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Eye-tracking and Virtual Reality in 360-degrees: exploring two ways to assess attentional orienting in rear space

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Eye-tracking and Virtual Reality in 360-degrees: exploring two ways to assess attentional orienting in rear space

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ABSTRACT

The Posner cueing task is a classic experimental paradigm in cognitive science for measuring visual attention orienting abilities. Recently, it was suggested that this paradigm can be adapted in virtual reality (e.g. in an immersive and ecological environment) to evaluate the effectiveness of perceptual stimuli in directing attention and by extension to study the underlying cognitive processes. In this study, auditory and visual endogenous cue were used to voluntary orient attention at 360°. Two groups of participants (N=33 and N=28) equipped with a virtual reality headset including integrated eye-tracking performed a modified version of the Posner cueing task in a 360° immersive environment. In this task, participants had to destroy space objects, as quickly as possible, through eye interaction. Predictive visual or auditory informed participants about target location. The results show that these endogenous cues significantly improve performance even if the object to be destroyed occurred outside the visual field or through a mirror. This experiment provides one of the first demonstrations that attentional orienting mechanism can improve performances of visual information processing in an immersive and ecological 360° environment where information can appear in rear space.

CCS CONCEPTS

• **Human-centered computing → HCI design and evaluation methods**; **Virtual reality**.

KEYWORDS

attentional orienting, virtual reality, endogenous, rear space, front space, cueing, Posner task

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1 INTRODUCTION

Virtual reality technologies are currently in full swing. Due to lower production costs and to the improvement of displays and interaction, virtual reality headsets are becoming more popular every day. Furthermore, virtual reality allows the development of fully configurable, controlled, ecological, and complex environments. It allows accurate recording of targeted responses [Larson et al. 2014], and, thus, offers a new way to explore the cognitive processes involved in the processing of visuospatial information. Indeed, the majority of studies conducted in laboratories use relatively simple environments and standard computer screens (e.g. [De Schotten et al. 2011; Greenwood et al. 1993; Wang et al. 2010]), lacking, therefore, ecological validity. As a result, we are currently unsure how we select information in 360° immersive and ecological environments with a larger stimulated field of view and 3D objects.

Attentional orienting is one of the cognitive mechanisms involved in perceptual information selection. It is a fundamental cognitive function in charge of preparing information processing located or likely to be located in a particular region of space [Posner 1980]. Attentional orienting can improve the processing of the expected information (process rate and accuracy). The Posner cueing task allows to study the covert orienting mechanisms (i.e., an attentional shifting in the absence of significant ocular movement). In the classic version of this paradigm, participants are to perform a simple reaction time task in response to a target stimulus that may appear at different spatial locations (to the left or right of fixation). Attention is previously directed to one of these locations by using a cue such as a peripheral flash (to the left or right) or a central arrow (pointing to left or right) indicating the location where the target stimulus will subsequently appear. The main results show shorter response times (RT) when the cue predicts the correct location (valid) rather than when the cue is unpredictive (neutral) or predicts the wrong location (invalid) of the target [Chica et al. 2014],

even under covert attention (without eye movement [Posner 1980]). These results are attributed to a benefit of covert orienting to the location predicted by the cue. In this classic version, the cues used to direct attention are visual. But it is also possible to use auditory cues such as voice instructions or spatialized sounds [Frassinetti et al. 2002; McDonald et al. 2000; Van der Burg et al. 2008].

There are two modes of orienting: the first mode refers to the automatic capture of attention that is an involuntary reaction towards the cue, such as a flash or a sound coming from some region of space (exogenous mode of orienting); the second mode refers to orienting that requires information decoding and the deployment of a voluntary orienting strategy to the region predicted by the cues. Endogenous orienting implies top-down processing, which is used, for instance, when you read a caution "wet floor" sign and then pay attention to the wet surface. Endogenous cueing requires cues to be predictive (i.e. more valid than invalid cues) of a target location to create expectations. When the percentage of valid cues is high (e.g. 80%) participants can elaborate endogenous guidance strategies. In this study, we focus on endogenous orienting.

