# Driver Perception Using A Camera-Based Digital Side Mirror: An On-Road Study

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## ABSTRACT

Camera-based digital mirrors purport to offer a range of benefits yet may influence drivers' ability to quickly and accurately extract salient information pertaining to driving. In an on-road study, fifteen experienced drivers (seated in the front, left, passenger seat) undertook an orientation-discrimination task requiring the extraction of real-world information using either a digital mirror (placed internally) or a conventional, external, reflective mirror. Participants were asked to complete each task as quickly and accurately as possible, and then return their attention to the driving scene, as if they were driving. Although there was no difference in performance accuracy or reported workload between conditions, participants responded sooner when using the digital mirror – suspected to be due to the wider field-of-view intrinsic to its design, although participants also reported feeling "rushed" when using the digital mirror. The majority of participants (9 out of 15) indicated a preference for the conventional mirror, raising numerous concerns associated with the digital mirror, relating to image quality, field-of-view, focal depth (particularly for wearers of varifocal or reading glasses), and potential deleterious effects of ambient weather conditions, demonstrating important human factors issues still requiring attention in this context.

## KEYWORDS

Digital mirror, perception, visual demand, workload

### Introduction

Legislation now permits the use of camera-based, digital rear and side-view mirrors within road vehicles in several countries (United Nations Economic Commission for Europe (UNECE), 2016). This technology is therefore beginning to pervade high-end marques, such as the Audi *e*-tron and the Lexus ES, where it purports to offer a range of benefits, including improved fuel economy (reduced drag), safety and vehicle styling. In addition, drivers may benefit from an increased field of view compared to reflective mirrors, thereby potentially eliminating "blind-spots". The technology also provides scope to "augment" reality, for example, by highlighting potential hazards and improving image clarity during night-time driving. Nevertheless, providing digitally reconstructed images to drivers is likely to fundamentally change the way that they see and perceive the world around them. This may lead to changes in perception and performance, such as the time and accuracy to extract salient information. It may also lead to unpredictable behaviour, for example, if the technology fails (Pampel et al., 2020). The current study aims to explore the former issue, by comparing drivers' ability to extract salient information using a digital mirror (located within the vehicle) with a conventional, reflective side mirror, in an on-road study.

### Background

Reflective "rear-view" mirrors typically comprise an internal mirror affixed to the top of the windscreen augmented by two external side mirrors mounted on the doors – normally at the A-pillar. In combination, these provide drivers with an expansive view of the road scene behind and around them, thereby enhancing visibility and safety (Gkikas, 2017). UNECE (2016) now approves the full replacement of reflective side mirrors with cameras and associated in-vehicle LCDs (so-called, “digital mirrors”). These operate by relaying a live video feed captured from an externally positioned camera to a digital display normally presented within the vehicle. Several studies have evaluated the feasibility of using digital mirrors in driving and have presented emerging design recommendations (e.g. Ali and Bazilah, 2014; Large et al., 2016). Digital mirrors have also been reported to enhance performance: Large et al. (2016) observed a reduction in decision time associated with digital mirror setups during overtaking manoeuvres in a driving simulator. Similarly, Doi, Murata, Moriwaka and Osagami (2018) demonstrated that during a tracking and monitoring task, reaction times for digital mirrors were shorter and accuracy scores higher than for conventional, reflective mirrors.

A further advantage is that digital mirrors are not fixed in their location, and consequently provide designers with new possibilities for vehicle design. Interior digital mirror displays can thus be located to enhance drivers’ visual processing of information: Murata and Kohno (2018) observed that configurations that centred around the driver, close to their forward-facing line of sight, were most effective at reducing reaction times. Such driver-centric layouts may also alleviate the physical workload typically associated with checking side rear-view mirrors, and can lead to improvements in driving performance and safety (Large et al., 2016). Ali and Bazilah (2014) postulated that digital mirror displays positioned on the dashboard are likely to reduce the repetitive head movements that are required to check external mirrors, and this can lead to shorter eye gazes and, therefore, reduce the total off-road glance durations.

