Analysing the Effects of a Wide Field of View Augmented Reality Display on Search Performance in Divided Attention Tasks

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ABSTRACT

A wide field of view augmented reality display is a special type of head-worn device that enables users to view augmentations in the peripheral visual field. However, the actual effects of a wide field of view display on the perception of augmentations have not been widely studied. To improve our understanding of this type of display when conducting divided attention search tasks, we conducted an in depth experiment testing various view management methods. Results show that depending on display method, search performance either drops or increases gradually up to 100 degrees of field of view. This suggests that a rapid turning point in performance exists at approximately 130 degrees of field of view. Results also indicate that users exhibited lower discovery rates for targets appearing in peripheral vision, and that there is little impact of field of view on response time and mental workload.

Keywords: Augmented reality, see-through head mounted displays, peripheral visual field, information display methods.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Ergonomics

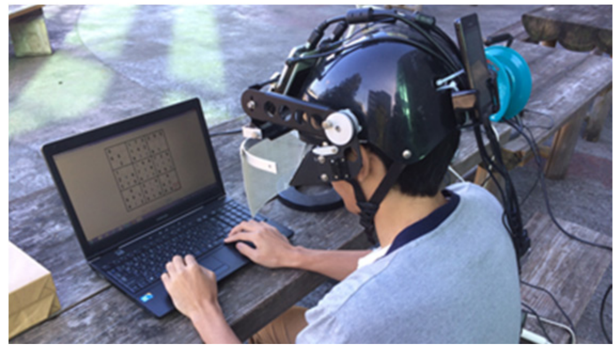

Figure 1: Outdoor experiment setup showing the task interface, wide FOV display, and head tracking apparatus.

1 INTRODUCTION

Augmented reality (AR) is a vibrant field of research that has steadily grown over the last decade. Nevertheless, many researchers are still trying to solve fundamental issues. In particular, perceptual issues have recently gained interest, mainly due to the development of new interactive visualization techniques optimized for visual perception and understanding. These techniques have traditionally been geared towards narrow field of view (FOV) displays, which are quickly entering the mass market. Wide FOV displays, which are more prevalent in immersive virtual reality (VR) setups, are likely to follow once technical limitations have been overcome. Still, even for this particular medium only few experimental results have been reported that focus on the understanding of the underlying mechanisms behind the perception of virtual content.

Enabling wide FOV in augmented reality displays has a number of benefits. AR see-through head mounted displays (HMDs) typically provide a 20-60 degrees of horizontal FOV [1], which is very narrow compared to the FOV of a human eye. The human eye enables vision within approximately 180 degrees horizontal and 125 degrees vertical. Humans rely heavily on the peripheral visual field [2], and limiting FOV greatly increases the difficulty of various visual tasks [3]. It can be expected that with a wider FOV, improved view management can be achieved since a wider screen provides more usable space, which can thereby reduce information clutter. In turn, this can considerably improve visibility, readability, and depth perception of labels [4]. However, to date, statistical and experimental evidence is not available to support these assumptions.

In this publication, we take a look at perceptual issues from a different angle, by analysing how wide FOV displays affect perception of augmented virtual objects. To do so, we conducted a thorough analysis of task performance when searching for target labels. The study presented in this paper is intended to provide the first insights into how the effects of a wide FOV display can be beneficial for the design and optimization of user interfaces for this kind of display. At the moment, design decisions are often conducted in an ad-hoc manner, mostly based on what is known from eye physiology and related work in (semi-) immersive environments. We explore to what extent a wide FOV affects search task effectiveness, and look more closely into related attention and mental workload issues.

Our study tackles these issues by monitoring user performance on a divided attention task. While solving a puzzle, users were asked to search for targets that are both within and outside their active FOV (the FOV containing augmentations), using two different types of view management. This task space is comparable to tasks generally encountered in AR navigation scenarios, where users also have to split their attention and concentration.

This work picks up where our previous study on wide FOV displays left off [5], offering a concentration-intensive setting more closely resembling real-world application, as shown in Figure 1. The experiment presented here focuses on a divided attention task to simulate a more practical outdoor AR scenario where users are presented with spatial guidance information while performing a real time task. Furthermore, the task was conducted outdoors with a wide FOV optical see through HMD, and

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involved a larger subject size yielding results which are more statistically sound. These results provide valuable and novel insights to the field of view management, and tell us more in general about search performance, related mental workload, and attention issues for designing appropriate interfaces for wide FOV AR displays. Subsequently, we will introduce related work and provide an introduction to fundamental physiological issues underlying the study and design of wide FOV displays. Thereafter, we present our study and outcomes, discuss implications of the results, and provide an outlook for future research.

2 Related work

2.1 Studies on perceptual issues in augmented reality

Perceptual issues have long been a central issue in the development of AR systems. Nonetheless, the in-depth study of these issues has only recently gained interest. In the mid-nineties, Drascic and Milgram [6] produced an initial overview of perceptual issues, which was recently structured and updated by Kruijff et al. [4]. At a general level, a number of AR perception studies exist that relate to issues in our study, like those focusing on stereo perception [7] and issues with egocentric depth perception [8][9].

2.2 Studies on wide FOV displays

Most studies targeting wide FOV have been performed on immersive and semi-immersive VR display systems. For example, Watson et al. studied level of detail effects in wide FOV setups, where low level of detail produced significantly worse search performance [10]. Targeting task performance, Arthur showed that the effect of FOV was significant in predicting performance for both searching for and locating a target by turning one's head, and walking through a simple maze-like environment [11]. A directly related study by Jones et al. found that peripheral visual information is important for the calibration of movement within medium-field virtual environments [12]. Similarly, Covelli et al. revealed that a narrow FOV alters head movement patterns of a pilot [13]. In contrast, Knapp and Loomis looked into the effects of narrow FOV, indicating that narrow FOV may not cause certain depth perception issues such as depth underestimation [14]. Finally, some studies have been performed on the effects of wide FOV within the frame of visualization on large display walls. Notably, Ball and North showed that from a number of tasks, increased opportunity for physical navigation is more critical for improved performance than increased field of view [15].

It remains to be seen if results from the VR domain also apply to AR, where our understanding is still rather limited. Looking predominantly at technical aspects of display design except AHMD [16], Nguyen et al. developed a wide FOV display [17], a rudimentary version of the display used in our study. Our previous study [5] investigated the effects of a wide FOV see-through HMD on finding target objects while navigating through a simulated outdoor maze using a CAVE display. It was shown that distribution of annotations to peripheral vision has a greater increase on the comfort of subjects than distribution only in the central visual field, while also decreasing the discovery rate, especially with FOV over 81 degrees.