In everyday life, people tend to focus their attention on a relatively small area of the frontal visual field (in front of the person). As a result, some studies on attentional orienting have largely focused on frontal space orienting in hearing and vision [Driver and Spence 1994; McDonald and Ward 1999; Mondor and Zatorre 1995; Posner 1980; Spence and Driver 1997]. Much less common are studies on rear space orienting (outside the visual field and usually in the rear space). Nevertheless, it seems that the perception and reaction to stimuli in the rear space are different from what is observed in the frontal space. For example, the study of Ho and Spence [2005] suggests that when a stimulus is identified as coming from the rear space, it is unrelated to the same attention mechanisms as when it's identified as coming from the front space, even if, the information is presented in front of the subject (mirror reflection). Soret and colleagues [2019] have shown that by using a modified version of the Posner cueing task, it is possible to assess the effectiveness of different perceptual stimuli (cues) to orient attention in an immersive and ecological environment through the use of a head-mounted display and eye-tracking system. In line with this research, in our study, we aimed to understand if manipulating endogenous orienting through auditory and visual cues could improve the processing of visual information in an immersive environment where information to be processed can occur at 360°. To do so, we have designed two distinct virtual reality experiments to assess the reliability of two modified versions of the Posner cueing task for the study of 360-degree attentional orienting. We assume that all cues would improve RTs when providing reliable information about target location (valid cues) but with different effects depending on the modality used and the localization of incoming information (in front or behind the person). According to the existing literature, RTs should be shorter when information occurs in front of the participant rather than behind [Ho and Spence 2005; Spence et al. 2017] and auditory cues should result in shorter RTs than visual cues [Fernandez-Duque and Posner 1997]. We also expect that following the classic results of the Posner cueing task. Valid cues should produce shorter reaction times than neutral cues, which in turn should be shorter than invalid cues. Additionally, the magnitude of these differences may vary depending on target location

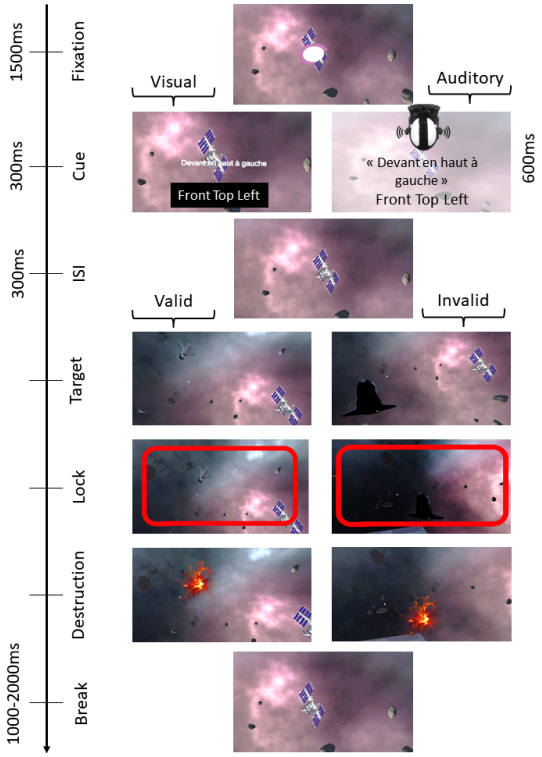

Figure 1: The time course of a trial (from top to bottom) of the first experiment.

(front/rear) and modality (visual/auditory). We assume that visual cue will be the most effective in frontal space [Chica et al. 2007; Schmitt et al. 2000], followed closely by auditory cues [Driver and Spence 1998; Tilak et al. 2008]. Auditory may be more effective than the intra-modal visual condition for the rear space [Ho and Spence 2005; Lee and Spence 2015].

2 FIRST EXPERIMENT

2.1 Materials and Methods

2.1.1 Participants. Thirty-three subjects (7 women, mean age±SD: 21±3), students of the French Aerospace Engineering School (ISAE-SUPAERO, Toulouse), volunteered to participate in the study. In accordance with the Declaration of Helsinki, all participants gave their written consent before the experiment. They did not receive any contributions for their participation.

2.1.2 Apparatus. We used an HTC Vive virtual reality headset with an integrated Tobii eye-tracking system. The eye-tracking system has a gaze data output frequency (binocular) of 120 Hz with an estimated accuracy of 0.5°. The trackable field of view of the eye tracker is 110° (full HTC Vive field of view). The experimental material consisted of a modified version of Posner cueing task developed using the Unity3D game engine supporting C# programming and the plugins needed for virtual reality (OpenVR and SteamVR) as well as the plugin needed for Tobii eye-tracking, Tobii Pro SDK.

2.1.3 Stimuli. The participant was placed in a virtual spatial environment and was surrounded with asteroids. Two types of cues were used: voice instructions corresponding to endogenous auditive cues and written instructions for endogenous visual cues. Instructions were three French words indicating the position: (Front/Back) × (Top/Bottom) × (Left/Right). Information provided by visual and auditory cues were identical. All instructions lasted 1.7s. The written instructions were displayed in a white font in front of the International Space Station (ISS). The target was a space shuttle of various size, from $11° \times 9°$ to $27° \times 14°$. The target consistently occurred outside the visual field and induced head movement of equivalent amplitude. The target could appear at 8 different positions according to the instructions. If we consider as a starting point a neutral head position (looking straight ahead), the frontal space extends from 90° to the left and 90° to the right. The field of view being 110° (55° on each side), the frontal targets were presented at about 70° to the right or left. Rear targets were presented beyond the front line at an angle of approximately 107° to the left or to the right. The top and bottom positions were perceived at a vertical angle of 30° up or down from a neutral head position (maximum vertical angle 100°, 50° up, 50° down). The central fixing point was the radial progression bar of diameter 18°. For valid trials, voice instruction was consistent with the effective position of the target. For invalid trials, only the vertical position of the target (up/down) was manipulated to avoid an active target search after cue occurrence.

