VERBAL DIRECTION OF INTERNAL ATTENTION IN VISUAL WORKING MEMORY ELICITS A RETRO-CUE BENEFIT WITHOUT HEMISPHERIC ASYMMETRY IN OCCIPITAL ALPHA: A MEG STUDY

Teemu Virtaintorppa

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Department of Psychology

University of Jyväskylä

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Visual attention can be focused not only on external stimuli, but also on internal visual working memory (VWM) representations. This internal attention is needed to prioritize relevant over irrelevant memory items, as the capacity of VWM is strictly capacity limited. Previous research has indicated that directing internal attention to VWM representations, as measured by retro-cuing, enhances memory performance. However, the neural mechanisms of this retro-cue benefit are not clear, although the neural marker of hemispheric asymmetry in occipital alpha has been associated with it. Previous research has focused mainly on symbolic cues. In contrast, this thesis investigated the impact of using verbal cues in shifting internal attention to VWM representations on memory performance and alpha activity. Specifically, we aimed to determine whether verbal cues elicit hemispheric asymmetry in occipital alpha and improve memory performance. We also sought to eliminate a confounding variable in the retro-cue paradigm. 14 participants performed a retro-cue task while undergoing MEG. We hypothesized that hemispheric asymmetry in occipital alpha would manifest as decreased alpha activity contralateral to the relevant memory item. We assumed this to be accompanied by a retro-cue benefit. Interestingly, only the latter hypothesis was supported; a clear retro-cue benefit was found, but no statistically significant asymmetry in occipital alpha was evident. We did note a trend towards stronger alpha activity in the right occipital hemisphere. These findings might have been caused by the lateralized processing of the verbal cues. Alternatively, they may imply that the neural mechanisms underlying shifts in internal attention to VWM representations are domain dependent. More generally our findings indicate that hemispheric asymmetry in occipital alpha is not essential for the retro-cue benefit, pointing to other possible neural mechanisms or pathways. Our findings contribute to a broader understanding of the interplay between internal attention and VWM as well as their research.

Keywords: internal attention, visual working memory, verbal cue, retro-cue, MEG, alpha oscillation, alpha asymmetry, occipital cortex

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Visuaalinen tarkkaavuus voidaan kohdentaa ulkoisten ärsykkeiden lisäksi visuaalisen työmuistin (VWM) representaatioihin. Tätä sisäistä tarkkaavuutta tarvitaan, jotta muistin sisältöjä voidaan priorisoida, sillä visuaalisen työmuistin kapasiteetti on rajoitettu. Takaumavihjeillä on osoitettu, että sisäisen tarkkaavuuden kohdistaminen visuaalisen työmuistin representaatioihin johtaa parempaan muistisuoriutumiseen. Ei ole selvää, millä hermostollisella mekanismilla takaumavihjeet parantavat muistisuoriutumista, mutta takaraivolohkojen välisen alfa-asymmetrian uskotaan liittyvän tähän takaumavihjehyötyyn. Aikaisemmat tutkimukset ovat keskittyneet lähinnä symbolisiin vihjeisiin. Tästä poiketen tarkastelimme tässä tutkielmassa sisäisen tarkkaavuuden suuntaamista visuaalisen työmuistin representaatioihin kielellisin vihjein. Tahdoimme saada selville, saavatko kielelliset vihjeet aikaan takaraivolohkojen välistä alfan asymmetriaa ja parantavatko ne muistisuoriutumista. Toivoimme samalla hankkiutuvamme eroon eräästä sekoittavasta muuttujasta takaumavihjeparadigmassa. 14 osallistujaa suoritti takaumavihjetehtävän MEG:ssä. Oletimme, että takaraivolohkojen välinen alfan epäsymmetria näkyisi vähentyneenä alfa-aktiivisuutena kontralateraalisesti relevantin muistiobjektin suhteen. Oletimme myös, että takaumavihjeet johtaisivat parempaan muistisuoriutumiseen. Kiinnostavaa kyllä, vain jälkimmäinen näistä hypoteeseista osoittautui paikkansapitäväksi; selkeä takaumavihjehyöty havaittiin, mutta tilastollisesti merkitsevää epäsymmetriaa takaraivolohkojen välisessä alfassa ei. Trendi kuitenkin havaittiin, jossa alfa-aktiivisuus oli korostuneempaa oikeassa takaraivolohkossa kuin vasemmassa. Nämä löydökset voisivat selittyä kielellisten vihjeiden lateralisoidulla prosessoinnilla. Vaihtoehtoisesti tuloksemme voivat viitata siihen, että hermostolliset mekanismit, jotka ohjaavat sisäistä tarkkaavuutta työmuistirepresentaatioihin, ovat domain-riippuvaisia. Yleisemmin tuloksemme indikoivat, että takaraivolohkojen välinen alfan epäsymmetria ei ole takaumavihjehyödyn edellytys, mikä voisi vihjata muiden hermostollisten mekanismien osallistumiseen. Löydöksemme parantavat ymmärrystämme sisäisen tarkkaavuuden ja visuaalisen työmuistin vuorovaikutuksesta sekä tämän tutkimuksesta.

