2023 IEEE Intelligent Vehicles Symposium (IV) | 979-8-3503-4691-6/23/$31.00 ©2023 IEEE | DOI: 10.1109/IV55152.2023.10186746

Characterizing Drivers' Peripheral Vision via the Functional Field of View for Intelligent Driving Assistance

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***Abstract*— Many intelligent driver assistance algorithms try to improve on-road safety by using driver eye gaze, commonly using foveal gaze as an estimate of human attention. While human visual acuity is highest in the foveal field of view, drivers often use their peripheral vision to process scene elements. Previous work in psychology has modeled this combination of foveal and peripheral gaze as a construct known as Functional Field of View (FFoV). In this work, we study the shape and dynamics of the FFoV during active driving. We use a peripheral detection task in a virtual reality (VR) driving simulator with licensed drivers in urban driving settings. We find evidence that supports a vertically asymmetric (upward-inhibited) shape of the FFoV in our active driving task, similar to previous work in non-driving settings. Additionally, we show that this asymmetry disappears when the same peripheral detection task is conducted in a non-driving setting. Finally, we also examine the dynamic nature of the FFoV. Our data indicates that drivers' peripheral target detection ability is inhibited right after saccades but recovers once drivers fixate for some time. The findings of the FFoV's task-dependent nature as well as systematic asymmetries and inhibitions have implications for gaze-based intelligent driving assistance systems.**

I. INTRODUCTION

Advanced driving assistance systems (ADAS) are a promising tool to increase on-road vehicular safety. For instance, Intelligent Speed Adaptation (ISA), which alerts the driver to slow down if exceeding the statutory local speed limit, is predicted to reduce $4 - 19\%$ of crashes in the Netherlands depending on penetration [20]. Forward collision warnings and automatic cruise control systems together are predicted to prevent $6 - 15\%$ of all rear-end collisions in the USA per year and upto 35% of near-crash events under foggy conditions [23], [36].

One mechanism of intelligence in such systems uses driver-facing sensors to infer and forecast driver mental states. In these human-centric paradigms, eye gaze commonly serves as a proxy for human attention. Gaze has been shown to be a useful signal in inferring people's goals in human-robot collaborative tasks [16], robot tele-manipulation [1] and even as auxiliary supervision for autonomous driving [4]. In the assistive driving setting, researchers have demonstrated the value of eye gaze as a signal to predict drivers' attention [25], situational awareness [18] and future actions [34].

This work was funded in part by the National Science Foundation (IIS-1900821 and IIS-1943072), the Tang Family Innovation Fund, and the Link Foundation's Modeling, Simulation, and Training Fellowship.

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Fig. 1: Experimental setup showing a subject in our virtual reality driving simulator. The bucket seat and steering wheel and pedals help provide a realistic physical interface for driving. Red crosshair represents user gaze in the experimenter view, while it is not visible in VR to the user. Inset shows the experimenter view more clearly. Note the red sphere which serves as the peripheral stimulus that participants must respond to.

Many of today's gaze-based driver awareness models only account for foveal (i.e., central) vision [34], [18], [19]. However, drivers routinely use their full range of vision, including peripheral vision, to maintain situational awareness (SA). While driving, we are responding to a constantly and rapidly changing environment involving other vehicles, surrounding pedestrians, traffic signs, and other objects. Relevant stimuli such as a jaywalking pedestrian or a speed limit sign often first appear outside of foveal (small region around the point of regard) gaze, but we are still able to perceive, process, and respond to them. To characterize this phenomenon, psychology researchers commonly use a construct known as the Functional Field of View (FFoV, also UFoV: useful FoV) — the region of our field of view (FoV) in which stimuli can be processed during a single fixation [2]. The FFoV consists of both foveal and peripheral vision. It has been shown that a degraded FFoV can be predictive of negative outcomes in real-world driving [7]. For instance, older drivers with a 40% or greater impairment in their FFoV were 2.2 times more likely to incur a crash in the 3 years following FFoV measurement [24]. This makes it an important visual phenomenon that is necessary for intelligent

Fig. 2: Hypothesized dynamics of Functional Field of View (FFoV) [8] (1-4: L-R):(*1*) Driver is fixating (fixation point indicated by red crosshair) at a road sign and the FFoV (blue ellipse, solid) is indicated at it's maximum level around the fixation point. (*2*) The driver saccades and starts fixating at the traffic light — the FFoV resets to a lower level than the maximum (blue ellipse, dotted). (*3*) Driver continues fixating on the traffic lights and FFoV expands. (*4*) The driver is still fixating on the light and the FFoV has expanded to its maximum level again.

driving assistance systems to model, in order to provide effective assistance.

