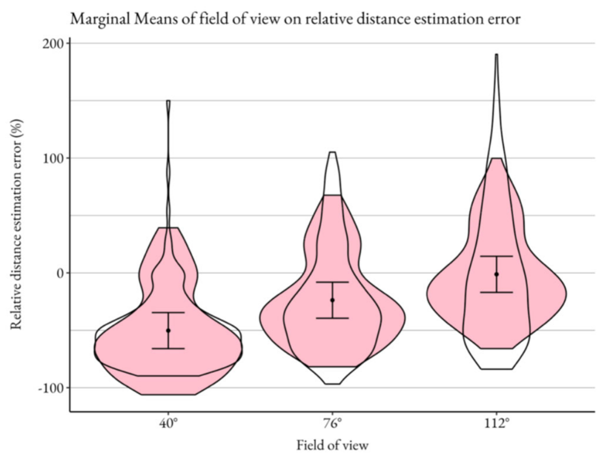


Figure 5: Distributions and EMM's with 95% confidence intervals for FOV on relative distance estimation error. Pink area shows the ANOVA model distribution, black outlined areas show raw data distribution.

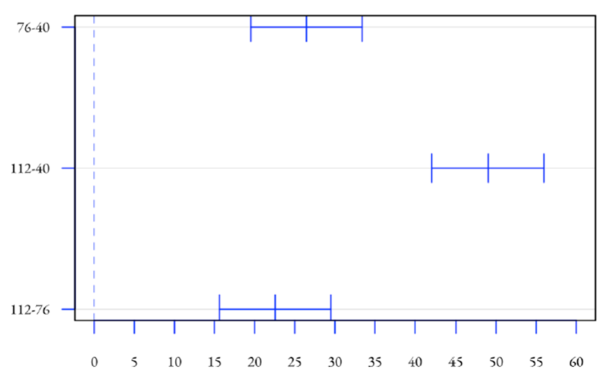


Figure 6 Post Hoc Tukey HSD test for pairwise comparisons between different FOVs on relative distance estimation error. Error bar represents 95% confidence intervals. If these do not include the value zero, the difference is significant.

Session LSG - Time to contact

Normality testing was conducted with respect to the measurement points using Shapiro-Wilk's test. For the measurement *camera height * FOV*: *conventional * 112,* the null hypothesis of normal distribution within the sample was rejected as $p < 0.05$. The null hypothesis was not rejected for the other measurement points. Mauchly's test showed that *FOV* was the only one of the two independent variables violating the assumption of sphericity. As the assumption of normality was met for all measurement points except one, Greenhouse-Geisser corrections were computed.

The ANOVA for the LSG data, indicated that each of the independent variables *FOV* and *environment* *(F (1.87, 48.66) = 8.67, p < 0.001, generalized η2 =0.01)* had significant effects on *TTC (F (1.29, 33.66) = 63.3, p < 0.001, generalized η2 =0.2)*. No significant effect was indicated for *camera height*. Neither was any significant interaction effect indicated.

Figure 7 shows 95% confidence intervals for EMM's for *TTC* across the different *FOVs*, using the ANOVA model distribution as shown in pink. The post-hoc test with Tukey HSD shows that all pairwise comparisons were significantly different (p < 0.05), see Figure 8.

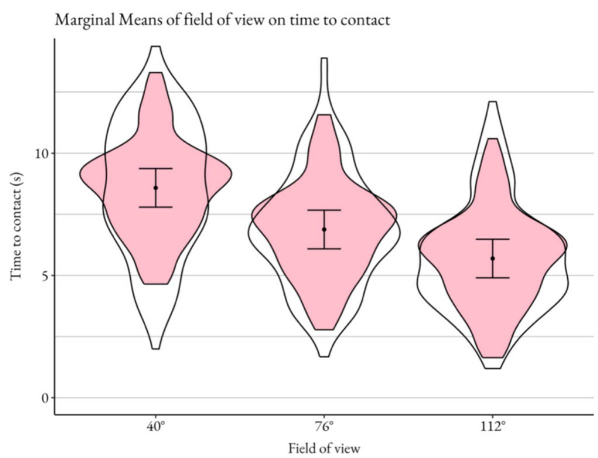


Figure 7: Distribution of LSG judgements and EMM with 95% confidence intervals of TTC (s) across different FOVs. Pink areas show the ANOVA model distribution, and black outlines show areas with raw data distribution.

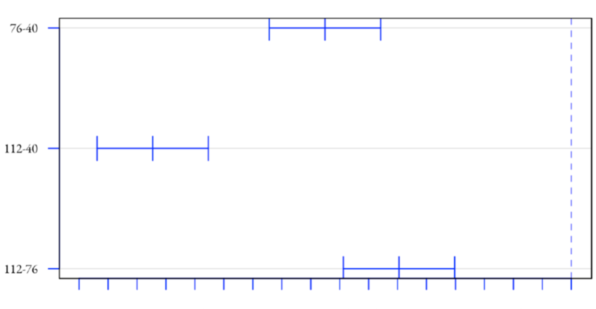


Figure 8: Post Hoc Tukey HSD test for pairwise differences of FOV in degrees for TTC in seconds. Error bar represents 95% confidence intervals. If these do not include the value zero, the difference is significant.