Avainsanat: Sisäinen tarkkaavuus, visuaalinen työmuisti, kielellinen vihje, takaumavihje, MEG, alfaoskillaatio, alfa-asymmetria, näköaivokuori

CONTENTS

1. INTRODUCTION

1.1. Internal attention, external attention, and visual working memory

A significant amount of processing is required by our visual systems to construct a coherent representation of the world. To appreciate this, it can be noted that most objects possess multiple visual attributes, such as color, shape, and location. These attributes must all be integrated to form a unified whole (Treisman, 1996). A crucial part of this process is visual working memory (VWM), which refers to the "active maintenance of visual information to serve the needs of ongoing tasks", according to Luck and Vogel (2013). This "flexible and goal-oriented mental storage system" (Ye, Hu, Ristaniemi, Gendron, & Liu, 2016; Ye et al., 2021) allows for the temporary retention of information for immediate use (Mance & Vogel, 2013). Its capacity, however, is limited to about three or four units (Luck & Vogel, 1997; Sauseng et al., 2009; Sperling, 1960), a fact well-acknowledged in the field (Chun, 2011). Different theories have been proposed on what exactly is the cause of the capacity limitation of VWM. What is not controversial, is that some mechanism is required to prioritize relevant over irrelevant information.

Attention, a topic of extensive debate in its definition (Jennings, 2020), generally refers to a cognitive process that biases the processing of information, favoring elements most relevant to a current task (Astle, Summerfield, Griffin, & Nobre, 2012; Klaver, 2009). William James (1983, pp. 403-404) famously defined it in "The Principles of Psychology" as "possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought". He also noted that "[i]t implies withdrawal from some things in order to deal effectively with others" (James, 1983, pp. 403-404). These definitions suggest the need for a further conceptual clarification – one between internal and external attention. The former refers to the aforementioned "trains of thought" and the latter to the "objects" that the mind can take possession of (Chun, Golomb, & Turk-Browne, 2011). Both kinds of attention then refer to the selection and modulation of information, but they differ in the type of information in question (Chun et al., 2011). According to Chun and others (2011), attention is classified as internal if the information in question is internally generated, and external if it is sensory information entering the mind. While attention can be directed towards various sensory modalities, this thesis specifically focuses on visual attention.

The concepts of visual attention and VWM are inherently intertwined. Both internal and external (visual) attention determine what enters visual working memory for retention, and conversely, the contents of visual working memory influence what garners attention internally and externally (e.g., Chun et al., 2011; Hollingworth & Maxcey-Richard, 2013). In addition to this bidirectionality, it is generally acknowledged that the concepts of VWM and visual attention overlap (Awh & Jonides, 2001; Awh & Vogel, 2006; Gazzaley & Nobre, 2012; Oberauer, 2019). Some authors go even further and suggest visual attention and VWM to be just different names for the same mechanism (e.g., Kiyonaga & Egner, 2013; Theeuwes, Belopolsky, & Olivers, 2009). This emphasizes the vagueness of the current conceptual framework, which fails to provide a satisfactory description of the underlying processes (See Hommel et al., 2019).