2.1.4 Procedure. After completing a consent form, the participants filled out a preliminary questionnaire and read the information sheet. The main instructions were to destroy the target as quickly as possible using the provided cue. They were aware that 25% of the trials would be invalid and 75% valid and that only the up/down location could be wrong. Finally, they were informed to focus on the fixing point (on the HUD) until debris (the target) was visible. If participants moved their eyes too early, the trial was canceled and a new one was generated. During the training phase, each cue and each target's location were displayed at least once. Three ipsilateral invalid cues were displayed to clarify this specific situation.

Once the training completed, the experimental phase started. At the beginning of each trial, participants had to fix the fixing point until the progress bar was full (1.5s required to complete it). Then, a cue appeared as a function of the experimental conditions for 1.7s. After an interstimulus interval (ISI) of 500 ms, the target appeared at one of the possible locations depending on the experimental conditions. Participants then had to destroy the target by looking at it and pressing the "trigger button" on the HTC-Vive controller. After target destruction, an interval of 1.5 seconds was respected before the next trial. This experimental phase was composed of 50 trials including 25 trials with auditory cues and 25 trials with visual cues. For each cue type, we had 20 valid trials and 5 invalid trials (75 percent of validity). In the 50 total trials, 25 trials oriented attention to the front and 25 behind. The experiment lasted 15 minutes.

2.1.5 Data Analysis. All eye-response times (Experiments 1 and 2) were obtained by using a raycast (an invisible beam going in a straight line) which follows the position and direction of the participants' eyes (determined by eye-tracking system integrated into the helmet) and which activates the recording of the RT when it collides with a predefined object in the scene (here the target).

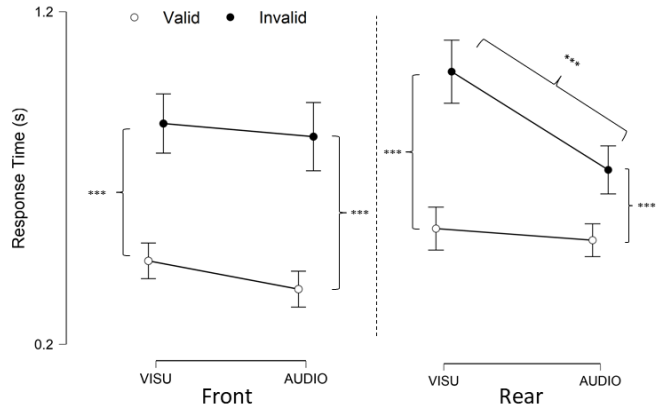

Figure 2: Mean RTs for Gaze–On-Shuttle according to validity, modality and location. $^{*} = p < .05, ^{**} = p < .01, ^{***} = p < .001$

We recorded two different RTs: motor response and ocular response. The motor RT, called Shuttle–Destruction, was the time between the end of cues' occurrence and the shuttle destruction by pressing a key on the controller. The eye-response time, called Gaze–On–Shuttle, was the time interval between the end of cue occurrence and the moment when the participant looks at the target.

We performed a statistical analysis to understand the effect of cues on subjects' RTs according to the spatial location of the target, validity of the cue and cue's modality. We excluded RTs greater than 1.4s (threshold often used in selective attention studies, e.g. [Schoeberl et al. 2015; Ter Huurne et al. 2015]) or shorter than 0.05s (1% excluded). The analysis includes 49.8±2.8 trials per participant for Shuttle–Destruction RTs and 49.9±1.9 trials per participant for Gaze–On–Shuttle RTs. We used the JASP software to perform a 3-way repeated-measure analysis of variance (ANOVA) on the average RT's for each dependent variable (Shuttle–Destruction and Gaze–On–Shuttle) in order to observe the effect of our manipulated factors: Validity (valid/invalid), Modality (visual/auditory) and Location (Front/Rear). Fisher LSD test was used for post-hoc comparisons.

