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Impact of virtual reality head mounted display on the attentional visual field

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Abstract

Concerns about head mounted displays have led to numerous studies about their potential impact on the visual system. Yet, none have investigated if the use of Virtual Reality (VR) Head Mounted Displays with their reduced field of view and visually soliciting visual environment, could reduce the spatial spread of the attentional window. To address this question, we measured the useful field of vision in 16 participants right before playing a VR game for 30 minutes and immediately afterwards. The test involves calculation of a presentation time threshold necessary for efficient perception of a target presented in the centre of the visual field and a target presented in the periphery. The test consists of three subtests with increasing difficulty. Data comparison did not show significant difference between pre-VR and post-VR session (subtest 2: $F(1,11) = .7$, $p = .44$; subtest 3 $F(1,11) = .9$, $p = .38$). However, participants' performances for central target perception decreased in the most requiring subtest ($F(1,11) = 8.1$, $p = .02$). This result suggests that changes in spatial attention could be possible after prolonged VR presentation.

Introduction

Concerns about the potential impact of VR HMD on the visual system are not new but of particular relevance nowadays in view of the recent increasing availability of several VR HMD sets on the consumer market. Fatigue, as well as eye fatigue and factors connected to it, such as possible alteration in perception, ability to concentrate or focus (see [34, 22] for review) are usually reported among virtual reality experience aftereffects. Several studies have also investigated the impact of VR HMD on various visual performances metrics (visual acuity [20, 27], stereopsis [20, 27], oculomotor system [35, 14]). However, none to our knowledge has investigated the potential impact on the spatial extent of the attentional window.

The useful field of vision (UFOV) test is an objective measure of the attention spread [1, 30, 18]. The term was suggested in the studies made by A.F. Sanders [28, 29], who used a similar term, functional visual field, defined as "the spatial area, that has to be apprehended by the subject in performing a visual task" [28, p. 33], to refer to how far attention can reach without moving eyes towards the area of interest. Thus, a good UFOV is critical for a number of activities such as safe navigation while walking or driving. UFOV is not static and can be improved by training (e.g., see [3]) and influenced by different factors such as cognitive load [23] or mind-altering substances use [15]. A number of studies with elderly people [9, 5, 16, 10] and patients suffering of various perception and attention disorders [6, 7, 17, 21] have reported increase in UFOV in the participants after perception training with the use of virtual reality presentation (all these studies used UFOV test as an objective attention measure). However no studies have investigated if using a VR helmet for entertainment rather than a specific training could reduce the UFOV.

We know that the visual system can demonstrate some adaptation to changes in the allocation of attention, which is also evident from UFOV test results [26], and the field of view (FOV), in a VR HMD is, for technical reasons, strongly limited. This limited FOV could lead the user to focus on a central task, in a relatively soliciting environment, two factors which are known to lead to a deterioration of peripheral visual performances [2]. The aim of this study was thus to assess if the use of a helmet could have an impact on the visual spatial attention spread (as measured by the UFOV test).

Methods

Subjects

16 participants were recruited for this study (age M = 25.9±6.2 years, 3 women and 13 men). Assuming an effect size (Cohen's d = 0.8) lower than the one reported by Bentley et al [4] between young and older subjects (Cohen's d = 1.33), this number allows achieving a power of 0.95. In addition this number is also similar to the sample sizes used in some other studies with UFOV test and healthy subjects [23, 15]. All had normal or corrected to normal vision. If vision correction was necessary, participants used their usual prescription glasses or contact lenses. The study was executed in agreement with the tenets of the Declaration of Helsinki.

Design and apparatus

All recruited participants were presented a virtual reality game (a first-person shooter (FPS) game "Robo Recall", Epic Games, Inc.) using the Oculus Rift VR HMD (frame rate 90 Hz, horizontal/vertical FOV: 80°/90°(throughout this paper the symbol °is used to represent the unit of angle in degree)). This game was chosen because it is highly immersive (monotonous and prolonged tasks can induce a reduction of the UFOV [25]), uses a locomotion means that does not produce cybersickness and is freely available. Also, we wanted a game that would moderately favour central attention, and, according to El-Nasr and Yan [12], players playing FPS games tend to concentrate their eyes on the centre of the screen.

VR experience lasted for 30 minutes, which was shown to

Table 1. The UFOV test procedure. The test is divided into 11 subtests. The subtests are organised in sessions. Three sessions are taken before using the VR headset (pre-session) and one afterwards (post-session). For each subtest, the nature of the central task and peripheral task is represented.