In this work, we study the shape and dynamics of the FFoV during active driving. To do so, we conduct a human subjects study involving a peripheral detection task within a virtual reality driving simulator. Our goal is to characterize the FFoV's shape and movement to inform intelligent driving assistance algorithms.

Initial descriptions of the shape of the FFoV simply describe it as a 30° region around the fovea [28]. More recent research suggests an asymmetric shape [29] with higher reaction times for stimuli in the upper and left portions of the visual field. Here, higher reaction times imply delayed attentional or processing mechanisms which may suggest the need for more assistance in these regions. Additionally, the slower reaction time in the left portion of the FFoV is speculated to be due to the asymmetric nature of traffic (the study in [29] was conducted in Japan, a left-sided driving nation). This would imply an opposite effect for the purposes of this study, where the human subjects population was drawn from the USA (right-sided driving).

On the other hand, FFoV dynamics during driving are less well studied. In non-driving settings, it has been found that visual sensitivity is degraded just before and during eye movements or saccades, a phenomenon termed "saccadic suppression" or "saccadic omission" [6]. While previous work in the driving setting suggests a similar narrowing of the FFoV right after a saccade, this effect has not been directly investigated. In the most related work, Crundall et al. [8] asked subjects to press a button when they detected peripheral stimuli during a driving video watching task. Their data suggested that people watching ego-centric driving videos are more likely to detect more eccentric peripheral stimuli the longer it has been since the last saccade. While this is consistent with saccadic suppression, that work did not analyze the data to confirm this effect.

The studies described above sometimes use driving video-watching as a proxy for driving, or use driving simulators with highway driving scenarios where the driver largely only has to steer for lane maintenance and collision avoidance. In contrast, we use an active urban driving task where the driver must follow in-world signs (Figs. 1 & 2) to navigate as well as deal with traffic lights and other on-road vehicles and pedestrians. This leads to a more ecologically valid cognitive load on the participating drivers and consequently a more representative FFoV behaviour.

In developing intelligent driving assistance, it is imperative that we model human visual perceptual abilities accurately, so as to provide assistance in situations where its limits are reached. For instance, models that are restricted to foveal vision may underestimate driver SA, resulting in redundant assistive alerts or interventions. In the well-established area of aviation assistance [5] and more recently in some controlled driving studies [12], users are shown to turn off these functions when they receive too many redundant alerts. Recently, some work in the area has started to account for the role of peripheral vision in maintaining situational awareness, but this does not consider the dynamic nature of human peripheral vision nor the asymmetric shape of it [35], [37]. Considering the important role that peripheral vision plays in maintaining situational awareness while driving [33], the shape and dynamics of the FFoV should be accounted for by driver assistance systems.

Our research questions inspired by these motivations are:

1) What are the asymmetries in the shape of the Functional Field of View during driving? Are they specific to the driving task?
2) What are the dynamics of the Functional Field of View? In particular, how does the Functional Field of View degrade post saccade during driving? Is post-saccade degradation explained by the post-saccade shrinkage and in-fixation expansion of the FFoV, as hypothesized in [8]?

We present data from two virtual reality user studies, one involving participants engaged in a Driving task and the other with a Non-Driving task, which demonstrate evidence for the asymmetrical shape of the field of view (FFoV) during the driving task but not during the non-driving task. Additionally, we examine the detection of peripheral targets with regard to their onset relative to the duration of the driver's fixation in order to investigate the effects of saccadic suppression and provide partial support for this hypothesis.

II. Related work

A. Shape of the FFoV

When first introduced, the FFoV or UFoV was hypothesized to simply be a $30°$ region around the fovea [28] but many studies since have showed properties such as it being wider in the horizontal direction than in the vertical direction [17], narrowing with age [8], narrowing with cognitive load [22] and sensitivity to other factors. However, much of this work is performed in non-driving settings. In this section, we will limit ourselves to discussing previous work that attempts to characterize the shape of the FFoV during driving, via a driving simulator.