2.2 Results

The exact same result pattern was observed for Gaze–On–Shuttle and Shuttle–Destruction. For clarity, we present only Gaze–On–Shuttle's RTs, . As expected, the analysis revealed a significant main effect of the cue validity, $F(1, 32) = 185.7, p < .001, \eta^2 = 0.85$. Subjects' RTs were significantly shorter when the cue was valid than when the cue was invalid (MD = 387ms). In addition, there was a main effect of cue modality, $F(1, 32) = 11.2, p = .002, \eta^2 = 0.26$. As already observed, the subjects' RTs were significantly shorter when the cue was auditory than visual (MD=113ms). Finally, the analysis showed a significant main effect of cue location, $F(1, 32) = 7.4, p = .01, \eta^2 = 0.19$. Like the results obtained by Spencer et al. [2017], participants obtained significantly shorter RTs when the target appeared in front rather than behind (MD=78ms).

However, there was a significant interaction between our three manipulated factors: validity, modality and location, $F(1, 32) =$

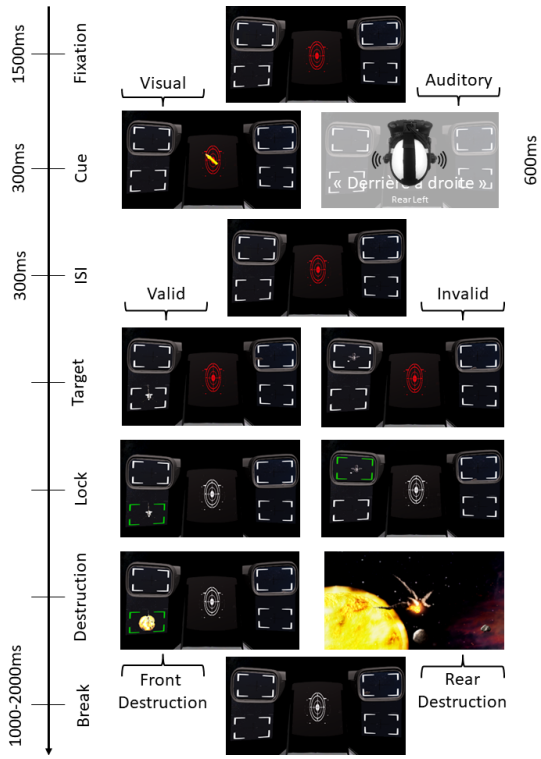

Figure 3: The time course of a trial (from top to bottom) of the second experiment.

11.35, $p = .002$. Analysis of simple effect of validity according to location and modality showed an effect of cue validity in all modalities of all other factors manipulated (all $p < .0001$) but the cueing effect (difference in RT between invalid and valid trials) varies depending on cue modality and target location. When the target appeared in front, the cueing effect seemed to be identical for the visual modality and auditory modality. On the other hand, when the target occurred in the rear, the cueing effect was more important for the visual modality than for the auditory modality. Besides, analysis of the simple effect of modality according to validity and location showed that RT was significantly shorter for auditory cues than visual for invalid rear trials only, see Figure 2.

2.3 Discussion and Conclusion

As expected, we observed a main effect of cue validity as in Posner's classic studies. Participants had shorter RTs when the cue indicated a correct target location compared to incorrect. However, although this effect was present independently of other conditions, its magnitude (cueing effect) varied according to the target location and cue modality as revealed by the triple interaction between cue validity, target location, and cue modality. Indeed, when the target to be destroyed appeared in front of the participants, the validity effect was similar for the visual cue compared to the auditory cue. On the other hand, when the target occurred in the rear space, the validity effect seemed to be greater for visual cue compared to auditory cue. We can assume that the presentation of visual cues in front of the subjects automatically captures attention to the front. Thus, they entail an additional disengagement cost when attention must be directed behind compared with auditory cues that do not come from a specific spatial location, which might explain the greater validity effect for visual cues. To support this assumption, neutral cues would have been required. Consequently, experiment 2 will incorporate neutral trials. Finally, note that the relatively large size of the observed validity effects (>150ms) leads us to believe that artifacts were probably due to the subject's head movement. In the second experiment, a new version of Posner's task limiting head movements effects was developed to minimize their impact.

3 SECOND EXPERIMENT

3.1 Materials and Methods

3.1.1 Participants and Apparatus. Twenty-eight participants (9 women, mean age±SD: 28±9) volunteered to participated in this study. The recruitment procedure was identical to Experiment 1. The same apparatus as in Experiment 1 was used.

3.1.2 Stimuli. The virtual environment was similar to Experiment 1 but this time participants were inside a fighter-like "spacecraft". "Aiming assistance tools" have been added at the front of the spacecraft to control target occurrence in specific areas of the visual field. These areas were identical in size and shape. This "aiming assistance tool" consisted of a head-up display (HUD) of $4° \times 5°$ size and which served as a fixing point. At the four corners of the HUD, there were two horizontally aligned transparent $6° \times 13°$ size viewfinders and two horizontally aligned $6.5° \times 13.5°$ size rear-view mirrors. The position of the rear-view mirrors and viewfinders was counterbalancing between the subjects.