1.2. Research on attention and VWM

Despite the interconnection between the concepts of visual attention and VWM, it is possible to study their distinct underlying processes. Of particular interest here is examining how focusing on a specific aspect of a stimulus can influence the subsequent mnemonic representation of that stimulus. It is widely recognised in the literature that based on our changing task goals top-down control from attentional orienting can have effects on our perceptual functions (Kastner & Pinsk, 2004; Nobre, Griffin, & Rao, 2008). This is exemplified by the Posner cuing task, where a spatial cue directs attention to a location potentially containing a relevant stimulus (for a detailed explanation of the procedure see Posner, 1980, 2016). The Posner cuing task has been instrumental in investigating the mechanisms of attention orientation (Souza, Rerko, & Oberauer, 2016), and studies have shown that when a cue is given at a target location before the stimulus, it leads to a significant increase in recall precision for the stimulus (Bays, Gorgoraptis, Wee, Marshall, & Husain, 2011; Gorgoraptis, Catalao, Bays, & Husain, 2011; Zokaei, Gorgoraptis, Bahrami, Bays, & Husain, 2011; for a review see Ma, Husain, & Bays, 2014). However, this enhanced VWM performance for cued items often leads to reduced recall precision for non-cued items (Bays & Husain, 2008; Bays et al., 2011; Gorgoraptis et al., 2011; for a review see Ma et al., 2014). In addition to these so-called pre-cues, the presentation of another type of cue, the simu-cue, which is a cue shown at the same time as the target stimulus, have been found to lead to similar results (Jiang, Olson, & Chun, 2000; Mössing & Busch, 2020). It has been concluded that the cue in both these conditions enhances detection and processing of the stimulus (Souza et al., 2016), or framed another way, help prioritizing relevant information before encoding has ended (Mössing & Busch, 2020).

More remarkably, it has been found that even cues provided after the disappearance of the stimuli improve performance (Griffin & Nobre, 2003; Hajonides, van Ede, Stokes, & Nobre, 2020; Mössing & Busch, 2020; Rerko, Souza, & Oberauer, 2014; Schneider, Göddertz, Haase, Hickey, & Wascher, 2019; for reviews see Gressmann & Janczyk, 2016; Souza & Oberauer, 2016). This experimental setting is called the retro-cue paradigm, and the improved performance resulting from it is called the retro-cue benefit (Makovski, Sussman, & Jiang, 2008; Rerko et al., 2014; Ye et al., 2021). The retro-cue benefit has been found to be of about similar size as a pre-cue benefit (Griffin & Nobre, 2003). Importantly, previous research has ruled out artefactual explanations for the retro-cue benefit, such as response biases (Griffin & Nobre, 2003), eye movements (Griffin & Nobre, 2003; Matsukura, Luck, & Vecera, 2007) and speed-accuracy trade-offs (Griffin & Nobre, 2003; Lepsien, Griffin, Devlin, & Nobre, 2005). It has been therefore concluded that our changing task goals can have effects not only upon perceptual functions but also on VWM representations (Griffin & Nobre, 2003; Landman, Spekreijse, & Lamme, 2003; Nobre et al., 2008; Poch, Campo & Barnes, 2014; Souza, Rerko & Oberauer, 2014; Souza & Oberauer 2016).

Conceptually, the retro-cue benefit is interesting as it involves prioritization of information that is no longer visible when the cue appears. This is where distinguishing between external and internal attention becomes crucial. As noted earlier, attention can be directed towards internal representations as well as external sensory information. It can be concluded then, that in the pre- and simu-cue conditions *external attention* prioritizes target stimuli according to the cue, while in the retro-cue condition attention is directed *internally* to prioritize the representation of the target stimuli according to the cue. However, the brain processes behind this are unclear.

1.3. Internal attention, VWM, and the alpha rhythm

Understanding how the brain prioritizes task-relevant aspects of internal memory representation is critical. Prioritization seems to imply at least one of two options. Either VWM resources are shifted to improve the relevant parts of the representation, or they are shifted to inhibit the irrelevant parts (or both) (Astle et al., 2012; Mössing & Busch, 2020; Ye et al., 2016). The first framework is called the facilitation hypothesis, and it is advocated by Rerko and others (2014) as well as Li and others (2023) for example. The second framework is referred to as the inhibition hypothesis. It is backed for example by Jensen and Mazaheri (2010), Poch and others (2014), Myers, Stokes, and Nobre (2017) as well as Lewis-Peacock, Kessler, and Oberauer (2018). The third hypothesis is that the prioritization of the task-relevant parts of the internal memory representation results from both facilitation and inhibition. This suggestion is advocated by Schneider and others (2019) for example. The neural mechanism by which any of these options could work is not, however, clear.