More recently, Park & Reed have used a flat screen frontal display and lane maintenance steering task to simulate driving [26], [27]. However, in these experiments: the display was limited to line drawings of a highway scene, peripheral targets were shown in specific fixed locations on the screen, and the driver's head was fixed using a chin rest and their gaze was fixed on a central fixation cross during the whole experiment. While this resulted in well-controlled gaze eccentricities of peripheral targets due to fixed gaze and target positions, the simulation of the driving task is limited since the participant does not have to perform complex navigation tasks and their cognitive processes are not similar to driving.

The closest work to ours was described by Seya et al. [29]. They performed an experiment with a screen-based driving simulator where participants drove on an expressway and performed a peripheral discrimination task where they responded to the sidedness of the character 'E' that would be intermittently displayed on the screen either naturally or mirrored. The peripheral 'E' was not fixed to be onset at particular screen locations and participant gaze was also free to move around naturally while driving, both improvements from previous studies. However, we address a few limitations in that study: first, right before peripheral target onset, the participant's current gaze position on the screen was displayed which could cue them to prepare for peripheral target presentation and hence change their attention behaviour from that during normal driving; second, they used a 19-inch screen which limits the extent of the driver FoV that can be studied (maximum eccentricity was $7.5°$; third, their peripheral targets were always spawned at fixed eccentricities from the gaze marker $(2.5, 5, 7.5°)$ while ours are not constrained; and lastly, participants drove on expressways which did not engage the same cognitive processes as complicated urban driving situations where driving assistance is likely to be required and FFoV needs to be understood.

B. Dynamics of the FFoV

The most explicit suggestion for saccadic suppression during driving comes from [8]. In this work, subjects were asked to view first-person driving videos on a 13.4" monitor and "look for any hazardous events in order to rate each clip on two 7-point Likert dimensions." The two dimensions asked the raters to evaluate the inherent danger and driving difficulty of the scene. Additionally, the screen had 4 overlays on the mid points of each side of the screen which occasionally lit up with a red light for $200ms$. Participants were asked to press a button when they noticed one of these targets light up. Unsurprisingly, they found that peripheral targets that were more eccentric (further) from the gaze center while appearing, were detected less often that those which were more central. One additional measure was that of onset fixation duration, which measured the length of the fixation that participants were making while the peripheral target was onset. Interestingly, spotted targets coincided with an average increase of $450ms$ in the OFD compared to missed ones. There were two possible explanations: spotting a target suppresses the next saccade, and increases the current fixation duration OR longer fixations may improve chances of spotting a peripheral target. It was also found that for more eccentric spotted targets, the OFD was larger, and most of this difference was pre target onset. This seems to support the latter explanation, that longer fixations improve peripheral detection but is not fully tested in previous work (or alternately, saccades lead to a narrowing of the FFoV). This is the particular effect we are looking to characterize out this paper. Other works have found similar indications —mostly in a non-driving setting [6], [15]. In driving settings, [29] shows that in a PDT, reaction times for peripheral target detection were longer for targets that appeared after the participant had saccaded in the last $100ms$.

Our experiment has some differences to the one in [8]. We use a virtual reality (VR) driving simulator instead of a flat screen, resulting in a much wider portion of the driver's field of view during driving being occupied (Fig. 1). Additionally, instead of using passive video viewing, we use a driving simulator, engaging cognitive processes closer to that of on-road driving. We also spawn peripheral stimuli in a larger range of FoV and in any location (as opposed to lighting up the fixed overlays used in previous work). Together, these changes enhance ecological validity of our experiment.

III. Experimental design

To answer our research questions, we conducted two psychophysics studies to gather data on peripheral detection task performance with and without driving. For the driving task, we ask participants to perform a direction following Driving Task (DT) in an urban environment using a VR driving simulator while also responding to peripheral stimuli that appear in various parts of their field of view (Fig. 1). In the Non-Driving Task (NDT), participants do not drive but are instead placed in a virtual "clean room" Fig. 3 where they also perform a peripheral detection task.

A. Driving Task

The experimental setup for our experiments, as shown in Fig. 1, consisted of a fixed-based virtual reality driving simulator. We used consumer grade hardware for the physical frame, steering wheel (Logitech G29), and VR headset (HTC Vive Pro Eye). The Vive Pro Eye was specifically chosen since it contains a built-in eye tracking module and easily interfaces with our simulator software via Unreal Engine. We used the DReyeVR simulator [30], which is a virtual reality simulator built on top of the Carla simulator [10], specifically for behavioural research. DReyeVR provides straightforward logging of simulated world events as well as participant behaviour (including eye gaze and driving actions) on a common timeline.