In contrast, Large et al. (2016), reported that locations more in keeping with conventional mirrors (e.g. on or near the doors next to the A-pillar), were most preferred by drivers, highlighting that these allowed drivers to continue to receive the additional benefits of peripheral vision during head movements. Nevertheless, it is also recognised that digital displays may provide a wider field of view, compared to reflective mirrors, thereby potentially eliminating visual blind-spots and reducing reliance on peripheral detection. This potentially renders exaggerated head movements, including “over-the-shoulder” checks, unnecessary. Such reductions in physical demand would naturally benefit drivers with limited mobility, as well as supporting novice drivers who purportedly engage in less mirror-checking behaviour than experienced motorists (Beck et al., 2019). Reductions in workload may be particularly advantageous in complex traffic situations and certain manoeuvres where mental workload levels are already notably higher (Hancock et al., 1990).

While the body of evidence presents a strong argument in support of digital mirrors, it has also been reported that drivers tend to exhibit different visual sampling patterns when using digital in-car displays. For example, in their evaluation of a rear parking aid, McLaughlin et al. (2003) observed significantly more glances made by drivers when they used the internal, digital screens to park compared to when they used external, reflective mirrors. Interestingly, participants rated the quality of their parking and their capability to judge distance on the digital screen as higher, despite taking considerably longer to park than when using the conventional mirror.

A further area of concern is that digital mirrors do not portray visual depth cues as accurately as direct vision, or when using planar mirrors. In particular, the lack of binocular convergence and disparity, accommodation and motion parallax cause the observed scene to seem flat or two-dimensional in a digital display, with all objects appearing at the same distance, irrespective of their actual position (Flannagan et al., 2001). This minification of objects can cause drivers to overestimate distances and underestimate speeds – effects that are also evident in convex reflective mirrors. Indeed, in their ‘last safe gap’ evaluation using digital mirrors (i.e. participants were required to indicate the last moment at which it was safe to pull out in front of an overtaking car), Flannagan and Mefford (2005) found that participants significantly underestimated distances.

In addition, the size of the display is important – a report by the National Highway Traffic Safety Administration (NHTSA) (2006) found that smaller screens in rear-view parking assist systems caused significantly poorer distance judgements. This is consistent with findings from Murata and Kohno (2018), although their study applied a vehicle discrimination rather than depth perception task: reaction times when using an 8-inch display were significantly quicker than with the smaller, 6-inch display. Moreover, reaction times increased further when the 6-inch display was positioned next to the external mirror, thought to be due the relative difference in the size of the objects. Nevertheless, Flannagan and Sivak (2006) found image size did not affect participants' judgements of depth, suggesting there may be other inherent depth cues available to the driver when using digital displays. Indeed, although electronic screens distort oculomotor, stereoscopic and motion-induced depth criteria, they are good at preserving monocular distance cues, such as height of field, brightness or shadow (Flannagan et al., 2001). It has therefore been suggested that drivers may require time to become accustomed to new mirror setups. However, findings from longitudinal studies are mixed. For example, Flannagan et al. (1996) demonstrated that increased familiarity through prolonged use can result in more accurate judgements, whereas Flannagan and Mefford (2005) showed that driver' judgements may become more conservative over time.

The range of conflicting findings reported in the literature suggests that there is further work to be done in this area. The current study therefore focusses on the extraction of real-world information using a digital mirror. Given the limitations in three-dimensional visual processing associated with driving simulators (Lambooij et al., 2009), the study was conducted on the road. Therefore, to ensure the safety and wellbeing of our participants – all of whom were experienced and active drivers, they were seated in the passenger seat of an instrumented car and performed a visual search task using a digital mirror whilst being driven. Participants were asked to complete the task as quickly and accurately as possible, as if they were driving themselves – and to return their attention to the driving scene between tasks.