Post experiment questionnaire regarding realism

After conducting both sessions of the study, each participant gave a score from 1 (not realistic at all) to 10 (just like a real driving experience) based on their opinion of the overall perceived realism of the simulation. The mean was 7.6 and the standard deviation was 1.5. Most of the participants did experience a high degree of realism in the experiment. This indicates that the experimental design measures to increase ecological validity had been effective. These included using a video presentation covering a large field of view and a wheel for test participants to virtually control the vehicle.

Conclusions

The findings suggest that wider *field of view* settings improve distance estimation accuracy for rearward vehicles but come with increased risks of overestimating distances, which could affect safety margins. Conversely, narrower *fields of view* encourage more cautious driving behavior, as seen in the longer time-to-contact values, indicating larger gaps in the last safe gap selection. The optimal *field of view* setting may depend on the specific driving context, particularly the distances involved. C*amera height did not* significantly impact distance judgment for rearward vehicles, or driver gap selection.

References

[1] Terzis, A. (2016). *Automotive Mirror-Replacement by Camera Monitor Systems*, in *Handbook of Camera Monitor Systems: The Automotive Mirror-Replacement Technology based on ISO 16505*, A. Terzis, Editor. Springer International Publishing: Cham. p. 3-50, DOI: 10.1007/978-3-319-29611-1_1.

[2] Palmer, S.E., (1999). *Vision Science: Photons to Phenomenology*. Bradford Bokk,

[3] Bernhard, C., R. Reinhard, M. Kleer, and H. Hecht, (2023). *A Case for Raising the Camera: A Driving Simulator Test of Camera-Monitor Systems.* Human Factors. **65**(2): p. 321-336, DOI: 10.1177/00187208211010941.

[4] Mortimer, R.G., (1971). *The Effects of Convex Exterior Mirrors on Lane-Changing and Passing Performance of Drivers.* SAE Transactions. **80**: p. 1795-1804.

[5] Smith, M., V. Kane, J.L. Gabbard, G. Burnett, and D.R. Large, (2016). *Augmented Mirrors:Depth Judgments When Augmenting Video Displays to Replace Automotive Mirrors.* Proceedings of the Human Factors and Ergonomics Society Annual Meeting. **60**(1): p. 1590-1594, DOI: 10.1177/1541931213601367.

[6] Thulinsson, F. and N. Söderlund. *Mirror, Mirror on the Car : An Explorative Study on how CMS Perspective Impact Driver Depth Perception and Decision Making*. (24039), UPTEC STS, Student thesis. 2024, Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-532768

[7] Bernhard, C. and H. Hecht, (2021). *The Ups and Downs of Camera-Monitor Systems: The Effect of Camera Position on Rearward Distance Perception.* Human Factors. **63**(3): p. 415-432, DOI: 10.1177/0018720819895866.

[8] Bernhard, C., D. Oberfeld, and H. Hecht, (2022). *Rear-view perception in driving: Distance information is privileged in the selection of safe gaps.* Transportation Research Part F: Traffic Psychology and Behaviour. **86**: p. 263-280, DOI: https://doi.org/10.1016/j.trf.2022.02.015.

[9] Nabati, P., D. Muftic, and M. Olszewski. (2010). *Accindi*. Available from: https://www.accindi.se/, Access Date: 8 Oct 2024.

[10] SAE International. (2019). *Terms and Definitions Related to Testing of Automated Vehicle Technologies*. DIN SAE Consortium.

[11] Ishihara, S., (2006). *Ishiharas's Tests for Colour Deficiency*. Tokyo, Japan: Kanehara Trading Inc,

[12] ITU-T. (2021). *Methods for the subjective assessment of video quality, audio quality and audiovisual quality of Internet video and distribution quality television in any environment* (ITU-T Rec. P.913). International Telecommunication Union, Telecommunication standardization sector.

[13] Fisher, R.A. (1992). *Statistical Methods for Research Workers*, in *Breakthroughs in Statistics: Methodology and Distribution*, S. Kotz and N.L. Johnson, Editors. Springer New York: New York, NY. p. 66-70, DOI: 10.1007/978-1-4612-4380-9_6.