Session	Subtest	Central task	Peripheral task
Session 1 (training)	1	⊞/⊠ or Nothing	⊞/⊠, without distractors
	2	⊞ or ⊠	⊞/⊠, 7 distractors
	3	⊞⊠/⊠⊞ or ⊞⊞/⊠⊠	⊞/⊠, 23 distractors
Session 2 (training)	1	⊞/⊠ or Nothing	⊞/⊠, without distractors
	2	⊞ or ⊠	⊞/⊠, 7 distractors
	3	⊞⊠/⊠⊞ or ⊞⊞/⊠⊠	⊞/⊠, 23 distractors
Session 3 (**pre-test**)	1	⊞/⊠ or Nothing	⊞/⊠, without distractors
	2	⊞ or ⊠	⊞/⊠, 7 distractors
	3	⊞⊠/⊠⊞ or ⊞⊞/⊠⊠	⊞/⊠, 23 distractors
Session 4 (**post-test**)	**2**	⊞ or ⊠	⊞/⊠, 7 distractors
	3	⊞⊠/⊠⊞ or ⊞⊞/⊠⊠	⊞/⊠, 23 distractors

be enough to cause aftereffects attributed to VR headset use [33]. Before (pre-session) and after the game (post-session), the participants went through the UFOV test (described in the next section and summarized in Tab. 1).

During the UFOV test, observers are to perform two tasks: identification of a target appearing in the centre of the FOV and identification of a target appearing peripherally. This test utilizes the decreasing detection abilities of observers with three factors: 1) central task demand, 2) peripheral task demand, 3) distance between the central and peripheral targets [1, 30].

The UFOV test was administered using a desktop monitor (frame rate 60 Hz, resolution 1920×1080, distance 60 cm, 41.5°). The test consisted of three subtests which followed one by one with increasing difficulty of the task.

As part of the pre-session, participants made two training attempts, as recommended elsewhere [4]. The first subtest was excluded from the post-session in order to shorten it, since the second and the third subtests had been shown to be more sensitive to complex attention and perception alterations [13, 36]. The post-session followed immediately after the virtual environment presentation. To summarize (see Tab. 1), participants took the UFOV-test four times: three in the pre-VR session and one in the post-VR session. The first two UFOV tests were used for training and the third one was used as baseline.

Procedure to test the UFOV

The procedure (summarized in Tab. 1) was based on the UFOV version administered with a personal computer [11]. A trial began with presentation of a black frame (7° wide and 4° high in the centre of the screen) on a light grey background (luminance = 18.2 cd/m^2). After one second passed, the central task target appeared in the black frame while the peripheral target appeared 20° away from the centre of the screen. The eccentricity of the peripheral target was chosen as the average eccentricity in the original procedure [1]. This choice was also based on several pilot experiments we carried out at 10° and 30°, which were respectively too easy or too difficult, i.e., performances were out of the recordable performance efficiency range of the test. Another argument was the fact that the chosen eccentricity is close to the ”eye-only range”, i.e., the range of gaze shift within which the head moves little or does not move at all [32]. The target (either central or peripheral) was a darker grey square (side 2°, luminance = 16.2 cd/m^2) either with a cross (⊠) or a plus (⊞) of light grey (luminance = 18.2 cd/m^2) in the centre. The target presentation was followed by a mask consisting of 400-500 white lines 1-3 pixels wide and 10-15° long, covering the area of the presentation for one second. After that, the participants answered the questions concerning the central and the peripheral tasks consecutively using the numpad keys of a regular computer keyboard. The procedure described here above was used for each subtest. The nature of the stimuli however varied as detailed here after.

In subtest 1, the central target appeared in 50% of trials, participants are asked to indicate if there has been any. In subtest 2, the central target was either a cross or a plus sign and participants were asked to indicate which of the two had been presented. In subtest 3, two central targets appeared side by side in the black frame, and participants were asked to indicate if the targets had been same or not.

The peripheral target appeared in all trials in all subtests in one of eight positions (top, top-right, right, bottom-right, bottom, bottom-left, left, top-left) at the distance of 20° away from the centre of the screen. The peripheral task was to indicate the position of the peripheral target. For the second subtest, in addition to the target, seven distractors (grey triangles with side 1.5°) were also presented in all the possible positions of the peripheral target except the one occupied by the peripheral target. For the third task, in addition to the 7 peripheral distractors, 16 more were presented 10° and 30° away from the centre of the screen. In all tasks, participants were asked to press “0” if they did not know the answer to the question.

The presentation time was varied with double staircase method [8]. Subtests consisted of blocks of 16 trials. 8 of them were presented for the shorter period of time (“ascending staircase”), the other 8 were presented for the longer period of time (“descending staircase”). If in 75% of a staircase trials both tasks were answered correctly, the presentation time was decreased, in the other case, presentation time was increased. Possible presentation time intervals fell between 16 ms and 240 ms with 32 ms step (7 positions in total). In the end of each block, the participant’s accuracy at answering correctly was presented to the subject.