2.3 Studies on view management in augmented reality

In comparison with studies on FOV, solving perceptual issues through novel visualization techniques has received more attention. The handling of clutter and occlusion in augmented environments, similar to the label management utilized in our study, can be found in various view management studies and systems. Among others, these systems optimize label placement for size and position [18], focus on depth-placed ordering [19], and involve label placement and appearance design in general [20][21], some with a focus on peripheral vision [22].

To the best of our knowledge, there are no studies that examine search behaviour in wide FOV wearable displays. This is the first study that 1) provides new insights on the effects of using a wide FOV for AR, and 2) analyses search behaviour and view management in such an environment.

3 Peripheral vision and search behaviour

In this section we provide an overview of peripheral vision aspects and interrelationships with search behaviour, and outline which factors are most relevant to our study.

3.1 Peripheral vision

Human vision is typically divided into central and peripheral vision. The parts of the eye responsible for central vision and corresponding degrees of FOV mainly consist of the fovea (5.2 degrees), parafovea (approximately 5-9 degrees) and perifovea (approximately 9-17 degrees), together forming the so-called macula [23]. In this publication, we regard peripheral vision as vision outside the perifovea, even though some regard peripheral vision as the area from about 60 degrees to 180 degrees [24].

3.2 Sensitivity

As has been known for long, the sensitivity of the central vision is very different from that of peripheral vision. Due to the distribution of rods and cones in the retina, peripheral vision is characterized by poor resolution [25] since the lower density of cells towards the border leads to the degradation in vision of colours, shapes, and text. For example, correct text information is acquired at no more than 2.5 degrees from the point of fixation when each character subtends approximately 0.25 degrees (a total of 10-11 characters) [26]. Some studies indicate the possibility of differences in colour perception in peripheral vision, pointing towards higher sensitivity of green and brown colours and slight differences between shapes [27]. In contrast, peripheral vision is relatively good for motion detection [28]. Velocity discrimination is as precise in the periphery as it is in the central vision, and motion detection in the periphery has been shown to direct eye movements in search tasks [29]. In relation to text recognition, studies have demonstrated specific thresholds for readability, with considerable increase in size towards the outer regions of the human field of view [30].

In this regard, the sensitivity of different areas in the retina is expected to affect view management of augmentations and search behaviour considerably. Both the noticeability and visibility of labels, as defined by parameters like colour, shape, and text, seem to be affected by location in the FOV, but the extent of these effects is not fully understood.

3.3 Pre-processing and attention

There is evidence that basic visual features (visible stimuli like colour, size and orientation) are pre-processed before actual attention is placed upon a certain object by moving the object into central vision [31]. Hence, we may know there are certain shapes (shapeless bundles of basic features) in the corners of our visual field in a wide FOV display, but have to put attention on the shape to recognize its form with all its local features. Object shape identifiers are believed to be stored in so called preattentive object files, which are different from the local features stored in object files [32]. Research seems to indicate that scenes are parsed in such preattentive objects, and that new objects seem to attract most attention, accessing information previously stored in preattentive object files [33].

In this regard, we may store scene content like labels or other augmentations in preattentive object files; however, we still need to look at and give our attention to the object to actually recognize the object during a search task. Attention is required to opt the preattentive object file and properly bind the features together. Attention itself is a complex issue, and only handled on a higher level in this article. More details can be found in [34].

3.4 Searching and discovery

Searching for information in the full visual field is affected by a number of factors. While searching, object features and context can significantly affect search behaviour. Search can be defined as identifying whether a target object is present or absent, and if present, where it is located [29]. Searching through preattentive objects is made possible in guided search processes, in which the combination of two or more feature processors operating in parallel in the visual field is used [35]. The features of an object in a preattentive object file can have an effect on search behaviour; however, to what extent is not completely clear yet. We assume that humans utilize overt attention to search for a similar target in a repeated manner. Hence, users will rely on past experience with the search task.

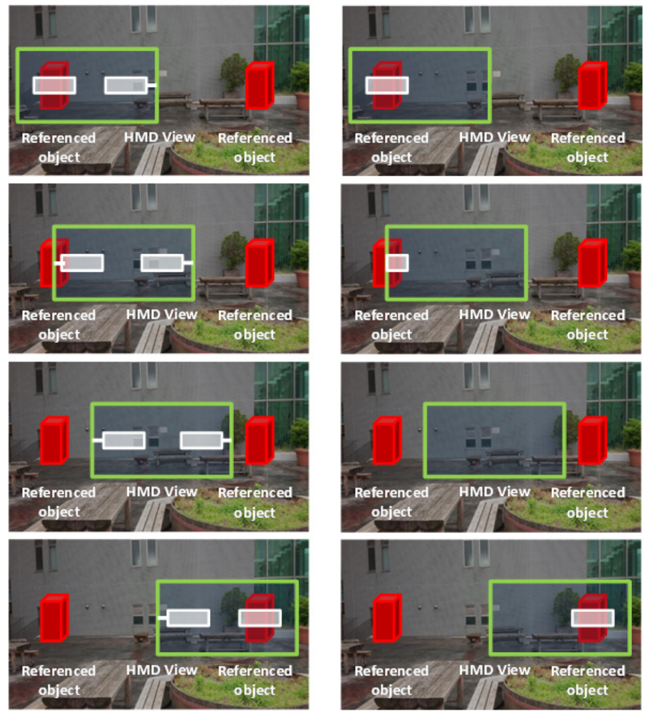
In this regard, it is generally believed that searching is affected by the context of the search task, which is created from a person's immediate environment [36][37], and may guide eye movement [38]. Context can thus be expected to directly affect search habits for virtual augmentations as well.

3.5 Mental workload

Finally, mental workload is known to reduce the area of one's visual field (perceptual tunnelling), but little is known about its effects on the shape of the visual field. Initial studies seem to indicate the expected limitation of the visual field and a potential shape distortion [39], but further research is needed. Regarding mental workload in divided attention tasks, some related research has been reported on car head-up displays (HUDs). For example, Horrey et al. showed that a HUD is better than normal displays regarding mental workload [40]. However, the extent to which a HUD may cause a decrease in mental workload is not completely clear. Some studies show it may cause increased mental workload during driving [40], yet other studies report the opposite [41].