## Method

### *Participants*

Fifteen participants (7 female, 8 male) between the age of 26 and 59 (M = 40, SD = 10.2) took part. All participants held a UK or EU driving licence for at least three years (ranging from 6 to 34 years) and were experienced and regular drivers – annual mileage was in the range 5,000 to 10,000 miles (mode). Participants primarily comprised University of Nottingham staff. They were recruited using an email advertisement and reimbursed for their time with £10 in shopping vouchers.

### *Experimental Design and Setup*

The study was conducted within-subjects: all participants completed a visual search task (detailed below) in two conditions: conventional mirror and digital mirror, whilst being driven around the University of Nottingham campus. The two conditions were counterbalanced and the order of trials within each condition randomised. During each drive, only the device being used (i.e. conventional mirror or digital mirror) was visible – the other was either disabled or obscured. An instrumented Ford Focus, owned and insured by the University of Nottingham, was used in the study. For safety reasons, participants were seated in the left-front passenger seat of the right-hand drive car, and utilised the left (nearside) mirror, while an experimenter drove the vehicle, aiming to achieve a constant speed of 20mph. The digital side mirror was created by mounting a GoPro Hero 5 Black onto the passenger side mirror to capture the rearward view (at 60 fps and a resolution of 1080p), and relaying this in real-time to a Lilliput 7-inch LCD monitor mounted inside the car (Figure 1).

Figure 1: Experimental setup showing conventional reflective mirror and internal digital mirror connected to GoPro camera mounted on external mirror. Note: blind spot mirror provided for experimenter who drove the vehicle.

As recommended by previous research (Large et al., 2016), the digital mirror was located on the door adjacent to the A-pillar. In addition to meeting drivers' preferences and expectations, this limited the difference in glance travel distance (and hence, time) between the two conditions, thereby minimising potential confounding effects. To preserve the ecological validity of the study, the digital mirror was of a similar physical size to the mirror but provided an increased field of view (FOV) as would be expected in a real-world application: 49.0 degrees FOV, compared to 24.2 degrees for the conventional mirror. The image was also flipped horizontally on the monitor to correspond with the reflected image visible in the conventional mirror and enable direct comparison. The existing reflective side mirror was planar.

### *Procedure and Visual Search Task*

Participants completed two journeys, each lasting approximately 10 minutes. During each drive, they performed a visual spatial search task in which they were verbally prompted to use either their side mirror or the digital display (although each condition was exclusive to a single drive) to view visual stimuli mounted to the back of roadside lampposts. Between tasks, participants were asked to direct their attention to the roadway, as if they were driving. The stimulus comprised a black bar and square, angled at 45°, on a white background, and was a variant of Humphrey et al.'s (2006) orientation discrimination tasks. This task was chosen to reflect the need to dynamically extract complex, salient information – quickly and accurately – while driving. Participants were required to identify both the orientation and location within four different stimulus configurations (Figure 2).

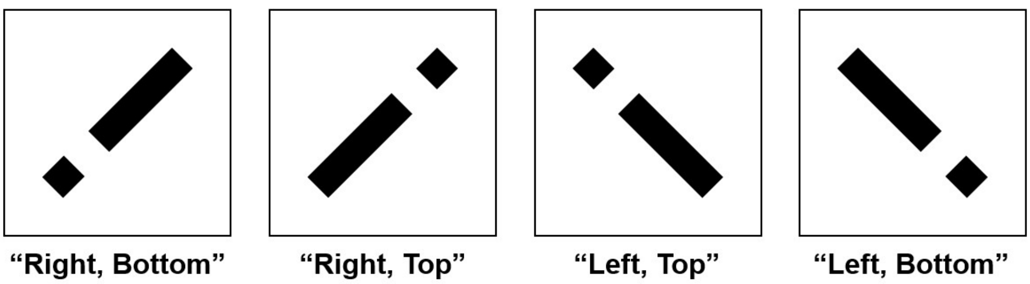


Figure 2: Visual search task, showing the four different orientations with correct responses