A subtest was finished when two conditions were met: the ascending staircase presentation time had decreased at least once (or stayed at the maximum level) and the descending staircase presentation time had increased at least once (or stayed at the minimum level). For the second and the third subtests, the starting positions for the presentation time staircases were set on the basis of the previous first subtest results. The mean between the presentation times of the two staircases was used as a measurement of UFOV for a given subtest (i.e., the presentation time threshold, PTT).

Results

The results of participants whose PTT reached 240 ms (the maximum possible value available in the test) for any subtest in the third or fourth sessions were excluded from the data set, because they were considered to fail the test. For this reason, results of four participants were omitted from further analysis.

Our results (see Fig. 1) showed that the PTT changed significantly with increasing difficulty of the test (rmANOVA $F(2,22) = 65.6$, $p < .001$). Contrasts confirmed increasing PTT with increasing difficulty of the test (subtest 1 against subtest 2: $t(22) = 6.6$, $p < .001$; and subtest 2 against subtest 3: $t(22) = 5.2$, $p < .001$; means: subtest 1: .049 s, subtest 2: .113 s, subtest 3: .159 s). This is in agreement with the previous studies on the original procedure [1, 30]. It demonstrates that the alterations in the original procedure made specifically for this study did not disrupt the validity and measuring abilities of the test.

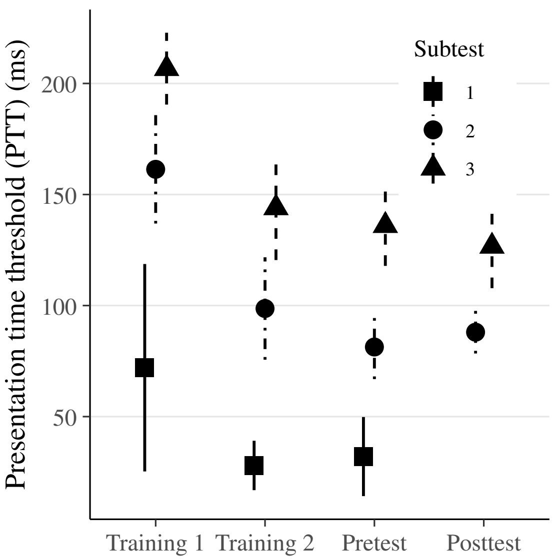

Figure 1. UFOV test results. *PTT for subtest 1 (circles), subtest 2 (triangles) and subtest 3 (squares). The lines indicate 95% confidence intervals for the given means. Session: 1, 2 - training, 3 - pretest, 4 - posttest. Note, that the data for subtest 1 (circles) are depicted only for first three sessions, since there was no subtest 1 in the post-session.*

The training effect in the pre-session was estimated in relation to the session number (sessions 1, 2 and 3). There was a main effect of session ($F(2,22) = 16.2$, $p < .001$). Contrasts showed significant decrease in PTT after the first session ($t(22) = -4.6$, $p < .001$; means: session 1: .11, session 2: .05), and no significant difference between the second and the third sessions ($t(22) = -.6$, $p = .57$). This provides support for the assumption that two training sessions were enough for the participants to reach the reliable level of efficiency.

The analysis of the effect of VR presentation on the UFOV test results showed that the PTT did not change significantly for subtest 2 ($F(1,11) = .7$, $p = .44$) nor for subtest 3 ($F(1,11) = .9$, $p = .38$). According to our results, the use of the VR headset did not thus lead to any attention spread changes compared to pre-test session base level.

Within the UFOV procedure, the participant's response is considered correct only if both central and peripheral tasks are performed correctly. Spread of spatial attention might, however, manifest in differences in peripheral and central tasks accuracy. For this reason, we also analysed the participants' performances in central and peripheral tasks separately. We used correct responses ratio as the accuracy metric separately for central and peripheral tasks in each of subtests 2 and 3. Repeated measures ANOVA analysis showed a significant decrease in accuracy in central task in subtest 3 after 30 s of VR-presentation ($F(1,11) = 8.1$, $p = .02$), whereas in perpipheral task no significant difference was found ($F(1,11) = .8$, $p = .39$). In subtest 2, no significant difference was found either in central task ($F(1,11) = .7$, $p = .41$) or in peripheral task ($F(1,11) = .4$, $p = .55$).

Discussion

Virtual environment exposure has been reported to have a long list of possible short-term aftereffects such as eye fatigue and disorientation [33]. Other studies have also shown that it could be successfully used to improve attention [10, 6]. The aim of this study was therefore to assess if the limited FOV imposed by the HMD together with a visually demanding environment could have an impact on our attentional spread shortly after use (and therefore possible consequences on some critical activities such as driving). As an objective measure of attention, we used the UFOV test [1, 30]. The UFOV is a validated test with proven reliability [11] to assess parallel attentional processing and that can be used to predict crash risk in older drivers.