A prominent theory points to a role of parieto-occipital alpha oscillations (8-13 Hz). Starting in the 1920s, various "brain rhythms" have been identified (Hari & Puce, 2017, pp. 39). Attention and visual working memory, in addition to all other cognitive capacities, rely on neurons communicating with each other. These cortical events can be measured by recording electric potential differences or magnetic fields from outside the head (Hari & Puce, 2017, pp. 1). An electrical potential or a magnetic field rising from the communication of one or two neurons is minute, but when patterns of electrical activity are summed up, the emerging potentials can be noticeable. The possibility to aggregate the electrical currents of multiple neurons arises from the synchronous firing of neurons, as seen for example in brain rhythms. Brain rhythms refer to "distinct patterns of massed neuronal activity" (Frank, 2009).

The first brain rhythm to be identified was the oscillation in the 8-13 Hz frequency band, which came to be known as the alpha rhythm (Hari & Puce, 2017, pp. 39). For a long time, it was supposed to be associated with the resting state of the brain and posterior alpha oscillation to reflect the resting state of the visual system especially (Adrian & Matthews, 1934; Hari & Puce, 2017, pp. 39; Klimesch, Sauseng, & Hanslmayr, 2007; Pfurtscheller, 1992; Sauseng et al., 2009; Walter, 1938; for a review see Pfurtscheller, Stancák, & Neuper, 1996). However, this assumption has been questioned in the recent decades (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Jensen, Gelfand, Kounios, & Lisman, 2002; Klimesch, Doppelmayr, Schwaiger, Auinger, & Winkler, 1999; Klimesch, Doppelmayr, Röhm, Pöllhuber & Stadler, 2000; Krause, Lang, Laine, Kuusisto, & Pörn, 1996). For example, Jensen and others (2002) showed that in a working memory task alpha oscillations "systematically increased with the number of items held in working memory", and many other papers have reached similar results (Busch & Herrmann, 2003; Jokisch & Jensen, 2007). It has therefore been concluded that alpha oscillations most likely play a functional role in visual working memory.

Much of the research on alpha oscillation in VWM has employed variations of the retro-cue paradigm. We focus on object-based retro-cues in this thesis. The paradigm involves participants directing their attention to a fixation point, followed by the presentation of stimulus objects on either side. The retro-cue, which cues the participant to direct their internal attention to one of the stimulus objects, is then given to the participant in one of three ways. The cue can be endogenous, exogenous or a feature cue (Ye et al., 2016, 2021). Endogenous cues (used e.g. by Astle et al., 2012; Landman et al., 2003; Nobre et al., 2008; Rerko & Oberauer, 2013; Souza, Rerko, & Oberauer, 2015; Souza et al., 2016) are shown centrally to the fixation point where they direct internal attention to the target location, while exogenous cues (used e.g. by Makovski & Pertzov, 2015; Matsukura & Hollingworth, 2011; Murray, Nobre, Clark, Cravo, & Stokes, 2013; Shimi, Nobre, Astle, & Scerif, 2014; Sligte, Scholte, & Lamme, 2008; Souza, Rerko, Lin, & Oberauer, 2014) are shown at the target location (Ye et al., 2016, 2021). Feature cues (used e.g., by Berryhill, Richmond, Shay, & Olson, 2012; Gilchrist, Duarte, & Verhaeghen, 2016; Heuer & Schubö, 2016; Heuer, Schubö, & Crawford, 2016; Hollingworth & Maxcey-Richard, 2013) in turn present one feature of one target object thereby indicating the target that is to be recalled (Ye et al., 2016, 2021).

1.4. Hemispheric asymmetry in occipital alpha

Recording brain activity with electroencephalography (EEG) or magnetoencephalography (MEG) is instrumental in retro-cue tasks. These methods enable the comparison of activity in the hemisphere that processes the cued object with that in the hemisphere that processes the non-cued object. EEG measures electric potentials on the scalp while MEG measures magnetic fields resulting from the electric potentials (Hari & Puce, 2017, pp. 1). EEG is cost-effective but limited in spatial resolution, whereas MEG, though more expensive, offers better spatial resolution. Both possess excellent temporal resolution, surpassing that of functional magnetic resonance imaging (fMRI) (Hansen, Kringelbach, & Salmelin, 2010, pp. 2; Hari & Puce, 2017, pp. 11).