Participants were asked to follow directions provided by in-world signs (*e.g.* blue GOAL signs in Fig. 2) while obeying standard United States traffic rules. Participants first undertook a test drive (approximately 5 minutes), to familiarize themselves with the controls and the experience of driving while wearing a VR headset. During this time, they were also introduced to the GOAL signs and the peripheral detection task and asked to practice driving while responding to peripheral targets. Following the test drive, participants completed a pilot route and 4 experimental routes, each of which took $3-5$ minutes to complete (this varied based on how fast participants chose to drive through the route; to encourage natural driving behaviour we did not prescribe a speed). These routes were in four different urban environments (unseen by drivers), with varying amounts of traffic. Some pre-scripted safety critical scenarios (e.g jaywalking) also occurred during each of these drives, encouraging high driver alertness. Participants were encouraged to take breaks and step out of the simulator between breaks, especially if they felt cybersickness.

1) Peripheral target generation: For peripheral detection tasks, it is common practice to use either physical lights on the viewing screen [8], [9], or spawn visual artifacts like red blocks [32], [11] or Gabor filters [13] as the stimuli that subjects respond to. Similarly, we spawn red orbs at various retinal eccentricities, in the field of view the participant (Fig. 1 inset). In many of the previous experiments mentioned above, the targets are spawned at fixed directions([29]) locations with participants required to either fixate on a central point during the experiment [32], [11] or not [8], [9]. In both cases, fixed targets can lead to priming, where participants anticipate the appearance of stimuli only in certain parts of their field of view. In our experiment, both participant eye gaze and stimuli spawn locations were unrestricted to allow natural gaze behaviour during driving and coverage of the entire field of view.

The red peripheral target has a $5cm$ virtual radius and subtends about $2°$, a proportional size to the stimuli from [8] (their display device was a single 13" flat screen rather than in VR, so ours is scaled up).

The peripheral stimuli are spawned randomly in segments of 12 second intervals, for 250 ms each, similar to [8], [9].

We spawn our stimuli at a fixed distance away from the participant's eyes but at different retinal eccentricities. Specifically, the spawn direction is parameterized as a pitch and yaw, centered around the participant's head direction. The pitch and yaw are sampled uniformly from a $28°$ and $68°$ extent centered on the head direction respectively. The vertical direction is offset upwards by $15°$, since the car's dash blocks the view in the lower area of the FoV. This span represents more than a double increase in the available FoV in both directions than the previous works which use flat screen based simulators. Participants are instructed to follow a route marked with directional signs to a goal and to respond by pressing a paddle on their steering wheel when they detect a red orb which appears in their field of view.

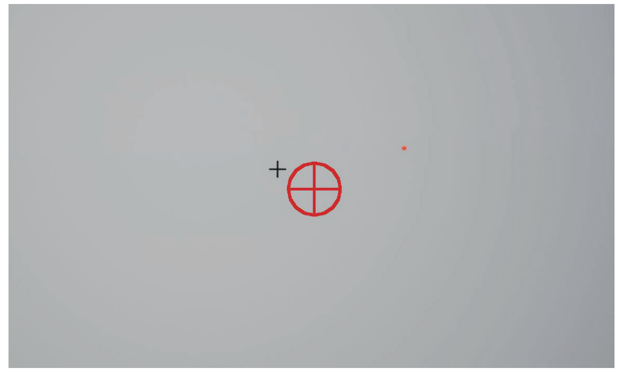


Fig. 3: Non-Driving task setup: simulated "clean room" with Fixation Cross (black cross), gaze location (red crosshair; not shown during experiment), and peripheral target (red sphere) displayed.

B. Non-Driving Task

The non-driving task was conducted in the same physical hardware setup as the driving experiment (Fig 1), with the paddles on the steering wheel used to indicated responses to peripheral targets. Participants were placed in a virtual clean room (Fig 3) where they were asked to fixate on a black cross (henceforth, Fixation Cross or FC) in the center of their FoV. Once the experiment started, the FC would intermittently move to a new location and participants were asked to keep fixating on it at all times. Once the FC moved, this would involve saccading to its new location. We moved the FC in order to control when the participants' gaze performed a saccade —as a reminder, we wanted to investigate if saccadic suppression was occurring in the non-driving task. After the FC moved and the participant gaze had moved to the new FC location, a peripheral target was sometimes randomly spawned for a brief period. Peripheral targets were not always spawned after an FC movement since we did not want the participants to game the task by responding every time the FC moved.