Two types of cues were used: voice instructions corresponding to endogenous audio cues and directional arrows as endogenous visual cues. The voice instructions were the French translation of "Front left", "Back left", "Front right" and "Back right" or "Left Front", "Left Back", "Right Front", and "Left Front". Word order was reversed according to the subjects. The arrows were $0.02° \times 0.06°$ size. The voice instructions had a duration of 500-600ms and the directional displayed during 300ms. The targets were "space debris" of varying size and randomly assigned according to the subjects. As in the first experiment, if we consider a head neutral position (looking straight ahead) as the starting point, the frontal space is 90° to the left and 90° to the right; the rear space extends from 90° to 180° to the left and right. The frontal targets were presented at 45° to the left or right and the rear targets at 135° to the left or to the right. For invalid trials, the target could not appear at a directly opposite diagonal position. For neutral auditory cue, instruction was the french translation of "nearby debris". For neutral visual cue all arrows were displayed simultaneously with a size of $1.2° \times 1.7°$

3.1.3 Procedure. Similar to Experiment 1 but all actions were performed by gaze only. The same instructions as in Experiment 1 were provided except for interaction. Participants were invited to lock targets by looking at the viewfinder or rear-view mirror corresponding to the target's position. They had to focus until the target was destroyed for frontal targets (viewfinder) or to turn around and look at the target to destroy it for rear targets (rear-view mirror).

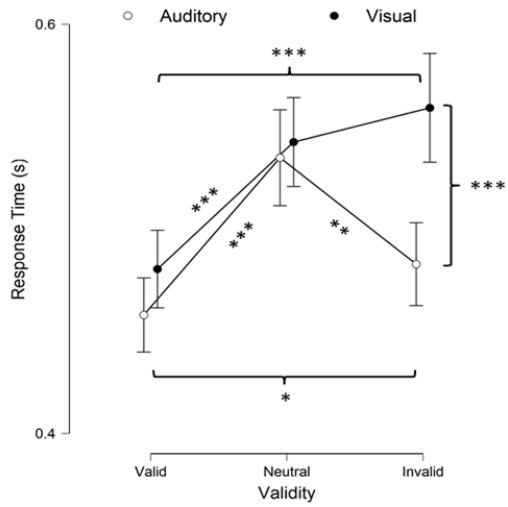

Figure 4: Mean RTs for Gaze–Initiation according to validity, and modality. $^{*} = p < .05, ^{**} = p < .01, ^{***} = p < .001$

Before the experimental phase, 16 trials were given to the participant as training (8 trials per cue type). After a 300ms ISI, the target appeared in one of the 4 possible locations. Once the target appeared, participants had to destroy it following instructions described above After the destruction of the target, a variable time interval of 1 to 2s was respected. The experimental phase consisted of 120 trials: 60 trials per cue type (visual/auditory), divided into 20 neutral trials, 30 valid trials (15 front and 15 behind) and 10 invalid trials (5 with target occurrence to the front and 15 to the rear). The total duration of the experiment was 35 to 45 minutes, including a minimum of 25 minutes of experimental sessions.

3.1.4 Data Analysis. We recorded two different eye-response times, both starting from the target appearance. Gaze–Initiation corresponds to the moment when the participant initiate eye movement, Target–Lockdown — when the participant gazed at the viewfinder / rear-view mirror corresponding to the target position (eye response). The same RT filter as in Experiment 1 was applied (1% excluded) The average RT of 2 participants for Target–Lockdown (M=1.975s and M=1.413s) was above the upper limit (Q3 + interquartile range × 1.5) compared to the sample. The data obtained on these participants were considered as outliers and removed from the analysis (see [Tukey 1977]). The analysis includes 118.8±2.7 trials per participant for Gaze–Initiation RTs and 116.6±7.8 trials per participant for Target–Lockdown RTs. We used the JASP software to perform a three-way repeated-measure analysis of variance (ANOVA) on the average RTs for each dependent variable (Gaze–Initiation and Target–Lockdown) to observe the effect of our manipulated factors: Validity (valid/neutral/invalid), Modality (visual/auditory) and Location (Front/Rear). Fisher LSD test was used for post-hoc comparisons.