Our results did not show any significant differences between UFOV results obtained right before VR presentation and immediately after it. Separate analysis of central and peripheral tasks performances revealed, however, a significant decrease in central task in subtest 3, i.e. the most difficult of the three subtests that combine identifying central and peripheral targets among distractors. This result is relatively surprising in view of our expectations (that peripheral performances could be reduced when compared to central ones) and the literature on UFOV (usually, reported changes in UFOV correspond to similar reductions for both tasks or a decreased performances for peripheral tasks [24]). This result could first be explained by fatigue. However, the UFOV test has been shown to produce similar scores up to five consecutive sessions (number limited by the overall number of sessions undertaken in the study) with 30 minutes long pauses between the sessions [4]. Since in our study participants took breaks between the sessions if necessary, we do not expect our test reliability to differ significantly from that achieved in this study [4]. This result could also be explained as a counter-effect of the limited FOV imposed by the VR headset. After having had their visual field constrained for 30 minutes, participants allocate more attention to the periphery at the expense of the central FOV. However peripheral accuracy did not improve and we did not really deprive the peripheral visual field. Matsushita et al. [19] have shown that the size of effective visual space [31], i.e. the size in which peripheral information can be utilized, is about 80° in diameter when playing FPS which corresponds to the FOV of the VR helmet used. Another possible explanation is that the nature of the game trained the visual search skills of the participant. Several studies (e.g. [3]) have shown that games, such as FPS, can improve visual attention skills. On the other hand, such improvement usually requires a very large number of trials, much longer than our 30 minute long game, e.g. Wu et al. [37] had 10 hours of training. In addition, such improvements do not generally transfer well to a different task and if FPS has common features with classic visual search, this is not the case of the UFOV test where the presentation time is too short for a classic search and the peripheral target appears at a fixed eccentricity. What might be possible is that the UFOV sessions and the VR session trained the subject to allocate slightly more attention to peripheral stimulus, explaining why accuracy in the central task in the most difficult subtest (two targets to identify in the third subtest opposed to one in the first and second subtests) decreased significantly.

In conclusion, our results show that the use of a commercial VR headset for 30 minutes entertainment does not present any risk in terms of UFOV reduction. The results also suggest that for better understanding of the effect of video games in a VR environment on the spread of attention across the FOV, further research may benefit from a larger sample size and, perhaps, more homogeneous task difficulty, as well as longer VR sessions.

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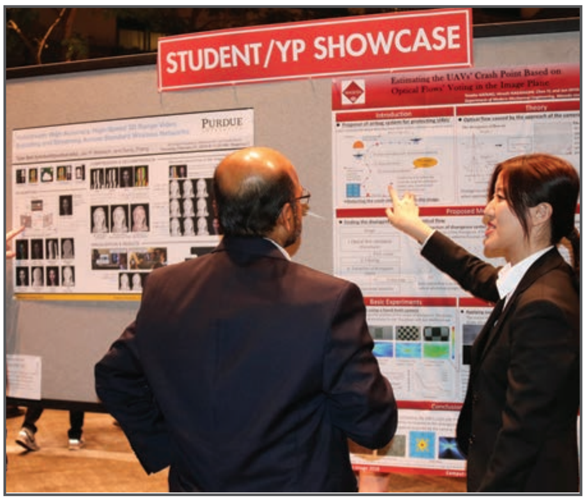

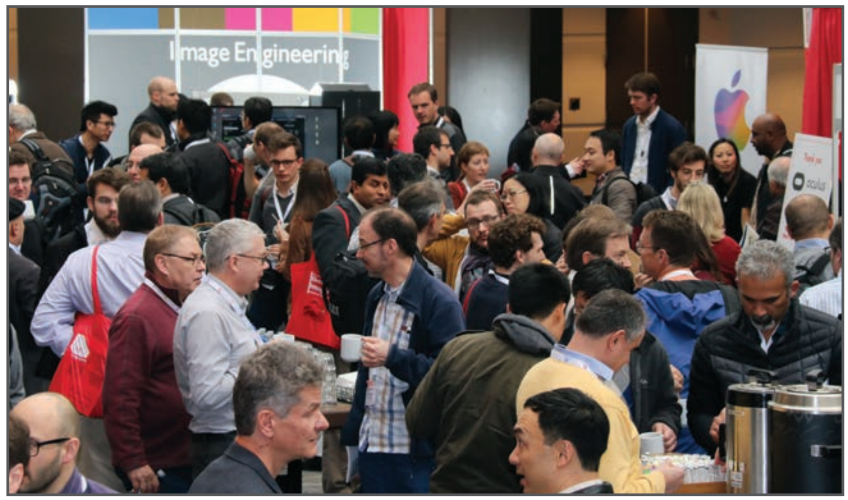

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