With regards to our study, the separation of content in the visual field between preattentive objects and "recognized" objects can raise a number of questions. To what extent is content in the corner of the visual field perceived and can it draw our attention towards examining the features? Are features ignored while focusing on a main task in the central visual field? While we cannot fully answer all these questions yet, the study reported in the next section will illustrate a number of issues raised.

Figure 2: The wide FOV optical see-through HMD used in our experiments.



a) In-view labelling b) In-situ labelling

Figure 3: Schematic views of the two labelling techniques used. In "in-view" labelling (left column), annotations appear on the display with a corresponding leader line. In "in-situ" labelling (right column), annotations appear without a leader line as if they are affixed to the referenced objects in the environment.

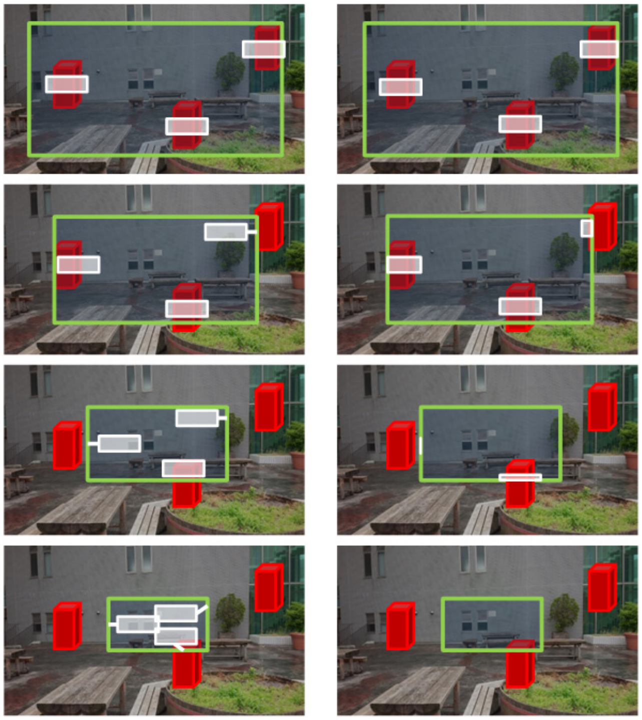
4 DISPLAY DESIGN AND VIEW MANAGEMENT

4.1 Display device and rendering

For the experiment, we used an adapted version of the wearable Hyperboloidal Head Mounted Projective Display (HHMPD), developed by Nguyen et al. [17] (see Figures 1 and 2). An HHMPD makes use of a retro-reflective screen placed around the user, with a hyperboloidal mirror and small projectors (3M MPro 110, VGA) attached to the user's head [42]. The projections are reflected back to the eyes from a mirror with a distortion correction algorithm, providing wide FOV (109.5 x 66.6 degrees) and optical see-through capability by a semi-transparent retro-reflective screen. The screen is made of thin strips of 3M Scotchlite High Gain Retro-reflective Sheeting 7610 with a 0.35mm interval attached on a curved acrylic plate. A visual acuity of around 20/200 for observed images is achieved with this configuration. The luminance of the observed white image is 60.2 cd/m^2. Further details on the adapted version can be found in [17]. Annotations are displayed in the environment using the GPS sensor and electronic compass of an Android-based smartphone (Samsung Galaxy S II) attached to the back of the display as shown in Figure 1.

4.2 Labelling techniques

Within the experiment we adopted two view management methods to handle labels. Depending on the display's current augmented FOV, objects may be within the "window on the world" outlined by the green box in Figure 3, or outside that window. We assume it may be useful to give users a pointer to referenced objects that are outside of the window. In particular, small FOV displays could benefit from increasing awareness of content outside the active FOV.



a) In-view labelling b) In-situ labelling

Figure 4: Schematic views of the two labelling techniques with different FOVs. In “in-view” labelling (left column), all annotations appear on the border of the HMD view regardless of the FOV. In “in-situ” labelling (right column), annotations appear only when the referenced objects are near the border of, or within the HMD view.

To test both methods for handling label placement, we adopted two different view management policies. The first policy, referred to as “in-view” labelling hereinafter, shows the direction of objects that are outside the FOV through a virtual annotation. This comes in the form of a small box at the border of the screen (closest to the referenced object), with a straight leader line that connects annotations and objects as shown in the left column in Figure 3. When the referenced object is within the viewing window, its annotation is simply placed on top of the object with no leader line.

The second policy, referred to as “in-situ” labelling hereinafter, simply registers annotations directly on top of the object in the environment as shown in the right column in Figure 3. Hence, in the latter case the user will not receive any cues to information that is outside the “view window.” Here, the user will need to rotate his or her head to scan for targets. In both cases, when multiple annotations overlap, their positions are slightly shifted to avoid occlusion.

Figure 4 shows schematic views of the two labelling techniques with different FOVs. In “in-view” labelling (left column), all annotations appear on the border of the HMD view regardless of the FOV. In “in-situ” labelling (right column), annotations appear only when the referenced objects are near the border of, or within the HMD view.

5 Experiments

Here we report on the methodology of the performed perception experiment, which was designed to examine particular perceptual issues encountered while using a wide FOV display for a search task. We selected tasks that would let us explore the relationship between FOV, view management, and location of targets in search tasks. In particular, we sought to answer the following questions:

Q1: Does FOV affect search performance in AR?
Q2: Does FOV affect mental workload in AR?

Lastly, in what way are these metrics affected if at all? To explore these issues, we used the two different label management techniques for displaying information during search tasks. This would allow us to measure the effectiveness of each technique at a different FOV, which was varied by changing the size of the window through which annotations were displayed. During the experiment, users split attention between a puzzle and searching for specific targets. Divided attention tasks like this often occur in AR environments, for example when navigating with virtual maps.