3.2 Results

For Gaze–Initiation, as for the first experiment, the analysis revealed a significant main effect of validity, $F(2, 56) = 26.0, p < .001, \eta^2 = 0.48$. A post-hoc test showed that subjects' gaze initiation were significantly shorter when the cue was valid compared to neutral ($p < .001$, MD = 69ms) or invalid cue ($p = .001$, MD = 52ms). Surprisingly, there was no significant difference between invalid and neutral conditions ($p = .318$). Besides, there was a main effect of modality with shorter RT for auditory cue than visual cue, $F(1, 28) = 9.25, p = .005, \eta^2 = 0.25$. Finally, the analysis revealed a significant main effect of cue location, $F(1, 28) = 5.63, p = .025, \eta^2 = 0.17$. Participants obtain significantly shorter RTs when the target appeared in front rather than behind them (MD = 29ms). However, we noted a significant interaction between cue validity and cue modality, $F(2, 56) = 10.6, p < .001, \eta^2 = 0.28$. Simple modality effect analysis according to validity indicated a significant difference between auditory and visual cues only for invalid trials ($p < .001$, MD = 169ms). Also, a post hoc test of validity according to modality indicated that when the cue modality is visual, the gaze initiation was shorter when the cue was valid than when the cue was neutral ($p < .001$, MD=62ms) or invalid ($p < .001$, MD=79ms) but there was no difference between neutral and invalid trials ($p = .652$). When the cue was auditory, gaze initiation remained shorter for valid cue rather than neutral ($p < .001$, MD=77ms) or invalid ($p = .048$, MD=25ms) but there was a very surprising difference between neutral and invalid trials with shorter RT for invalid cues compared with neutral cues ($p = .003$, MD=52ms), see Figure 4.

For Target–Lockdown, the analysis revealed a similar result pattern. The principal effect of validity was significant, $F(2, 52) = 38.8, p < .001, \eta^2 = 0.60$, with significantly shorter eye response for valid compared with neutral ($p < .001$, MD=80ms) and invalid condition ($p < .001$, MD=73ms). There was no significant difference between the invalid and neutral conditions. The modality effect also still significant, $F(1, 26) = 6.1, p = .021, \eta^2 = 0.19$, but the location effect was no longer significant $F(1, 26) = 0.86, p = .364, \eta^2 = 0.03$. However, the analysis revealed a significant interaction between cue validity and location. An analysis of the simple validity effects as a function of the location showed that RTs were shorter in the rear space than in the front space only for valid cue ($p = .05$, MD=17ms). No difference was found for neutral ($p = .38$) nor invalid cue ($p = .218$), see Fig. 6. Finally, the interaction between modality and validity was significant, $F(2, 52) = 7.2, p = .002, \eta^2 = 0.22$. Simple modality effects analysis according to validity indicated a significant difference between auditory and visual cues only for invalid trials ($p < .001$, MD=168ms). Also, post-hoc test of validity according to modality indicated that for the visual modality, there was a statistical difference between all validity condition with shorter RT for valid cues than neutral cues ($p < .001$, MD=68ms), for valid cues than invalid ($p < .001$, MD=98ms) and for neutral than invalid ($p = .026$, MD=30ms). For the auditory modality, participants' eye responses were shorter for valid cues than neutral ($p < .001$, MD=92ms) and for valid cues than invalid ($p = .018$, MD=47ms). we also found that RTs for invalid cues tended to be shorter than for neutral cues ($p = .054$, MD=45ms), see Figure 6.

3.3 Discussion and Conclusion

As expected, we observed a main effect of cue validity as in Experiment 1. While participants react more quickly for a valid cue, there is no significant difference between neutral and invalid trials. This

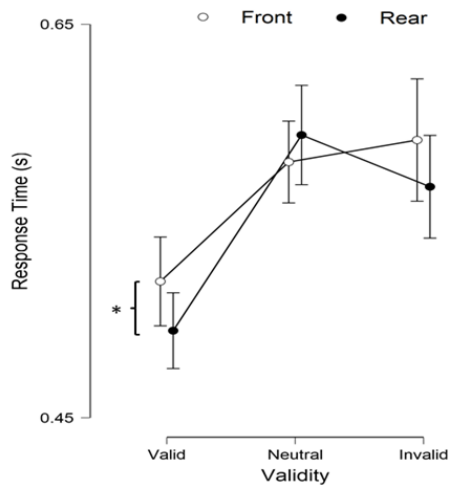

Figure 5: Mean RTs for Target–Lockdown according to validity and Location. $^{*} = p < .05, ^{**} = p < .01, ^{***} = p < .001$