The facilitator prompted the participant by saying "Go" when the car was directly adjacent to the sign. Participants were then required to respond as quickly and accurately as possible by identifying whether the image perceived in the mirror was left- or right- leaning from the top and whether the small square was at the top or bottom (Figure 2). The stimuli were attached at a height of 1.9m above the ground. Lampposts were situated approximately 2m from the kerb and the signs were angled at approximately 10° to the road's horizontal alignment. Signs were 42×42cm and made of black duct tape on laminated white paper. During each drive, participants were presented with two occurrences of each orientation, resulting in a total of eight trials per condition. The order of trials was randomised within each condition. This meant that despite potentially noticing upcoming signs, participants could not predict which ones they would be required to identify. Before the first drive, participants completed two practice trials in the first condition and one in the second condition. Each participant took approximately 40 minutes to complete the experiment, and all sessions were scheduled to finish before sunset. In addition, every effort was made to ensure that testing only occurred in dry, clear conditions.

### *Measures*

A participant-facing camera mounted on the dashboard was used to record participants' visual behaviour and responses. Recordings were subsequently coded using BORIS event logging software (Friard an Gamba, 2016) to capture task score, reaction time, response time, processing time and off-road glance duration. *Task score* is defined as the percentage of correctly identified responses. *Reaction tim*e is defined as the time between the instruction to start the task ("Go" verbal cue), and the start of the glance. *Response ti*me is defined as the difference between the start of the experimenter's verbal cue and the start of the participant's verbal response. *Processing time* measures the period between glance start and response start, and indicates how long it took participants to process the stimulus from the time they took their eyes off the road to the time they began their response. Finally, *total off-road glance time* measures the period between the start and end of the glance in line with convention. Participants also rated their perceived workload using the NASA-TLX (Hart and Staveland, 1988) for each condition, and lastly, indicated their preference (conventional or digital mirror), and provided verbal comments to support this, with responses recorded by the experimenter.

## Results

Initial analysis of visual behaviour suggested that, as they were not actively driving, some participants may have extended their off-road glances beyond completion of the visual search task. In other words, although participants followed the visual search task as instructed, responding promptly and delivering the 'correct' response, their gaze may have subsequently lingered on the sign, rather than returning immediately to the road. To overcome this potential limitation (apparent due to the need to ensure the safety and wellbeing of our participants), *processing time* is used as the primary measure of visual demand (as this eliminates any additional, unproductive time), rather than *off-road glance duration*. For brevity, only *response time* and *processing time* are reported here. While extended, residual glances would likely increase the potential for distraction, this effect would not be expected to occur if participants were actually driving

### *Task Performance and Visual Demand*

Overall task score was high in both conditions: participants identified 93% of stimuli correctly with the conventional mirror and 90% of stimuli with the digital mirror. A McNemar test showed no statistical difference between the scoring rates ($p = 0.34$). For visual demand, two-tailed, paired-samples $t$-tests were used to compare response time and processing time. Response time associated with the conventional mirror (M = 2.07s, SD = 0.63) was significantly longer than for the digital mirror (M = 1.80s, SD = 0.53), $t(118) = 3.624$, $p < 0.001$). Processing time was also significantly