5.1 General design

We recruited 16 subjects (8 male and 8 female, mean age 23.4), and the study was conducted as a within-subject study, employing a 2x4 factorial design. As shown in Figure 1, subjects wore the HHMPD while seated on a chair in a university campus during a fixed timeframe in the afternoon, avoiding strong sunshine and rain, so background view was consistent between subjects. Using this setup, users were required to complete search tasks while solving Sudoku puzzles that were shown on a 15.6” laptop screen. A diagram of the experiment setup can be seen in Figure 5. The laptop was located on a table directly in front of the subject at a

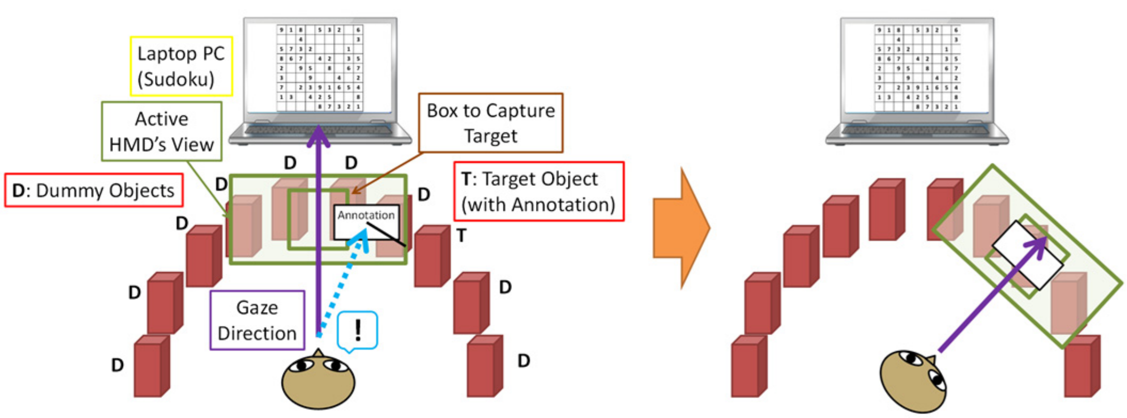


Figure 5: The experiment setup (left), showing participant gaze direction, dummy objects (red), the viewing field of the HMD (outer green box), the Sudoku interface on the laptop, and a sample annotation with leader line indicating that a dummy object has become a target (white box). Subjects rotated their heads (right) in order to select annotated targets by keeping its center within the inner green box for two seconds.

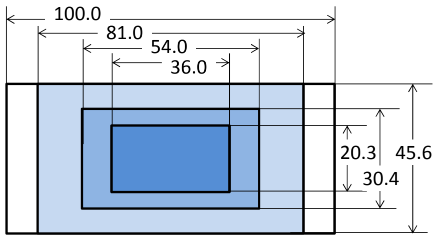


Figure 6: Four sets of horizontal and vertical FOV angle parameters in the experiment, 36 x 20.3, 54 x 30.4, 81 x 45.6, and 100 x 45.6 degrees, respectively.

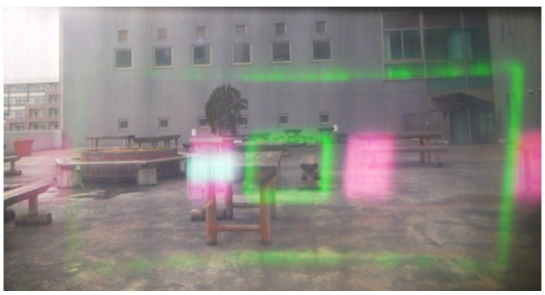


Figure 7: An example of a user's view seen through the HMD. In this case the active FOV is 54 x 30.4 degrees, indicated by an outer green box, in which white annotations will appear. Note that red dummy and target objects always appear in the entire FOV of the HMD regardless of the active FOV.

distance of approximately 50cm, and all participants knew how to play Sudoku.

While the subject solved the Sudoku puzzle, 10 virtual rectangles appeared on the display of the see-through HMD. Every 10 seconds, one of the objects, selected randomly, was annotated with a white rectangular target mark. Participants were tasked with finding these targets throughout the experiment. To prevent users from automatically looking for a target every 10 seconds, annotations were only displayed 10 times per Sudoku puzzle, randomly distributed between 29 of 10-second intervals over the course of each puzzle.

Focal distance (disparity plane) from the subject to the virtual dummy rectangles was fixed at 1 meter. Each rectangle was 8cm in width and 16cm in height, yielding its apparent size of approximately 4.6 by 9.2 degrees. The rectangles were displayed at angles in the real world ranging from -90 to 90 degrees in the horizontal, near the limits of the participant's peripheral vision, with minimum distances of 20 degrees in between. We define zero degrees as the angle of the subject's eyes to the centre of the laptop screen. Hence, angles were fixed in the reference frame defined by the laptop and the initial pose of the subject's head.

Independent variables were method of view management (in-view or in-situ) and angular FOV settings of the view window. We used four sets of horizontal and vertical FOV angle parameters, 36 x 20.3, 54 x 30.4, 81 x 45.6, and 100 x 45.6 degrees, respectively (see Figure 6). The choice of FOV was based on our previous study [5] to make a more effective comparison. The 100 degree parameter was added to this experiment, which is near the physical limits of the HMD. An example of a user's view seen through the HMD is illustrated in Figure 7. For each condition, we analysed error rates and head rotation to reveal any changes in attention on specific objects in the visual field. Though we did not measure the exact sensitivity of the eye, we can make some assumptions about differences in sensitivity of the retina with regards to noticing targets. We also looked into possible interactions with mental workload indicators. The following sections describe the study and discuss results, primarily in the context of performance and mental workload.

5.2 Search task and conditions

While the subject was solving each Sudoku puzzle, he or she was also required to center his or her gaze on a target if an annotation appeared. To count the target as found, he or she had to keep the gaze over the target for two seconds in order to count the target as found. To delineate the center of the screen, a 10 x 10 degree virtual green box was provided, as shown in the center of the virtual viewing field in Figures 5 and 7. The area was large enough to keep the target in the center box area with little effort. Once the target object was counted as noticed by the experiment software, it disappeared from the participant's field of view. Even if an object went unnoticed, it disappeared by the end of the 10 second interval in which it appeared. Task completion occurred when a Sudoku puzzle was finished or 5 minutes had passed.

As a result of the relationship between puzzle solving time and the appearance of targets, subjects ended up performing a different number of trials. The mean number of annotations displayed per subject per task was 18.0 (stddev 3.22), totaling 144.0 for the eight conditions. This resulted in a total of 2304 trials for 16 subjects for the eight conditions. Data recording failed during three trials for unknown reasons, leaving 2301 valid trials out of 2304 total. All eight view management and FOV conditions were counter-balanced between the subjects through Latin-square distribution. During the tasks, we measured completion times, discovery rate, and parameters that may provide some indication of attention [34], including head rotation. After solving two Sudoku puzzles (hence, after each condition) participants answered a survey regarding the subjective ease of noticing targets and ease of concentration on the puzzle. Mental workload was rated using the NASA TLX task load index [43].