Additionally in the non-driving task, participants were instructed to utilize the left response paddle for peripheral stimuli presented to the left of the central fixation cross and the right response paddle for stimuli presented to the right. This manipulation was included as a means of ensuring that participants were accurately attending and responding to the target stimuli, rather than potentially gaming the task.

During pilots, some participants did not gaze at the FC immediately after it moved. Hence, to make sure targets were responded to only after the participants had completed a saccade to the new FC location, they were spawned after participant gaze moved near the FC.

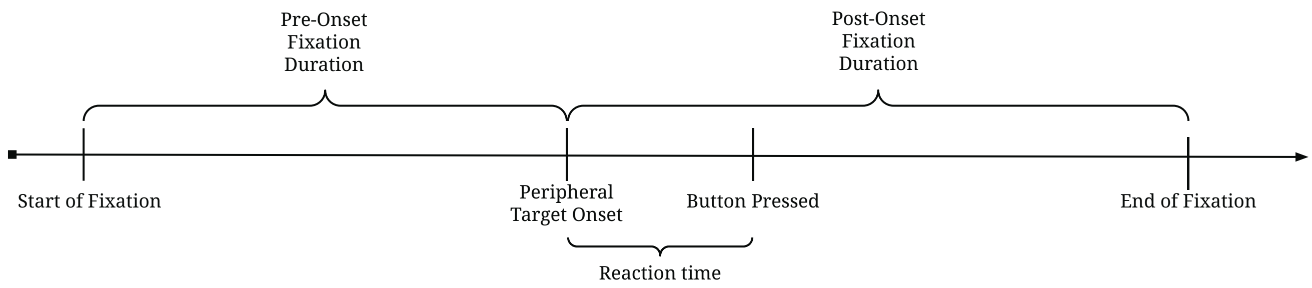


Fig. 4: Timeline of events during the trial in the case when participant responds to the peripheral target. Note that while the typical order of "End of fixation" and "Button Pressed" events is depicted here, they may interchange in order.

C. Participants

For the Driving task, participants were pre-screened using the Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short) [14] and participants scoring over the 75th percentile were not considered. Additionally, two participants who could not complete the test-drive without feeling nauseous, were also disqualified. In the driving task, we present data from $N = 10$ participants (not including pre-screens/test-drive failures) recruited using word-of-mouth from around the university (age mean: 24.7, range: $18-36$). All participants had held a driver's license for at least one year (mean: 6.7, range: $1-20$). Some of the participants were unable to complete all four drives and were immediately asked to stop when they felt slightly dizzy, resulting in 31 total collected driving episodes. The study was approved by the university's Institutional Review Board.

For the Non-Driving task, we recruited $N = 6$ participants using word-of-mouth recruiting. There was no requirement for these participants to have a driver's license nor were they screened for motion sickness (not required since the NDT did not involve a moving background). The NDT required fewer participants to get a comparable amount of data in terms of number of peripheral target onsets.

IV. Data collection and analysis

Before we delve into the data analysis, we will define some terms that will help clarify the timeline of events during a typical peripheral target appearance. Such a timeline is shown in Fig. 4. Usually, some time after a participant enters a fixation, a peripheral target appears. In the case where a participant accurately responds to a peripheral target, a button press occurs after the peripheral target onset and the time between these events is termed the "reaction time". For our experiment, if a button press was not detected in the 2 seconds following the appearance of a peripheral target, the target was considered to be "missed" by the participant.

At some point after the peripheral target onset, the participant usually exits their fixation. This may or may not be after the button press. The time from the start of the fixation during which the peripheral target is onset to its end is known as the "Total Onset Fixation Duration" (TOFD) corresponding to that peripheral target. This is divided by the peripheral target into the "Pre-Onset Fixation Duration" and "Post-Onset Fixation Duration". The "Pre-Onset Fixation Duration" is the time since the end of the last saccade and is the important part of the TOFD for the purposes of determining the effect of saccadic suppression on the FFoV. The "pre-OFD" will be simply known as the "Onset Fixation Duration" (OFD) in the rest of the paper.