Research using both EEG (e.g., Myers, Walther, Wallis, Stokes, & Nobre, 2015; Schneider, Mertes, & Wascher, 2015, 2016) and MEG (e.g., Mok, Myers, Wallis, & Nobre, 2016; Poch et al., 2014) has consistently found that following a retro-cue, alpha oscillations are more prevalent in the hemisphere that processes the distractor stimulus (non-cued stimulus) compared with the hemisphere that processes the target stimulus (cued stimulus) (e. g., Mok et al., 2016; Myers et al., 2015; Mössing & Busch, 2020; Poch et al., 2014; Schneider et al, 2015, 2016, 2019). This phenomenon is referred to as hemispheric asymmetry in alpha (Schneider et al., 2019).

Although this asymmetry has been extensively documented (e.g., Myers et al., 2015; Mössing & Busch, 2020; Poch et al., 2014; Schneider et al., 2015, 2016, 2019), a potential confounding factor has been largely overlooked in the literature. Most studies have utilized endogenous arrow cues (Berryhill et al., 2012; for a review, see Souza & Oberauer, 2016). Arrows are inherently spatial cues, which could influence the hemispheric asymmetry in occipital alpha, confounding the effects of the cue with those of the subsequent attentional shift in the VWM representation. To our knowledge, no study has tried to eliminate this confound by using endogenous, abstractly represented location word retro-cues.

1.5. Verbal and symbolic cues

Influence of retro-cues on directing internal attention can be studied by using verbal location word cues, such as the words “left” and “right”. This differs from arrows by requiring processing at an abstract level. Unlike arrows, verbal cues may not confound the effects of spatial attention with cue processing. In the context of Päiviö’s (1971) dual coding theory, which proposes that our brain processes visual and verbal information through two distinct pathways, arrows might activate the visual processing system, while verbal cues could predominantly engage the verbal processing system. This distinction underscores the need to investigate how verbal cues affect attention and memory processes.

Previous research indicates that directional word cues, as well as arrow cues, effectively direct visual attention to the location designated by the cue (Hommel, Pratt, Colzato, & Godijn, 2001). Interestingly, Hommel and others (2001) observed different cuing effects between arrows and words, which may be attributed to the less ambiguous nature of arrows or the differences in their processing time courses. Overall, their findings imply that verbal cues could be as effective as arrows in eliciting hemispheric asymmetry in alpha, potentially even superior by removing a confounding variable from the paradigm.

Furthermore, the use of verbal cues requires the participant to process the cue at a verbal level, which could engage different cognitive processes compared to processing symbolic cues like arrows. This eliminates a potential confounding variable and allows for the examination of the domain-independent nature of cue impacts on brain activity. Specifically, it remains unclear to what extent the cue-induced brain effects represent general, domain-independent processing. Using location word cues could, therefore, shed light more generally on the mechanisms underlying the shifting of internal attention to VWM representations.

1.6. Research questions and hypotheses

This thesis aims to deepen our understanding of the neural basis of visual working memory, particularly focusing on how internal attention is shifted to VWM representations. We selected an endogenous retro-cue approach to reduce any external factors that might influence our results. Crucially, we employed a novel type of verbal cue to avoid the spatial bias of arrow cues traditionally used. This approach can contribute to our understanding of the extent to which retrospective attention to a VWM representation operates similarly with verbal cues, as has been demonstrated for symbolic cues, and provide new insights into whether the effects retro-cues are domain-independent. To our knowledge, no prior study has employed a verbal endogenous retro-cue in an object-based retro-cue task.

Our aim was, firstly, to clarify whether focusing retrospective attention to a VWM representation functions similarly with verbal cues, as has been demonstrated for symbolic cues. To investigate this, we asked whether hemispheric asymmetry in occipital alpha is evident in a retro-cue task when direction word cues are used. Prior studies have demonstrated alpha asymmetry in various retro-cue contexts (e.g., Myers et al., 2015; Mössing & Busch, 2020; Poch et al., 2014; Poch, Capilla, Hinojosa, & Campo, 2017; Schneider et al., 2015, 2019) and evidence suggests that directional word cues can direct attention as effectively as arrow cues (Hommel et al., 2001). Based on these findings, we hypothesized that alpha asymmetry, characterized by a decrease in alpha activity contralateral to the cued stimulus, would be observed in our study.

Secondly, we wanted to make sure that this novel type of retro-cue results in retro-cue benefit. We therefore asked whether the presentation of a valid direction word retro-cue leads to better memory performance in the retro-cue task than the presentation of a verbally presented neutral retro-cue. Following a large body of previous research that has found a retro-cue benefit (e.g., Griffin & Nobre, 2003; Hajonides et al., 2020; Mössing & Busch, 2020; Rerko et al., 2014; Schneider et al., 2019; for reviews, see Gressmann & Janczyk, 2016; Souza & Oberauer, 2016) we hypothesized that retro-cue benefit would be also found here.