6 Results

Here we discuss tendencies in the data we found using the 2301 valid trials, some of which we can compare to the previously conducted study in [5]. The results are divided into two sections, including search performance and mental workload. Within each of these sections, analyses of the impact of both FOV and view management are presented. Significant results (ANOVA with Bonferroni correction) and a comparison to prior research are presented in the discussion section.

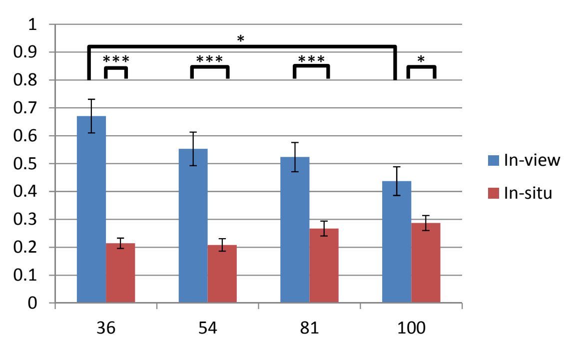


Figure 8: Target discovery rates with regard to FOV, showing the large difference between view management types. Linear regression suggests that a rapid turning point exists at 132.7 degrees of FOV.

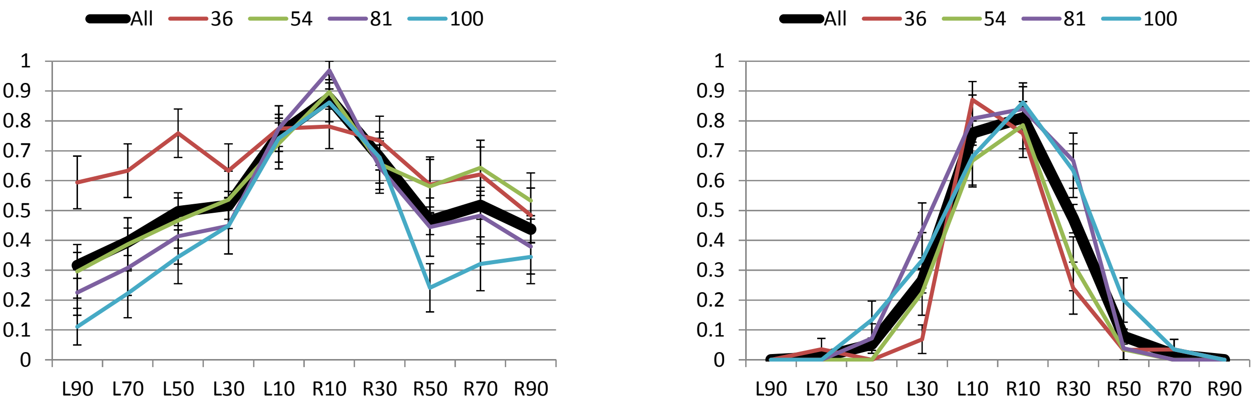


Figure 9: Target discovery rates with regard to target angle. (left) In-view labelling, (right) In-situ labelling.

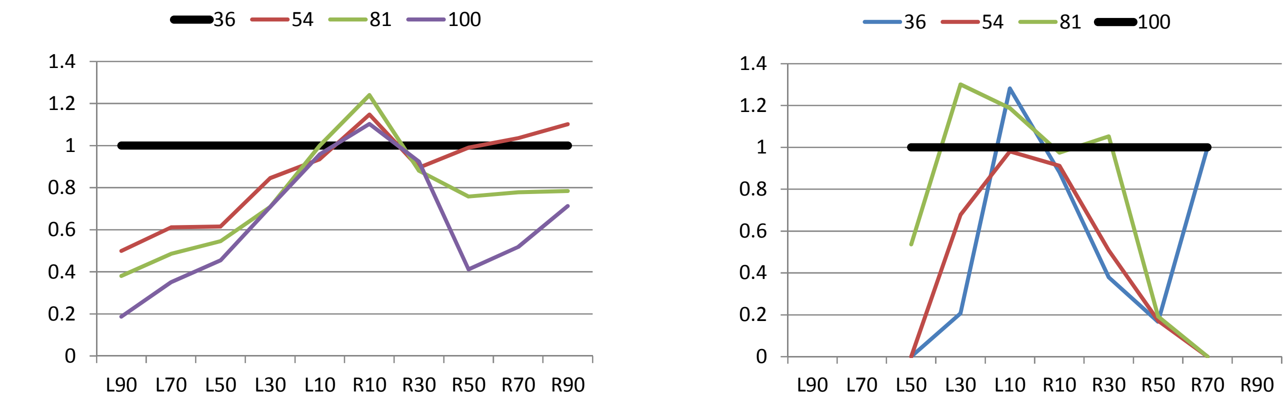


Figure 10: (left) Target discovery rates relative to that at FOV=36 degrees in In-view labelling, (right) target discover rates relative to that at FOV=100 in In-situ labelling.

6.1 Search performance

6.1.1 Discovery Rate

Our first finding with respect to **Q1** was a main effect of FOV on the discovery rate of target objects and an interaction between FOV and the view management method (in-view or in-situ labelling). Figure 8 shows the mean target discovery rates with regard to FOV. With in-view labelling, the discovery rate dropped as FOV increased ($F(3, 124) = 2.93$, $p = .0361$) whereas with in-situ labelling, the discovery rate rose as FOV increased ($F(3, 123) = 2.69$, $p = .0496$). With all FOVs, in-view labelling had a significantly higher discovery rate than in-situ labelling (36 degrees ($p = 8.47e-10$), 54 degrees ($p = 1.24e-06$), 81 degrees ($p = 5.02e-05$), and 100 degrees ($p = .0129$)). Furthermore, with in-view labelling there was only a significantly higher discovery rate between 36 degrees FOV and 100 degrees ($p = .0207$). As shown in Figures 9 and 10, target discovery rates are rather similar for different FOVs when targets are in the central visual field, but they drop for wider FOVs as targets appear further away from the central visual field. Determination coefficients of linear regression are very high ($R = 0.917$ and 0.895 for in-view and in-situ labelling, respectively) which suggest that a rapid turning point exists at 132.7 degrees of FOV.