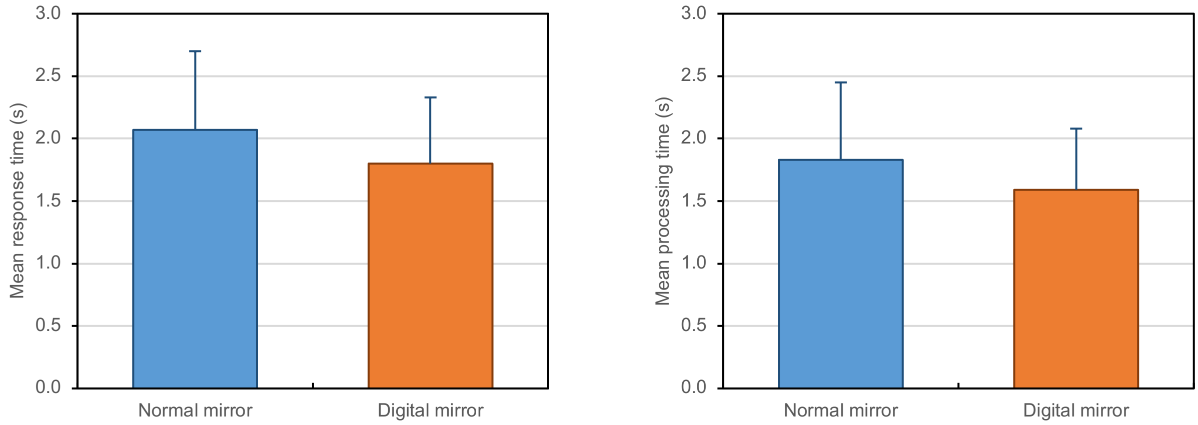


Figure 4: Mean response time (left) and processing time (right) for the conventional ("normal") and digital mirror, with standard deviation error bars

longer when using the conventional mirror (M = 1.83, SD = 0.62) compared to the digital mirror condition (M = 1.59s, SD = 0.49), t(118) = 3.404, *p* = 0.001) (Figure 4).

### *Subjective Workload and Preference*

Total workload was determined as the sum of all individual raw NASA-TLX (RTLX) scores, on a 21-point Likert scale, across the six dimensions (mental demand, physical demand, temporal demand, performance, effort, stress), in line with common practice. A paired-samples *t*-test showed no significant difference in participants' workload ratings (t(14) = -1.19, p = 0.25) between the conventional mirror (M = 223.0, SD = 99.6) and digital mirror (M = 240.3, SD = 87.7).

Sixty percent (N=9) of participants stated that they preferred the conventional mirror. They cited reasons such as image size and clarity ("*the signs were bigger and clearer*"), ease of use and familiarity ("*it's in the place where I want it to be*", "*I was more familiar with it and I knew what to expect*"). Those participants (N=6) who indicated a preference for the digital mirror, highlighted the larger field of view as advantageous, recognising that this allowed the target item to enter their field of view sooner – and remain there longer. One participant also commented on the closer proximity of the digital display (i.e. inside the vehicle), suggesting that it required less head movement ("*didn't have to lean across as much*").

## Discussion

For several of the performance metrics, there was apparently little discernible difference between the conventional and digital mirror. For example, participants scored highly on the visual search task and accurately identified over 90% of visual stimuli for both mirrors, and workload ratings using RTLX were statistically similar for both configurations. However, it was also evident that participants responded sooner when using the digital mirror (response time), and also extracted salient information more quickly (processing time). Response time is likely to be influenced by the larger field of view presented by the digital mirror, meaning that the target object appeared sooner in the visible frame (estimated to be approximately 500ms). Rather than this being a limitation in the experimental design, it demonstrates a potential advantage due to intrinsic design factors associated with digital mirrors. However, an unexpected consequence of this is that the target item declined rapidly in size relative to the visible frame – effectively, an accelerated reverse looming effect. This means that although it appeared sooner, the available time during which the details of the target object were discernible was arguably reduced. In other words, the information on the sign rapidly become too small to see clearly. This is likely to have elevated the processing time.