2. METHODS

This study was conducted as part of the broader “MindEye” research project at the University of Jyväskylä, which was concerned more generally on the mechanisms of internal attention and VWM. While the larger project included both object-based and dimension-based retro-cue tasks, this thesis focused only on the former. Accordingly, only the object-based task will be reported here. The data were collected at the Centre for Interdisciplinary Brain Research at the University of Jyväskylä during the autumn of 2022, and the spring and summer of 2023.

2.1. Participants

16 people participated in the study. The data from two participants had to be removed from further analyses because of poor data quality leaving a final sample of 14 participants aged between 22 and 48 years. The average age of participants was 30.21, with a standard deviation of 7.90. The gender distribution was balanced, with seven males and seven females. Participants were recruited through various channels, including university email lists, personal contacts, university websites, and public

leaflets in Jyväskylä. The human sciences ethics committee of the University of Jyväskylä has approved the research project's study plan, and the research was conducted according to the principles of the Helsinki Declaration. The participants signed a consent form before the start of the study.

Eligibility criteria stated that participants needed to be in the age gap of 18 to 55. Exclusion criteria for the study were the following: Reading skills needed to be adequate so that instructions could be comprehended. Given the study's focus on VWM, visual impairment was a clear exclusion criterion. Hearing impairment was a relative exclusion criterion as the participant had to be able to hear the experimenter. Other criteria included the exclusion of those with psychiatric and neurological diseases and those on medications targeting the central nervous system. Normal exclusion criteria for MEG research also applied. These included certain medical implants, medication pumps, medical stimulators or other magnetic/electrical devices that could not be removed, metallic dental implants and braces as well as irremovable metallic piercings around the cranial area.

2.2. Experimental setup

In the retro-cue task, the objective was to remember two differently coloured and oriented bars (length 1.1°, height 0.4°) positioned on different sides of the visual field (figure 1). The presented colours and orientations of the bars were randomly selected from a pool of 360 colours and 180 possible angles (1° – 180°). The visual stimuli to be remembered in the task were akin to those used in the study by Ye and others (2021).

The bars were displayed for 300 ms followed by a 700 ms pause, exceeding the duration of iconic memory (Sperling, 1960). After this, participants were shown a retro-cue for 500 ms, after which a 1500 ms pause ensued. Valid retro-cues consisted of the text "vasen" or "oikea" (Finnish for "left" and "right", respectively) in the centre of the screen, aiming to direct internal attention to the relevant stimulus object. A neutral retro-cue comprised the text "random" on the screen, offering no bar-related information to aid in memory recall; participants were to retain the entire scene in mind.

The recall phase involved either a colourful circle (inner radius 5.8°, thickness 2.2°) or a white bar (1.1° × 0.4°). If the colourful circle appeared, participants were to report the colour of the relevant bar, whereas in case the white bar appeared the orientation of the relevant bar was to be reported. At this point a white square (1.2° × 1.2°) indicated which bar was the relevant one. The target bar was indicated by a white square at the bar's original location. For colour related responses, the appropriate shade was selected from the colour circle using an optical mouse. Orientation related responses were indicated by rotating the white response bar on the screen to the desired orientation through mouse clicks. The desired answer could be previewed with the mouse in both task types. The reporting phase continued until the participant responded, and after responding, they received performance feedback. During the feedback phase, participants were informed of a difference score, reflecting their proximity to the correct answer. The protocol is shown in figure 1.

The task included four segments of approximately 10 minutes each, with the entire task lasting around 45 to 60 minutes, depending on the participant's response speed. There were short breaks between the segments, during which participants could stretch or engage in other activities. Overall, the task involved 240 trials. Prior to the task, participants were given a practice period for however long they deemed necessary to make sure they understood the task.