6.1.2 Response Time

With respect to response time, we found a main effect of FOV on the response time for successful trials, measured from the moment of the target's appearance to the completion of its "capture" within

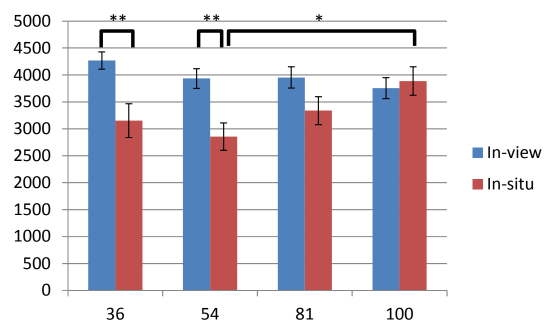


Figure 11: Response time in milliseconds (ms) for found targets with regard to FOV.

the 10 x 10 degree box in the centre of its view ($F(1, 916) = 15.0$, $p = .000117$). We also found an interaction between FOV and the view management method ($F(7, 916) = 3.01$, $p = .0295$). Figure 11 shows the mean response time with regard to FOV. With in-view labelling, FOV did not affect the response time. However, with in-situ labelling, the response time at FOV of 54 degrees was significantly faster than at 100 degrees FOV ($p = .0418$). The response time with in-view labelling was generally longer than in-situ labelling for narrow FOVs (36 degrees ($p = .00121$) and 54 degrees ($p = .00205$)). This is probably because the subjects succeeded in finding the targets that are mostly near the central visual field with in-situ labelling, as annotations would not appear when the targets are outside the HMD viewing window.

In Figures 11 and 12, for succeeded tasks, it is shown that FOV

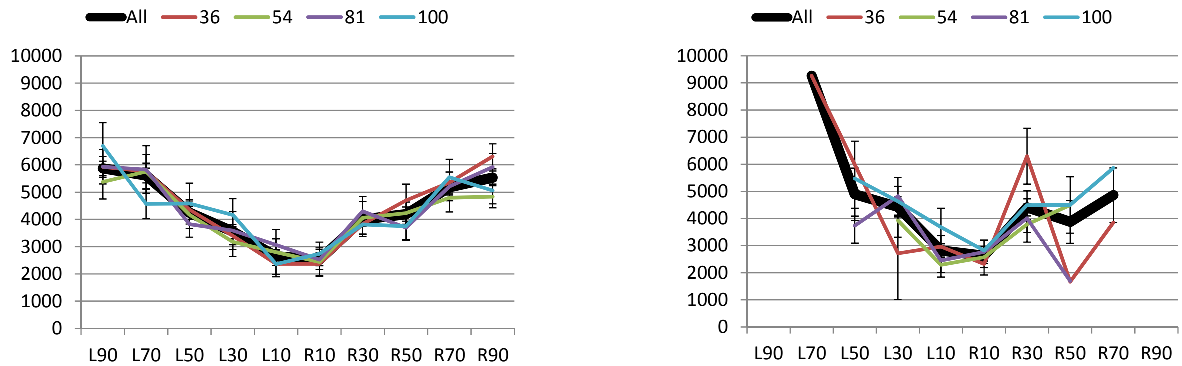


Figure 12: Response time (in ms) with regard to target angle with in-view labelling (left) and with in-situ labelling (right).

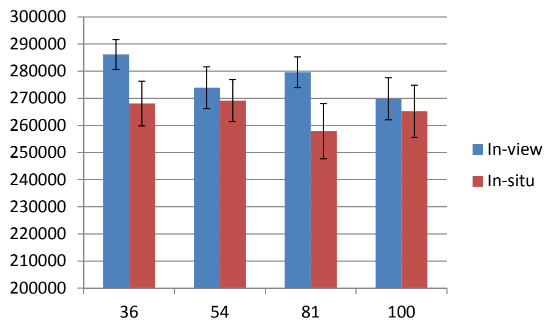


Figure 13: Time (in ms) to solve a Sudoku puzzle.

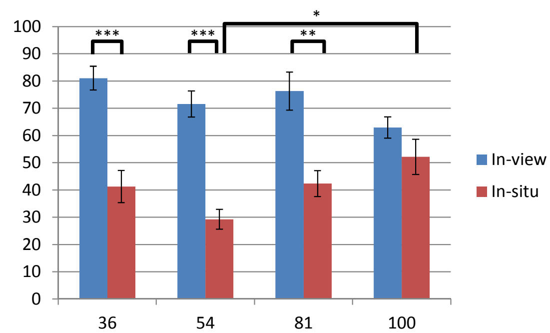


Figure 14: Head rotation (degrees) per succeeded tasks.

did not affect response time for in-view labelling, but a wider FOV resulted in slower response time for in-situ labelling, and that response time with regard to target angle was relatively consistent to different FOVs. The response time was faster with a narrower FOV for in-situ labelling, probably because the subjects just did not see the targets at wide angles and succeeded mostly for easy ones. We also found a strong correlation between the target discovery rate and the response time (R = -0.902).

However, it is quite surprising that we found no interaction between FOV and target angle on the response time (in-view ($F(39, 608) = 0.566$, $p = .964$), in-situ ($F(39, 251) = 0.954$, $p = .502$)). While discovery rate of targets would change with a wider FOV, the actual time did not differ. Normally, one would expect that as targets are noticed more easily, the response time would also be quicker, since users could focus directly on a target more easily.

6.1.3 Mean time to solve Sudoku puzzles

Figure 13 shows the mean time to solve a Sudoku puzzle with respect to FOV. A significant difference was found between the view management methods and Sudoku solving time ($F(7, 247) = 4.81$, $p = .0292$). We did not find any significant differences in correct Sudoku answers and number of key presses. Sudoku puzzles were solved faster with in-situ labelling. This result is consistent with the result of subjective ease of concentration on Sudoku (middle of Figure 14). However, no significant difference was found between FOV and Sudoku solving time ($F(7, 247) = 0.633$, $p = .595$). With wider FOV, solving times only improved slightly, which may be due to the decrease of object clutter in the visual field.

6.1.4 Head rotation

The analysis of head rotation with respect to target angle of both succeeded and failed tasks reveals some interesting issues. As expected, the head rotation exhibits patterns that are very similar to the response times shown in Figure 10, from which we may conclude that response time was affected considerably by the amount of head rotation needed to find a target.