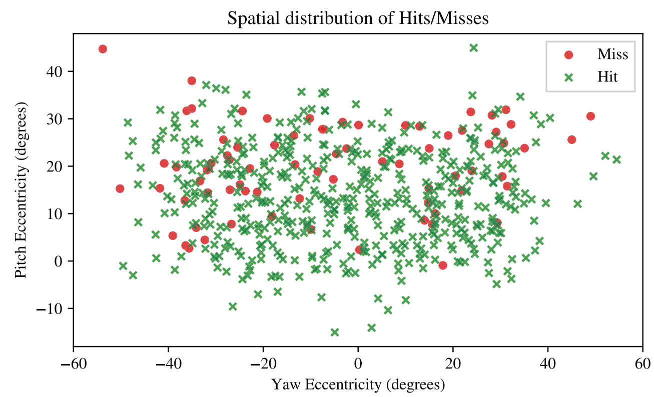


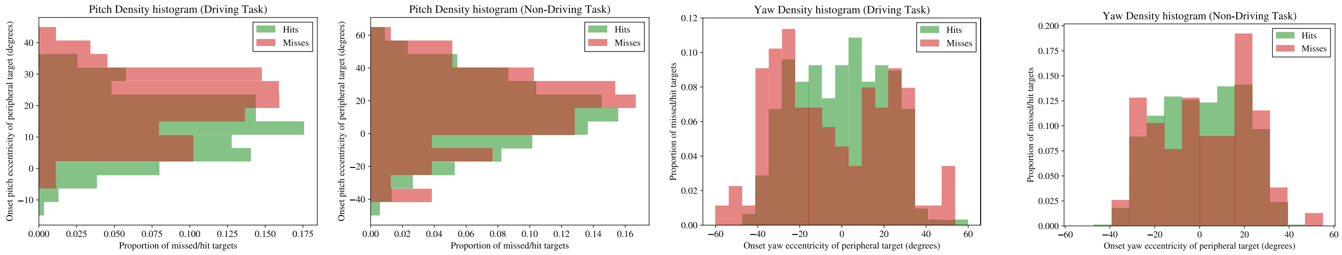
Fig. 5: Spatial distribution of peripheral targets with respect to driver gaze direction at the time of target onset (Driving Task only).

A. Gaze event detection

The gaze data obtained from our experiment was post-processed offline. The VIVE Pro Eye was used to obtain this data at the rate frames were displayed on the VR headset (approximately $50Hz$). This frame rate was not constant, due to different computational demands associated with rendering different parts of the simulated world. We used the I-BMM gaze event detector [31] to segment the gaze into fixations, gaze, and noise. This model uses a Gaussian Mixture Model to cluster point-to-point 3D gaze velocities. Two means corresponding to fixations (low velocity) and saccades (high velocity) are initialized.

B. Gaze eccentricity

When a peripheral target is onset, our experiment produces data tuples of the form: $(t_{ls}, \theta_t, \gamma_t, r)$, where t_{OFD} is the time since start of the last fixation (in ms), θ_t and γ_t are the pitch $\&$ yaw difference between the gaze direction and the peripheral target direction (in degrees), r is a Boolean indicating whether or not the driver responded to the peripheral target. The pitch and yaw are further combined



(a) Target pitch distribution during Driving Task.

(b) Target pitch distribution during Non-Driving Task.

(c) Target yaw distribution during Driving Task.

(d) Target yaw distribution during Non-Driving Task.

Fig. 6: Distributions of peripheral target pitches (a, b) and yaws (c, d) with respect to participant gaze direction at the time of target onset. Red curves correspond to misses and green to hits. Both distributions are normalized within groups. In the DT pitch distributions, misses have a statistically significant upward bias, indicating a "pitch blindness" effect during driving. Pitches of missed and hit targets are not statistically distinguishable in the NDT indicating the "pitch blindness" effect is modulated by the driving task.

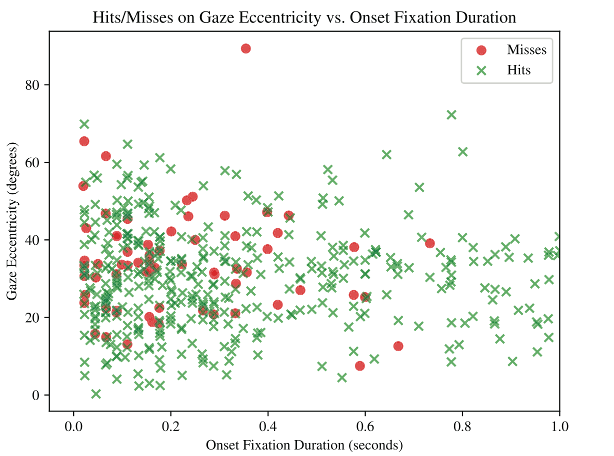


Fig. 7: Distribution of Gaze Eccentricities of peripheral targets vs corresponding (pre) Onset Fixation Durations. Only targets with OFD $<$ 1s (left) shown.