Although this was not necessarily reflected in the subjective workload ratings, it is supported by comments made by participants, all of whom recognised this minification effect (consistent with other research (Schmidt et al., 2020)). Several participants specifically commented that this made the visual search task feel more "rushed" because the target object decreased in size faster than in the mirror ("*it disappeared quite quickly and it got pixely and then I was scared that I wouldn't be able to see where it was in time*"). Moreover, this concern was also reflected in preference data, with many of those who selected the conventional mirror as their preferred option, commenting on the fact that images appeared "bigger" and remained legible for longer in the conventional mirror compared to the digital mirror. Nevertheless, one participant suggested that it may be possible to "zoom in" using a digital mirror in certain situations, and the whole image could potentially be presented on a much larger screen within the vehicle. During the study, screen and mirror size was intentionally kept the same (as far as was practicable) to avoid confounding size effects. However, this remains the subject of other research. Indeed, Doi et al. (2018) recommended that displays should be at least 5-inches, and Murata and Kohno (2018) found 8-inch displays enabled much shorter reaction times than 6-inch displays. In the current study, some participants also commented on the potential benefits of the wider field of view associated with the digital mirror, during "normal, everyday driving". Others, however, stated that they felt the wider field-of-view may become distracting (as it would contain a larger amount of visual information) and suggested instead reducing it, "*to the same range as the reflective mirror*". Field-of-view therefore remains an important consideration. While a wide field-of-view could provide additional information and reduce blind-spots, a narrower field-of-view would result in smaller compression rates and minification effects. The optimum size may therefore be a compromise between the two – wide enough to eliminate blind-spots but narrow enough to reduce minification effects.

Image quality was also highlighted during the interviews, with mixed responses. Individuals who preferred the digital mirror, stated that they found it easier to see with and described it as presenting a "*higher resolution*" and "*clearer*" image, whereas advocates of the conventional mirror said that it provided a clearer ("*higher definition*") and more "*natural*" picture, suggesting that users' subjective preference influenced their objective evaluation of material qualities. However, participants were in general agreement that the image quality of the digital mirror should be the highest resolution possible and that factors, such as achieving appropriate brightness and colour balance, could play an important part in achieving this. Other, environmental factors, such as the prevailing weather conditions and ambient lighting, also noticeably influenced image clarity. Indeed, although every effort was made to collect data under similar weather conditions, participants who experienced episodes of light rain reported that the digital mirror provided a brighter image and better view than the external mirror; in addition, the clarity of the external mirror was reduced due to raindrops on the door glass. Sunlight also influenced results, consistent with Schmidt et al. (2020). For example, at a certain angle/vehicle orientation, the sun shone directly into the external mirror creating glare. As a consequence, participants commented that the digital mirror was "*more protective*" (against the effects of the sun) and provided better vision and a brighter image in this context. Nevertheless, when sun rays fell directly onto the camera lens, they caused blooming and a pixelated image.

One important issue, highlighted by participants' responses, concerns drivers with visual impairments, such as hyperopia, presbyopia or astigmatism, i.e. conditions that could make it difficult for individuals to focus on close objects. One of the participants, for example, who wore glasses for reading but not driving, said they can usually read in-car information, such as the speedometer, quite well. In the digital mirror condition, however, they criticised the screen, suggesting that it was "*low resolution*", but was unable to tell if this was a result of digital image quality itself, the participant's vision (i.e. without glasses) or a combination of both. More insight came from a participant wearing glasses with varifocal lenses. They reported having to adjust their head position to bring the objects on the screen into focus (bifocal and varifocal lenses are worn by those needing two different prescriptions). There were no reported problems when using the conventional mirror – evidently because the distance of the reflected image in the mirror was the same as the real object's distance to the mirror. Digital screens, on the other hand, present all elements in a two-dimensional plane at the distance of the screen itself and, therefore, a driver's eyes would need to adjust to a closer image. For a participant who wore bifocal glasses, the digital mirror's position at the same height as the external mirror meant they experienced difficulty focussing on the screen using either the top or bottom of the glasses. They stated: "*I'm having to use [my glasses] a bit further down but it's not like a really close thing, like looking at your phone. It's that sort of mid-point range*". Both cases raise important issues for digital mirror designs. If drivers are to safely use digital mirrors, they must be able to comfortably switch their eyes' focus between the road and the displays. Current regulations by the UK Driver and Vehicle Licence Agency (DVLA, 2016) only set out standards for far vision, as existing driving tasks tend to require the driver's eyes to focus in the distance. Future studies will need to investigate the extent to which presbyopia/hyperopia affects digital mirror use. Furthermore, appropriate anthropometric measurements (height, distance, angle) will have to be determined to accommodate for drivers who struggle to focus in close range, and these may differ between vision impairment type.