Figure 14 shows the mean total head rotation per succeeded task. Linear regression suggests that a rapid turning point exists at 140.7 degrees of FOV, however, determination coefficients are not very high (R = 0.619 and 0.442 for in-view and in-situ labelling, respectively). In general, in-view labelling resulted in significantly more rotation than in-situ overall ($F(1, 916) = 51.0$, $p = 1.90e-12$), but with a higher rate of success (Figure 7), which is somewhat surprising. Previously, we found that the difference in response time for found targets with regard to FOV was much smaller between in-view and in-situ labelling (Figure 11). This indicates that in-situ labelling resulted in a much slower head rotation speed. A possible explanation may be that users searched more carefully, since they could not directly follow the line indicator as was possible with in-view labelling.

Upon analysing head rotation for failed tasks in Figure 15, some patterns can be noticed that are in line with expectations, but some also seem out of place. At first glance, one could expect that the graphs would look similar to the head rotation graph for succeeded tasks, since users did not know in advance if a target was visible or absent. Hence, we first expected that offsets caused by ignoring targets, or passing the 10 second threshold would be equally distributed among succeeded and failed tasks, yet the graphs look quite different. Additionally, there are some outliers for in-view labelling, where one would expect 100 and 81 to be close together, but rather 36 and 100 are closer, indicating random behaviour. A more accurate explanation is probably that head rotation is completely decoupled from the behaviour for failed tasks, letting users behave quite similarly; both graphs for failed tasks show a high similarity.

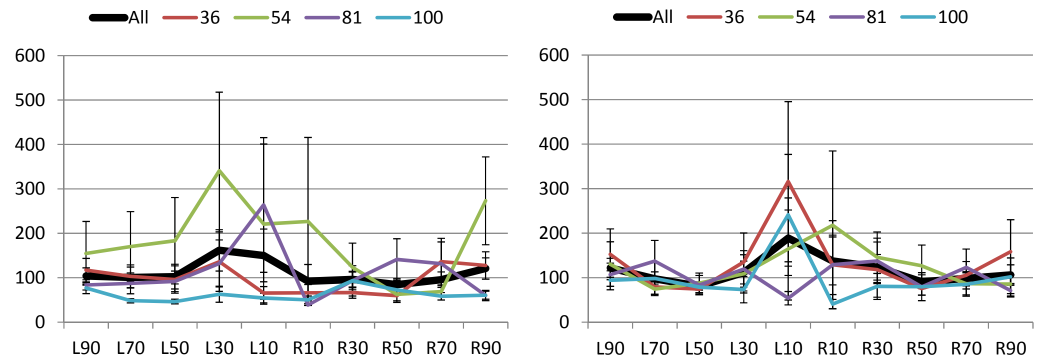


Figure 15: Head rotation (degrees) with respect to target angle, for failed tasks when target was existing, (left) In-view labelling and (right) In-situ labelling.

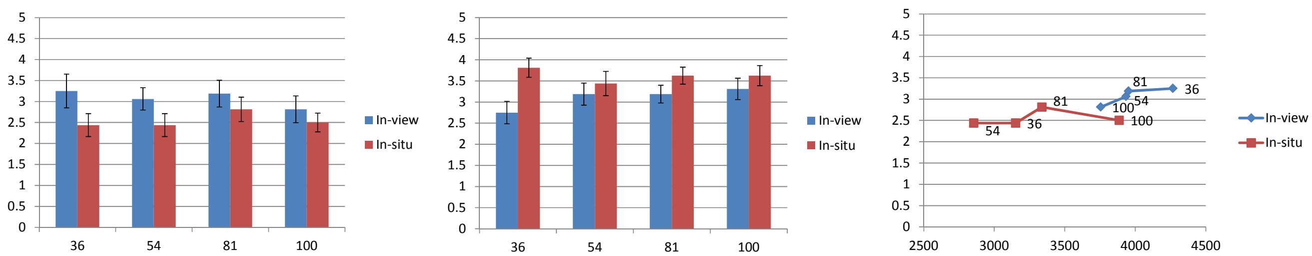


Figure 16: (left) Ease of noticing annotations, (middle) concentration on main (Sudoku) task, (right) response time and ease of noticing annotations.

6.2 Impact of FOV on mental workload

Regarding **Q2**, we expected that a wider FOV would reduce mental workload, since we assumed targets would be easier to find. However, our statistical analysis showed no main effect of FOV on mental workload for any target angle. Also, as we have shown in Section 6.1, target discovery rate and response time did not necessarily improve with FOV (in-view labelling). Users noted they were about evenly stressed by target search ($F(7, 120) = 1.94$, $p = .127$), Sudoku solving ($F(7, 120) = 0.525$, $p = .666$), and the overall task ($F(7, 120) = 0.0607$, $p = .980$) which may indicate that they truly divided their attention over both tasks quite evenly. We currently do not have a clear explanation why a wider FOV would not lead to a lower (self-reported) mental workload. As stated in Section 6.1, it may be that having targets at the border of the screen does actually increase mental workload. However, even though users would find more targets with a wider FOV (with in-situ labelling), the self-reported ease of noticing targets did not change significantly with FOV ($F(7, 120) = 0.296$, $p = .828$, Figure 16, left). The subjects felt it was easier to find annotations with in-view labelling than with in-situ labelling ($F(7, 120) = 6.26$, $p = .0137$).

The self-reported concentration on to the main (Sudoku) task did not change significantly with FOV either ($F(7, 120) = 1.16$, $p = .329$, Figure 16, middle). Users felt they concentrated more on Sudoku with in-situ labelling than with in-view labelling ($F(7, 120) = 8.86$, $p = .00352$). However, surprisingly there is no correlation to mental workload. Also there is no indication that cognitive resources are freed up from the secondary task and used for the primary task; ease of noticing and concentration levels stay approximately at the same level. Still, in general the ease of noticing may be surprising, since users obviously found significantly fewer targets at the outer regions of the FOV. A possible explanation may be that users were simply unaware they were producing errors. Linear regression suggests that a rapid turning point exists at 134.3 and 126.6 degrees of FOV, from ease of noticing annotations and concentration on main task, respectively. However, some determination coefficients are very low (e.g. $R = 0.067$ for concentration with in-view labelling). Finally, when comparing response time with ease of noticing over time, we see a rather flat result (Figure 16, right), where the fluctuation in response times may be caused by FOV rather than by the difficulty of noticing annotations.