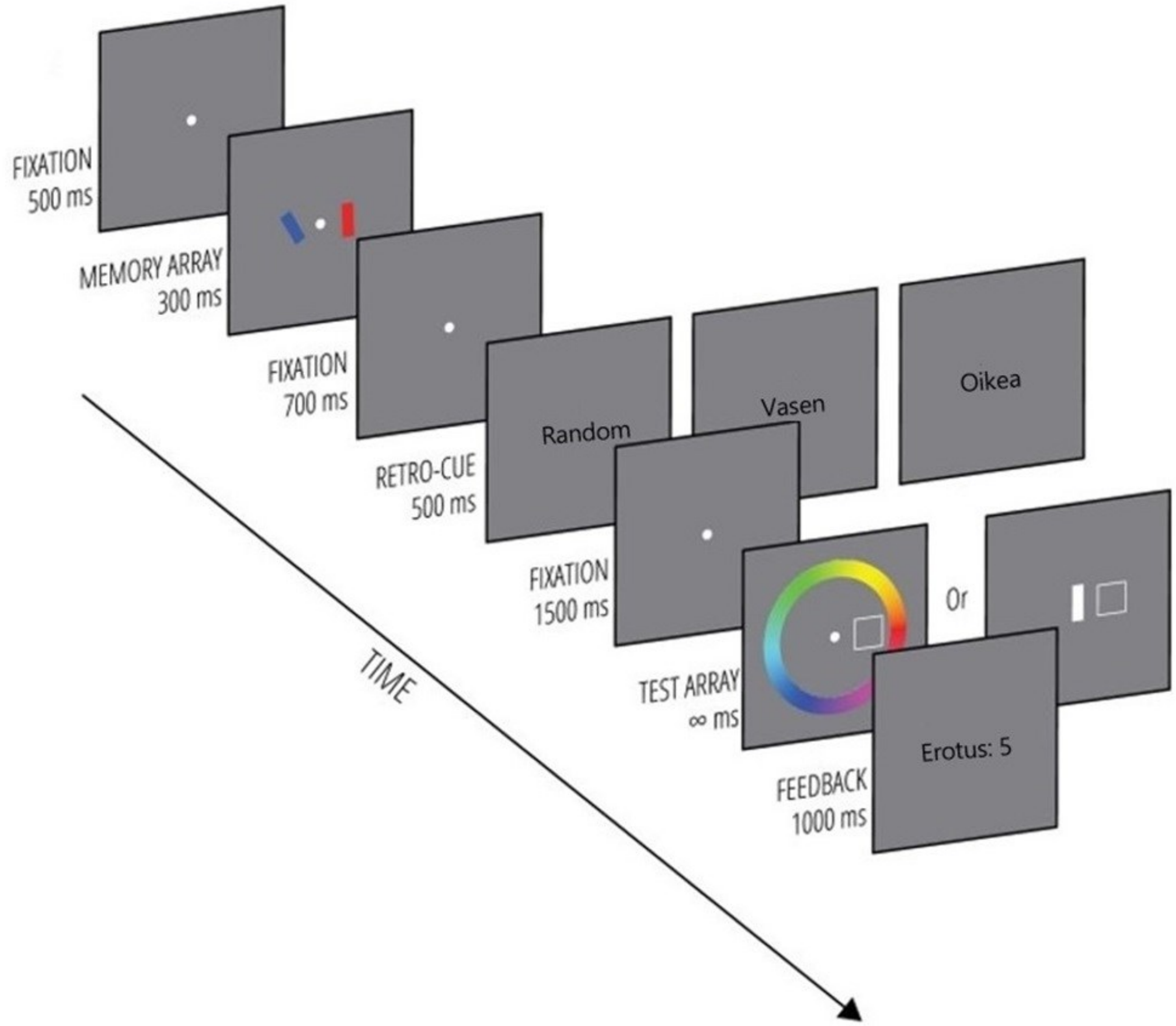


Figure 1. The retro-cue task. First, the participant saw a fixation screen which was a tiny immobile white dot in the centre of the screen. Second, two bars were presented, one on each side of the fixation dot. Participants had been instructed to memorize both the colour and orientation of the bars. After a brief pause, the participant was shown the retro-cue, which was either neutral (the word "*random"*) or valid (the word "*vasen"* or "*oikea"* – Finnish words for left and right, respectively). Subsequently, a 1500 ms fixation ensued, after which one of two test arrays appeared indicating whether the participant needed to give an answer about the colour or orientation of the relevant bar. In both test arrays a white square outlined the tested bar's location. Lastly, the participant could move to the feedback phase by clicking the mouse. The word "erotus" in the last phase, meaning "difference," refers to the difference score the participant received as feedback.