[14] Shapiro, S.S. and M.B. Wilk, (1965). *An Analysis of Variance Test for Normality (Complete Samples).* Biometrika. **52**(3/4): p. 591-611, DOI: 10.2307/2333709.
[15] Mauchly, J.W., (1940). *Significance Test for Sphericity of a Normal n-Variate Distribution.* The Annals of Mathematical Statistics. **11**(2): p. 204-209.
[16] Greenhouse, S.W. and S. Geisser, (1959). *On methods in the analysis of profile data.* Psychometrika. **24**(2): p. 95-112, DOI: 10.1007/BF02289823.
[17] Tukey, J.W., (1977). *Exploratory data analysis*. Addison-Wesley,
[18] Schmider, E., M. Ziegler, E. Danay, L. Beyer, and M. Bühner, (2010). *Is it really robust? Reinvestigating the robustness of ANOVA against violations of the normal distribution assumption.* Methodology: European Journal of Research Methods for the Behavioral and Social Sciences. **6**(4): p. 147-151, DOI: 10.1027/1614-2241/a000016.

Acknowledgement

This research has been funded by Sweden´s Innovation Agency (VINNOVA, dnr. 2023-00755) through the Vehicle strategic research and innovation (FFI) program.

Author Biography

Felix Thulinsson was a M.Sc. student in sociotechnical engineering at Uppsala University and conducted the study described in this paper at RISE as part of his master's thesis.

Niclas Söderlund was a M.Sc. student in sociotechnical engineering at Uppsala University and conducted the study described in this paper at RISE as part of his master's thesis.

Shirin Rafiei received her B.Sc. and M.Sc. degrees in Electronics and Telecommunications in 2009 and 2014, respectively. Since 2020, she has been a researcher and Ph.D. fellow at RISE Research Institutes of Sweden and Mid Sweden University. Her research focuses on interdisciplinary mixed-method approaches, integrating UX and QoE in industrial remote-control systems. She also works in extended reality applications and explores user interaction paradigms using visual interfaces for remote control systems, with emphasis on visual perception.

Bo Schenkman received his PhD in psychology from Uppsala University, Sweden, in 1985. Since 2020 he is a Senior Scientist at RISE Research Institutes of Sweden. He is also a guest scientist at KTH Royal Institute of technology. His interests are in image quality and human echolocation.

Anders Djupsjöbacka is a researcher with an expertise in optics and communication technologies. His current research activities include theoretical and experimental physics, optics, optical transmission, and video quality. Anders is the single author of ~15 publications, co-author of another ~65 publications, holder of ~20 patent applications, and co-author of one book.

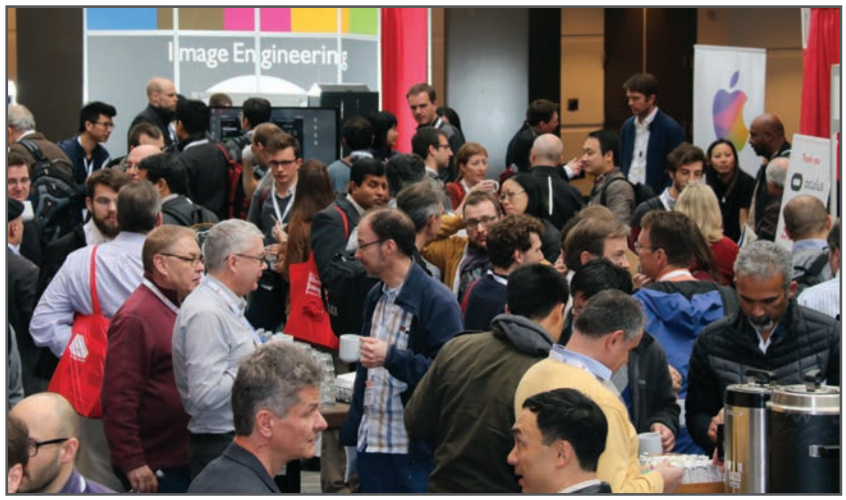
Börje Andrén has worked with optical research, image quality and color issues and visual ergonomics for both 2D and 3D for almost 43 years. He has participated in the development of the visual ergonomic part of the TCO label since 1995, developing requirements and test methods. For about ten years, Börje has helped Intertek Semko with the development of its visual ergonomics laboratory and measured and evaluated more than 4,000 screens.

Kjell Brunnström is a Senior Scientist at RISE Research Institutes of Sweden AB and Adjunct Professor at Mid Sweden University. He is leading development for video quality assessment as Co-chair of the Video Quality Experts Group (VQEG). His research interests are in Quality of Experience for visual media especially immersive media. He is area editor of the Elsevier Journal of Signal Processing: Image Communication and has co-authored > 100 peer-reviewed scientific articles including conference papers.

JOIN US AT THE NEXT EI!

electronic IMAGING

Imaging across applications . . . Where industry and academia meet!



• SHORT COURSES • EXHIBITS • DEMONSTRATION SESSION • PLENARY TALKS •
• INTERACTIVE PAPER SESSION • SPECIAL EVENTS • TECHNICAL SESSIONS •

www.electronicimaging.org