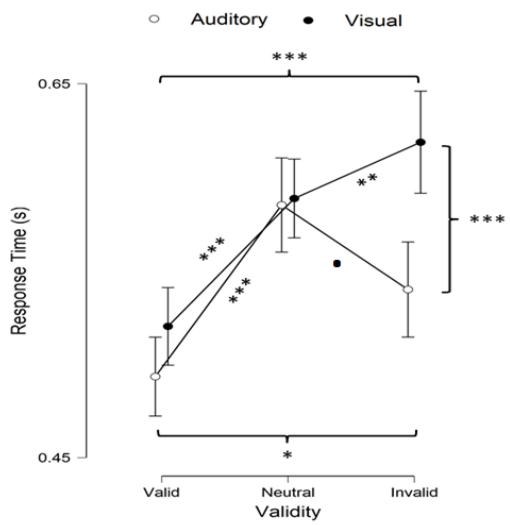

Figure 6: Mean RTs for Target–Lockdown according to validity and modality. $^{\cdot} = p < .10, ^{*} = p < .05, ^{**} = p < .01, ^{***} = p < .001$

is true for Gaze–Initiation and for Target–Lockdown. A significant interaction between modality and cue validity sheds further light on these unexpected results. It would seem that all the cues can be used to improve information processing regardless of its position in space but their costs seem to vary depending on modality and metrics. For visual cues, no significant cost was observed for gaze initiation. But, for target lockdown, our results replicate those usually encountered in the literature. Indeed, we observe shorter RTs when the cue indicates the correct position of the target compared to neutral cue (which does not provide information about target location). In turn, neutral cues triggered shorter RTs than invalid cues. For auditory cue, the results suggest a benefit when the cue indicates a wrong location of target occurrence rather than when the cue provides no information. This benefit seems to be significant for gaze initiation and marginal for target lockdown. This result is unexpected and determining its precise origins is rather difficult. Further study is needed to replicate and understand this effect. Finally, the main effect of cue location is significant for gaze initiation and shows shorter RTs for targets appearing in front rather than in the rear. This result suggests that participants processed information more efficiently when it appeared in front (viewfinder) rather than behind (rear-view mirrors mirror) even if all the information to be processed was provided in front. As in the experience of Ho and Spence [2005] and hypotheses suggested by Spence et al. [2017], it would seem that information that exists outside the visual field but is seen by reflection requires different cognitive processes than those involved in information processing that is actually present in front of us. Note that this effect is no longer significant for target lockdown. But a significant interaction between cue validity and location shows that RTs are shorter when the target appears in the rear rather than in the front when the cue provides correct information about target location, which could explain the absence of the main effect of location for this metric.

4 GENERAL DISCUSSION

The Posner cueing task is a classic experimental paradigm in cognitive science for measuring attentionnal orienting. Recently, it has been suggested that this paradigm can be adapted in virtual reality (i.e. in an immersive and ecological environment) to evaluate the effectiveness of perceptual stimuli in directing attention [Soret et al. 2019]. The objective of this study was to understand whether these mechanisms could improve the processing of visual information when this information appear outside the direct visual field and especially in the rear space. To do this, we assessed visual information processing performance (reaction time and oculometric response) in two spatial tasks when endogenous cues are provided to participants to trigger a voluntary attentional orienting in a specific region of the visual space (FOR of 360°). The two experiments replicated the classical results of the literature on Posner task which shows that it can be adapted for the investigation of the effects of 360-degree attentional orienting. Besides, our study suggested that a modification of this paradigm could allow us to study the orienting mechanisms involved in the treatment of rear space. In particular through the use of reflecting devices, such as a mirror, to simulate rear space which does not seem to involve the same mechanisms as those involved in the treatment of frontal space. Indeed, in experiment 2, even if all the information to be processed (the targets) was provided in front of the participants, as in a classic Posner task, it could be perceived through a window (viewfinder) or by reflection (rear-view mirrors mirror). This difference is not perceptual (the information being perceptually identical in both cases) but cognitive, i.e., the subjects were aware that the information seen in the mirror existed in the immersive environment behind them while the information seen through the window only existed in front of them, leading to statistically different response times between these two conditions. This result suggests that the real spatial location of the information to be processed (inside or outside the visual field of the subject) will influence the processing even if it is perceived in the frontal visual field. However, further studies are

needed to understand and measure the difference between orienting in front and orienting in rear space but this exploratory study lays the foundation for a new method of studying the processing of spatial information outside the visual field.

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REFERENCES

Ana B Chica, Elisa Martín-Arévalo, Fabiano Botta, and Juan Lupiánez. 2014. The Spatial Orienting paradigm: how to design and interpret spatial attention experiments. *Neuroscience & Biobehavioral Reviews* 40 (2014), 35–51.

Ana B Chica, Daniel Sanabria, Juan Lupiáñez, and Charles Spence. 2007. Comparing intramodal and crossmodal cuing in the endogenous orienting of spatial attention. *Experimental brain research* 179, 3 (2007), 353–364.

Michel Thiebaut De Schotten, Flavio Dell'Acqua, Stephanie Forkel, Andrew Simmons, Francesco Vergani, Declan GM Murphy, and Marco Catani. 2011. A lateralized brain network for visuo-spatial attention. *Nature Precedings* (2011), 1–1.