into e_t, the onset gaze eccentricity of the peripheral target (in degrees). The gaze eccentricity is defined as: $e_t = \sqrt{\theta_t^2 + \gamma_t^2}$

V. Results & Discussion

A. Shape of the FFoV

We first examine the spatial distribution of peripheral targets that were detected (hits) and not detected (misses) (Fig. 5). We find that driver misses are likely to occur higher in their field of view, indicating a downward bias of attention and supporting previous results in similar experiments. However, we find no evidence to support a right-ward or left-ward bias in attention which is suggested in some previous work [29].

Pitch. During the Driving Task, the distribution of misses was centered at a higher pitch (vertical) eccentricity in the driver's FoV than the distribution of hits (Fig. 6a). Using a two-sample Student's t-test, we found that the pitch eccentricity of hits ($\mu_{hit} = 12.94°$) was statistically significantly different than the pitch eccentricity of misses ($\mu_{miss} = 19.81°$) during driving $t(df) = -5.73, p < 0.001$). However, this difference is not observed in the Non-Driving task ($t(df) = -1.55, p = 0.12$).

Yaw. In the Driving task, we see fewer misses toward the center of the yaw (horizontal) axis, which is to be expected since attention is central (Fig. 6c). However, we do not see any significant horizontal asymmetry of hits or misses in either Driving or Non-Driving task (Fig. 6). To test this, we divided the yaw miss distribution into two halves about $yaw = 0$, resulting in yaw_{right} (> 0) and yaw_{left} (< 0). Next, we mirrored the left side of the yaw distribution: $yaw_{mirror} = -yaw \ \forall yaw \in yaw_{left}$. Since these were not normally distributed, we compared yaw_{mirr} and yaw_{right} using a two-sided two-sample Kolmogorov-Smirnov test, which did not show a statistically significant difference between these distributions ($ks = 0.08$, $p = 0.65$). We also see no statistically significant difference between the two sides of the yaw distribution in the Non-Driving task ($ks = 0.06$, $p = 0.42$).

Reaction times. Additionally, we analyzed reaction times (time between target onset and participant response) for both tasks (for hit targets only). Average reaction time was 0.734s during the Driving Task and 0.605s during the Non-Driving Task. While there was no significant difference across the horizontal or vertical meridians within each task, the average reaction times across tasks did differ significantly ($t(df) = 11.35, p =< 0.001$), which is to be expected since the driving task is much more cognitively taxing.

Discussion. In prior work [29], the authors found an attention deficit in the upper and left portions of the FFoV. Their study used a slightly different peripheral detection task in which participants had to discriminate between the appearance of a mirrored/non-mirrored "E" in fixed locations around their point of regard. In their task, peripheral targets remained on screen until the participant responded. Hence, that study measured reaction times instead of detection rate as in our study. Our results partially agree with results found in prior work by finding an attention deficit in the upper region of the FFoV. However, we did not not find any attention deficit in the left region of FFoV.

The authors posit that slower responses in the leftward FFoV region may be due to left-sided driving in Japan (where the study was conducted) and the allocation of more attention to the right. Since our study was conducted in the USA (with right-sided driving), an equivalent result in our study would have indicated a leftward attention bias and a greater degree of misses in the rightward region of the FFoV. However, we found no difference between misses in left and right regions of FFoV.

One explanation for the difference in results between our study and prior work [29] could be that the driving scenarios in the prior work were expressway-based, while our scenarios involved urban driving. In expressway driving, there tends to be a more explicit separation of lanes than in urban driving. Due to the more structured nature of expressway driving, it may have been the case that fewer driving-relevant stimuli first appeared from the leftward direction. This bias would not be reflected in urban driving scenarios that our participants saw, where both left and right turns were represented and no dividers were present to separate oncoming traffic, yielding a more horizontally symmetrical distribution of attention.

Both our study and prior work found a downward-biased FFoV asymmetry in driving, but this effect did not hold in our Non-Driving Task. One explanation offered by Seya et al. [29] was the nature of the human visual system: "research has shown that the number of ganglion and cone cells is higher in the superior (lower) direction than in the inferior (upper) direction on the retina." However, our results provide evidence against this explanation, since vertical asymmetry does not occur during the non-driving task and hence cannot be attributed to the human visual system.