7 Discussion

7.1 Discussion of significant results

As we showed in Section 6.1, a wider FOV does not necessarily lead to better search performance. In general, the results are not counter-intuitive, but it should be clearly noted that when using in-view labelling, a wider FOV does decrease performance considerably, while in-situ labelling never showed a significant improvement in performance over in-view labelling. In other words, FOV only positively affected a user's ability to find objects without leader lines, even though it never reached the performance of those with leader lines. Looking at Figure 8, an interesting question arises; in which FOV (if any) will there be no difference between tasks using in-view or in-situ labelling? While we cannot answer this question with the current set of data, linear regression consistently suggest convergence at around 130 degrees. A further experiment is needed to prove this assumption.

Regarding mental workload, increasing FOV does not necessarily lead to lower self-reported mental workload, but we noted a discrepancy between ease of noticing, actual response times, and discovery rate. Ease of noticing only declined slightly with FOV, but discovery rate rose (error rate dropped) with a wider FOV for in-situ labelling. Discovery rate dropped for higher target angles for both view management types. In subsequent experiments, it would be interesting to investigate a different balance between primary and secondary tasks, thereby studying the effect of wide FOV on mental workload in more complex search task conditions.

By design, both types of view management perform similarly while objects are within the same FOV since label display is the same for both techniques. Only in-view labelling can refer to objects outside the FOV. Current results seem to indicate that a point exists around 130 degrees at which performance in both in-view and in-situ labelling will be equal. Still, whether the point actually exists and where the two performance metrics converge is unknown. Additionally, increasing the FOV did not affect the Sudoku performance.

Finally and surprisingly, we found no significant learning effects or considerable improvements in performance over time.

7.2 Comparison to prior studies

Similar tendencies were reported in our previous experiment using an immersive CAVE environment [5]. In that study, target discovery rate was around 90% with a virtual wide-view HMD at 36 degrees FOV, which dropped to around 80% at 81 degrees for in-view labelling ("Type A" in [5]), while it was around 40% at 36 degrees which rose to around 60% at 81 degrees for in-situ labelling ("Type B" in [5]). This means that the target discovery rates are lower by more than 20 percent in the present experiment, but the general tendency is quite similar. The significant drop in the discovery rates is likely due to the more attention intensive nature of the puzzle task and outdoor lighting conditions.

A previous study in a virtual environment [11] reported a search performance drop by 12% and 24% when the FOV was 112 and 48 degrees, respectively, compared to that of 176 degrees. This is comparable, to some extent, to a performance drop by 12.9% and 31.1% with in-situ labeling when the FOV was 100 and 54 degrees, respectively, compared to that of an estimated saturated discovery rate at 132.7 degrees of FOV.

An increase in FOV with in-situ labelling would directly result in increased availability of targets (more targets were in the active FOV), even when targets were still difficult to notice farther in the periphery. Here, the physiological shortcomings of the eye likely affect results for in-view and in-situ labelling in a similar way. This is supported by the results shown in Figure 9 (right) and Figure 10 (right), where discovery rates are relatively similar for different FOVs for targets in the central visual field, but they drop for narrower FOVs as targets appear further away from the central visual field, specifically around L50, L30, R30 and R50. These numbers are interesting, since they seem to relate to specific decreases in sensitivity in the human eye, as noted by Osterberg [25], who revealed steeper drop offs at 35 and 55 degrees. From physiology literature, we can assume that once a target is within the visual field, information is processed at a low level, a process we previously labelled as preattentive object files (see Section 3).

Previous research has shown that visual events in peripheral vision would direct gaze [2], hence an optimization would be expected in both in-view and in-situ labelling. However, our data does not suggest this; the actual time is almost identical, with only a few outliers. Finally, when analysing the standard, we noticed that the deviations are not dependent on target angle in in-view labelling, since users can simply follow the leader line. In contrast, for in-situ labelling, the user will need to scan the visual field to find the target. A previous study using an immersive projection wall [13] revealed that a FOV less than 80 degrees horizontal alters visual scan pattern significantly. However, this tendency was not clear in the present study. Studies have also shown that when given manual control of content in the visual field, users tend to place text in a more central location just below the visual field in a video see-through display [44]. Our results support this previous finding in the optical see-through case, shown by the improved performance of in-view versus in-situ.

8 Conclusion and Future Work

Wide FOV displays are likely to change the way we perceive and understand augmented content, yet the full span of their effects are not well understood. In this paper, we shed light on several related issues by exploring to what extent a wide FOV affects performance in divided attention search tasks. We showed that search performance drops (in-view labelling) or increases (in-situ labelling) smoothly until 100 degrees of FOV. This suggests a potential convergence of the performances of two different view management methods at around 130 degrees in the FOV. In terms of design of head mounted displays, it is likely more important to consider method of annotation than FOV for search related tasks.

The analysis of head rotation confirmed some of the expectations that seem to be a direct trade off from the technique's characteristics (the availability or absence of a notifier to objects outside the FOV), showing similar patterns to changes in response time. Rotation behaviour for succeeded and failed tasks seems to be decoupled, which did not match our expectations. Regarding discovery rate, users are more likely to make errors for targets in peripheral vision. However, there is little impact of FOV on response time and surprisingly little impact of FOV on mental workload. Finally, in a divided attention task, FOV in certain circumstances can improve performance of main task, depending on view management method.

Our experiment and discussion thereof has a few limitations. As stated in Section 5, the number of trials was not consistent among subjects or conditions. It depended on the Sudoku performance of the subject. This introduces a slight bias toward those people who are not good at Sudoku puzzles, but, it is likely that the bias is very small due to the large number of trials. We did use a fixed number of targets and dummies. Also, we made a number of assumptions related to the eye physiology and attention, which will need more formal verification once better observational equipment can be coupled to wide FOV setups.

For further work, it will be very interesting to study the effect of FOV on differences in densities of targets. We expect that different levels of clutter will produce different results. Furthermore, to check for other attention effects, it would be useful to analyse actual eye movements with an eye-tracking apparatus. Finally, since users in the current setup were stationary, we intend to conduct an additional experiment by focusing on mobile content. This will allow us to analyse the effect of FOV on user performance while navigating through a larger environment embedded with dynamic augmentations.

In conclusion, we have provided valuable new insights into the understanding of the effects of different FOVs on search performance, showing both expected and unexpected behaviour. We hope these results can serve as basis for future research, to further extend our knowledge in this complex but highly interesting area.

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