Jon Driver and Charles Spence. 1998. Cross–modal links in spatial attention. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences* 353, 1373 (1998), 1319–1331.

Jon Driver and Charles J Spence. 1994. Spatial synergies between auditory and visual attention. *Attention and performance XV: Conscious and nonconcious information processing* (1994).

Diego Fernandez-Duque and Michael I Posner. 1997. Relating the mechanisms of orienting and alerting. *Neuropsychologia* 35, 4 (1997), 477–486.

Francesca Frassinetti, Nadia Bolognini, and Elisabetta Làdavas. 2002. Enhancement of visual perception by crossmodal visuo-auditory interaction. *Experimental brain research* 147, 3 (2002), 332–343.

Pamela M Greenwood, Raja Parasuraman, and James V Haxby. 1993. Changes in visuospatial attention over the adult lifespan. *Neuropsychologia* 31, 5 (1993), 471–485.

Cristy Ho and Charles Spence. 2005. Assessing the effectiveness of various auditory cues in capturing a driver's visual attention. *Journal of experimental psychology: Applied* 11, 3 (2005), 157.

Eric B Larson, Maia Feigon, Pablo Gagliardo, and Assaf Y Dvorkin. 2014. Virtual reality and cognitive rehabilitation: a review of current outcome research. *NeuroRehabilitation* 34, 4 (2014), 759–772.

Jae Lee and Charles Spence. 2015. Audiovisual crossmodal cuing effects in front and rear space. *Frontiers in psychology* 6 (2015), 1086.

John J McDonald, Wolfgang A Teder-SaÊlejaÊrvi, and Steven A Hillyard. 2000. Involuntary orienting to sound improves visual perception. *Nature* 407, 6806 (2000), 906–908.

John J McDonald and Lawrence M Ward. 1999. Spatial relevance determines facilitatory and inhibitory effects of auditory covert spatial orienting. *Journal of Experimental Psychology: Human Perception and Performance* 25, 5 (1999), 1234.

Todd A Mondor and Robert J Zatorre. 1995. Shifting and focusing auditory spatial attention. *Journal of Experimental Psychology: Human Perception and Performance* 21, 2 (1995), 387.

Michael I Posner. 1980. Orienting of attention. *Quarterly journal of experimental psychology* 32, 1 (1980), 3–25.

Michel Schmitt, Albert Postma, and Edward De Haan. 2000. Interactions between exogenous auditory and visual spatial attention. *The Quarterly Journal of Experimental Psychology Section A* 53, 1 (2000), 105–130.

Tobias Schoeberl, Isabella Fuchs, Jan Theeuwes, and Ulrich Ansorge. 2015. Stimulus-driven attentional capture by subliminal onset cues. *Attention, Perception, & Psychophysics* 77, 3 (2015), 737–748.

Rébaï Soret, Pom Charras, Christophe Hurter, and Vsevolod Peysakhovich. 2019. Attentional orienting in virtual reality using endogenous and exogenous cues in auditory and visual modalities. In *Proceedings of the 11th ACM Symposium on Eye Tracking Research & Applications*. 1–8.

Charles Spence and Jon Driver. 1997. Audiovisual links in exogenous covert spatial orienting. *Perception & psychophysics* 59, 1 (1997), 1–22.

Charles Spence, Jae Lee, and Nathan Van der Stoep. 2017. Responding to sounds from unseen locations: Crossmodal attentional orienting in response to sounds presented from the rear. *European Journal of Neuroscience* (2017).

Niels Ter Huurne, Sean James Fallon, Martine van Schouwenburg, Marieke van der Schaaf, Jan Buitelaar, Ole Jensen, and Roshan Cools. 2015. Methylphenidate alters selective attention by amplifying salience. *Psychopharmacology* 232, 23 (2015), 4317–4323.

Rohan Tilak, Ilir Xholi, Diane Schowalter, Thomas Ferris, Shameem Hameed, and Nadine Sarter. 2008. Crossmodal links in attention in the driving environment: The roles of cueing modality, signal timing, and workload. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 52. SAGE Publications Sage CA: Los Angeles, CA, 1815–1819.

John W Tukey. 1977. *Exploratory data analysis*. Vol. 2. Reading, Mass.

Erik Van der Burg, Christian NL Olivers, Adelbert W Bronkhorst, and Jan Theeuwes. 2008. Pip and pop: nonspatial auditory signals improve spatial visual search. *Journal of Experimental Psychology: Human Perception and Performance* 34, 5 (2008), 1053.

Yan Wang, Jianhui Wu, Shimin Fu, and Yuejia Luo. 2010. Orienting and focusing in voluntary and involuntary visuospatial attention conditions. *Journal of Psychophysiology* (2010).

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