B. Dynamics of the FFoV

The distribution of the onset gaze eccentricities of the peripheral targets e_t (defined in Sec. IV) vs the Onset Fixation Duration (OFD, Sec. IV) for peripheral targets across all participants during the Driving task is shown in Fig. 7. From this plot (and Figs. 5, 6a, 6c), misses are observed to be overall more eccentric than hits during the driving task: mean eccentricity for hits and misses are $25.89°$ and hits $32.90°$ respectively (a t-test revealed this difference to be statistically significant, $t(df) = 5.02, p < 0.001$). This is also consistent with our findings in the previous section.

Additionally, we examined the distribution of OFDs for hits and misses. Misses tended to have shorter associated OFDs (0.41s on average) than hits (0.69s). Using a two-sample Kolmogorov-Smirnov test (to account for non-normally distributed data), we found that this timing of hits and misses was statistically significantly different ($ks = 0.234, p = 0.0011 < 0.01$). Further, we observed that 81.5% of all misses occurred within 0.5s of fixation onsets, while only 62.1% of all onsets fell within that period (89.5% misses/80% onsets within 1s).

Together, these data indicate that misses are most likely to occur in the first second of a new fixation. Note that this does not necessarily imply that drivers should avoid moving their eyes in order to maximize peripheral visual performance, since eye movements are necessary to perceive important scene elements during driving maneuvers such as turning, merging, lane changing, navigating, etc. However, the implication for driving assistance systems is that it may be beneficial to raise the cautiousness levels of the system during and right after driver saccades since drivers may be more likely to miss stimuli entering their peripheral FoV in these periods.

Lastly, we also examined interactions between OFD and onset eccentricity of peripheral targets to investigate the FFoV contraction and expansion hypothesis from Fig 2 and [8]. While misses were more eccentric and on average occurred closer to the start of driver fixations (indicating partial support for saccadic suppression), misses did not occur at significantly higher eccentricities at higher OFDs. Hence, no evidence was found for the hypothesis that the FFoV contracts post saccade and expands during fixations.

C. Limitations & Future work

A point of consideration in this work should be the interaction of any potential effect of saccadic narrowing of the FFoV with the narrowing caused by cognitive load. The widely accepted theory of general interference states that the FFoV narrows uniformly across all eccentricities under increased cognitive load [8], [9], [3], [13]. This is in contrast to the perceptual tunneling theory which posits an increased degradation of the FFoV at higher eccentricities under cognitive load [32]. In our experiment, we do not control nor explicitly measure cognitive load. If the general interference theory is true, then in the limit of large amounts of data, the effects of cognitive load would even out, since the degradation is uniform across eccentricities. However, if cognitive load is correlated either with higher OFDs (drivers fixate longer under higher cognitive processing) or higher eccentricities (more eccentric gaze behaviour is required during high cognitive load inducing tasks), in our limited sample this may have a competing effect.

To control the effect of cognitive load in FFoV dynamics measurement, a similar experiment could be carried out in which drivers are explicitly cognitively loaded at different levels via a calibrated N-back task [21]. If the same relationship between OFD and detection rates persists across all levels of cognitive load, we may rule out an interaction between those confounds.

Finally, more work is required to integrate our findings about the FFoV into intelligent driving assistance systems. Simple integrations could seek to allocate more perceptual resources, such as active sensing from the vehicle, to the upper portion of the driver field of view. Additionally, such perceptual systems may seek to lower their threshold of intervention if important stimuli enter the driver's FoV during, or less than one second after, a saccade.

VI. Conclusion

We investigated the shape and dynamics of the Functional Field of View of drivers' with a view on identifying psychophysical limitations that could be augmented by driving assistance systems. We found an effect of inhibition of peripheral target detection in the upper portion of drivers' field of view as well as an inhibition in the first second after a saccade occurred. However, we did not find support for the previously hypothesized post-saccade FFoV shrinkage and post-fixation expansion. Future work should investigate the effectiveness of deploying targeted assistance to augment drivers' perceptual capabilities keeping these limitations of the FFoV in mind.

Acknowledgments

We would like to thank Joe Chuen (George) Yu for his assistance in developing the experimental system and Reuben Aronson in brainstorming and inspiring this project.

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