Finally, it is acknowledged that participants' preference for the conventional mirror may have been influenced by their existing experience with real mirrors, not only in cars but during everyday life. It is therefore suggested that a familiarisation period would be required for drivers to become accustomed to using digital mirrors, and this could potentially influence preferences. Furthermore, participants were not actually driving, and even though they were instructed to visually attend to the driving scene between tasks, as if they were driving, they may have lacked intrinsic motivation. This has been addressed by extracting the relevant aspects of their visual behaviour (i.e. response time and processing time were specifically computed to eliminate any potential effects from lingering glances), and we would also highlight that the investigation focusses on *relative* behaviour (i.e. comparing the digital mirror with a conventional mirror). It is also worth commenting on the orientation-discrimination task chosen during the study. While this was selected as a highly-controlled method to replicate the need to dynamically extract complex, salient information while driving, employing a real-world task requiring the use of side mirrors (such as overtaking) would also have been possible, and this may have added further validity to the findings.

## Conclusion

The study compared the ability of drivers to extract salient information from a digital, camera-based mirror (located within the vehicle) with a conventional external mirror. Using a recognised visuo-spatial orientation-discrimination task, requiring the extraction of real-world information, the study demonstrated that the wider field-of-view associated with the digital mirror enabled participants to extract salient information more quickly, although no advantages were found in terms of performance accuracy and reported overall workload. An unexpected consequence of the wider field-of-view was that several participants reported feeling "rushed" when using the digital mirror, due to the fact that the area of interest rapidly declined in size and clarity (effectively, an enhanced reverse looming effect); as such, the majority of participants (9 out of 15) indicated that they preferred the conventional mirror. Even so, design solutions associated with the digital mirror, such as "zooming in" at critical times, were suggested by participants. Overall, the study therefore supports the adoption and integration of digital mirrors within consumer vehicles, but also reveals important new, human factors issues requiring further investigation. These include factors, such as: digital image quality, field-of-view and depth perception, and in particular, the impact of these on users with minor visual impairments that necessitate the wearing of bifocal or varifocal glasses. In addition, environmental factors, such as rain and sun glare, require further attention.

**References**

J.S. Mohamed Ali, and F. Fatin Bazilah. 2014. Mirrorless car: A feasibility study. Applied Mechanics And Materials 663: 649-654. DOI: https://doi.org/10.4028/www.scientific.net/amm.663.649.

Donghyun Beck, Jaemoon Jung, and Woojin Park. 2019. Evaluating the effects of in-vehicle side-view display layout design on physical demands of driving. Human Factors. DOI: https://doi.org/10.1177/0018720819884781.

Toshihisa Doi, Atsuo Murata, Makoto Moriwaka, and Takumi Osagami. 2018. Camera monitor systems as replacement of side mirror in rearward monitoring. In International Conference on Applied Human Factors and Ergonomics: 544-553. Springer, Cham, 2018.

Driver Vehicle Licensing Agency. 2016. Visual Disorders: Assessing Fitness To Drive. GOV.UK. https://www.gov.uk/guidance/visual-disorders-assessing-fitness-to-drive (accessed January 1, 2020).

Michael J. Flannagan, Michael Sivak, and Eric C. Traube. 1996. Driver perceptual adaptation to nonplanar rearview mirrors. SAE Technical Paper Series 105: 1012-1019. DOI: https://doi.org/10.4271/960791.

Michael J. Flannagan, Michael Sivak. 2006. Distance cues and fields of view in rear vision systems. SAE Technical Paper Series 115: 843-849. DOI: https://doi.org/10.4271/2006-01-0947.

Michael J. Flannagan, and Mary L. Mefford. 2005. Distance perception with a camera-based rear vision system in actual driving. In Proceedings of The Third International Symposium on Human Factors In Driver Assessment, Training And Vehicle Design. Rockport, Maine. DOI: https://doi.org/10.17077/drivingassessment.1143.

Michael J. Flannagan, Michael Sivak, and Julie K. Simpson. 2001. The relative importance of pictorial and nonpictorial distance cues for driver vision. In Proceedings of The First International Driving Symposium On Human Factors In Driver Assessment, Training And Vehicle Design. Aspen, Colorado. DOI: https://doi.org/10.17077/drivingassessment.1041.

Olivier Friard, and Marco Gamba. 2016. BORIS: A free, versatile open-source event-logging software for video/audio coding and live observations. Methods In Ecology And Evolution 7 (11): 1325-1330. DOI: https://doi.org/10.1111/2041-210x.12584.

Hancock, Peter A., Gabriele Wulf, D. Thom, and P. Fassnacht. 1990. Driver workload during differing driving maneuvers. Accident Analysis & Prevention 22 (3): 281-290. DOI: https://doi.org/10.1016/0001-4575(90)90019-h.

Sandra G. Hart, and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. Advances In Psychology 52: 139-183. DOI: https://doi.org/10.1016/s0166-4115(08)62386-9.

Glyn W. Humphreys, and M. Jane Riddoch. 2006. Features, objects, action: The cognitive neuropsychology of visual object processing, 1984–2004. Cognitive Neuropsychology 23 (1): 156-183. DOI: https://doi.org/10.1080/02643290542000030.

Marc Lambooij, Wijnand IJsselsteijn, Marten Fortuin, and Ingrid Heynderickx. 2009. Visual discomfort and visual fatigue of stereoscopic displays: A review. Journal Of Imaging Science And Technology 53 (3): 30201 1-14. DOI: https://doi.org/10.2352/j.imagingsci.technol.2009.53.3.030201.

David R. Large, Elizabeth Crundall, Gary Burnett, Catherine Harvey, and Panos Konstantopoulos. 2016. Driving without wings: The effect of different digital mirror locations on the visual behaviour, performance and opinions of drivers. Applied Ergonomics 55: 138-148. DOI: https://doi.org/10.1016/j.apergo.2016.02.003.

Shane B. McLaughlin, Jonathan M. Hankey, Charles A. Green, and Raymond J. Kiefer. 2003. Driver performance evaluation of two rear parking aids. In Proceedings of The 18th International Technical Conference On The Enhanced Safety Of Vehicles. Nagoya, Japan.

Atsuo Murata, and Yuki Kohno. 2018. Effectiveness of replacement of automotive side mirrors by in-vehicle LCD–effect of location and size of LCD on safety and efficiency–. International Journal Of Industrial Ergonomics 66: 177-186. DOI: https://doi.org/10.1016/j.ergon.2018.03.010.

National Highway Traffic Safety Administration. 2006. Vehicle backover avoidance technology study: Report to congress. Washington, DC.

Sanna Pampel, Thomas Southey, and Gary Burnett. 2020. Understanding the distraction and behavioural adaptations of drivers when experiencing failures of digital side mirrors. IET Intelligent Transport Systems. DOI: https://doi.org/10.1049/iet-its.2019.0673.

Eike A Schmidt, Heike Hoffmann, Rainer Krautscheid, Maxim Bierbach, Alexander Frey, Jost Gail, and Christine Lotz-Keens. 2020. Camera-monitor systems as a replacement for exterior mirrors in cars and trucks. In Handbook Of Camera Monitor Systems. Augmented Vision And Reality 5, 369-435. Cham: Springer.

United Nations Economic Commission for Europe (UNECE). 2016. World Forum for Harmonisation of Vehicle Regulations (WP.29).