2.3. MEG protocol

Before starting the task, participants' head shapes were digitized. Five head position indicator (HPI) coils were positioned on their scalps to monitor head movements during the experiment. Three of the coils were placed on the forehead and one behind each ear. The MEG head coordinate system was defined using three anatomical landmarks: the nasion, and the left and right preauricular points. The head shapes (>100 points evenly distributed over the scalp), the positions of the HPI coils, and the anatomical landmarks were digitized using the Polhemus Fastrak 3D Digitizer and Quad Sensor Motion Tracker devices (Polhemus, Vermont, USA). During measurement, eye movements were measured using horizontal and vertical electro-oculography (EOG), and heart rate was measured using electrocardiography (EKG) to minimize disturbances from these signals.

The task was performed inside a magnetically shielded and isolated room (VacuumSchmelze GmbH, Hanau, Germany), and their brain activity was measured using a 306-channel (204 planar gradiometers and 102 magnetometers) Elekta Neuromag TRIUX system (MEGIN Oy, Helsinki, Finland). Participants were seated in a helmet-shaped MEG recording device, facing a display approximately one meter away. The task stimuli were presented using Presentation software, and participants interacted with the task using an MEG-compatible optical mouse. Data were collected at a sampling rate of 1000 Hz, with a low-pass filter at 330 Hz and a high-pass filter at 0.03 Hz. The MEG was recorded in a 68° upright gantry position.

2.4. Analysis of data

2.4.1. Preprocessing of MEG data.

We performed noise reduction on the MEG data using the Maxfilter program. This program removes external interference signals from outside the head in the MEG measurement data. After noise reduction, further processing of the data was performed using the MEGGIE (Heinilä & Parviainen,

2022) program at the University of Jyväskylä. With MEGGIE, we applied a high-pass filter of 0.1 Hz and a low-pass filter of 40 Hz to the MEG data. Following this, an independent component analysis (ICA) was utilized to remove noise signals caused by eye movements and heart rate from the data.

Subsequently, epochs were extracted from the continuous data using a time window of -1000 ms to 2500 ms, with the retro-cue onset time as the zero point and a baseline of -200 ms to 0 ms. These epochs were created separately for valid (left cue and right cue) and neutral cues. For each condition there were 80 epochs. This setup allowed us to analyze alpha activity in relation to the presentation of valid and neutral cues. By comparing the brain responses to these different cue types, we aimed to answer our research question regarding the impact of cue type on hemispheric asymmetry in occipital alpha.

2.4.2. Calculating hemispheric asymmetry in occipital alpha

Time-frequency representations (TFRs) (figure 2) were created from the epochs. These TFRs, generated using wavelet transformations, visualized the average oscillation magnitude across participants within specific time intervals. TFRs were created for the time window of 1000 ms to 2500 ms with the retro-cue onset being the zero point and the baseline being -200 ms to 0 ms. We chose the time window starting 1000 ms post-cue onset to focus on the period beyond initial stimulus response. This choice was made to more accurately capture the brain's activity related to the deeper cognitive processing involved in the visual memory task. The analysis covered the frequency range of 5-30 Hz for each participant. Given that our focus was on the alpha band, we restricted our analysis to the amplitude modulation of oscillatory activity between 8 and 13 Hz. Temporal spectral evolution (TSE) time series, which represent the evolution of the magnitude of the signal over time, were calculated for each type of cue. We calculated these time series as averages of the channels overlying the occipital lobes as we were interested in visual working memory. The TSEs were limited to cover 8–13 Hz.

In the initial visual inspection of the TFRs (figure 2), there was a clear increase of alpha between 1000 and 2000 ms after the cue. We selected this time window for further analysis of power differences between conditions. Next, the maximum amplitude of the alpha oscillation of each participant was calculated for the time window with Microsoft Excel software. The calculations used values measured with gradiometer sensors, as they provided more precise data for signal localization than magnetometer sensors. This approach allowed for better evaluation of the signal sources directly from the measured data without source modelling.

2.4.3. Calculating retro-cue benefit and memory performance

To evaluate memory performance and the retro-cue benefit, the difference scores that served as feedback in the task were utilized. The difference scores represented the proximity of the participants' answers to the right answer with 0 being a perfect match and 180 representing the furthest deviation. These difference scores were averaged for each participant and for each condition to create variables that could be compared to answer the research question. To ensure consistency the same two participants that were excluded for bad data quality in the MEG data were also excluded here. The subsequent analyses were performed using IBM SPSS Statistics 28 software.

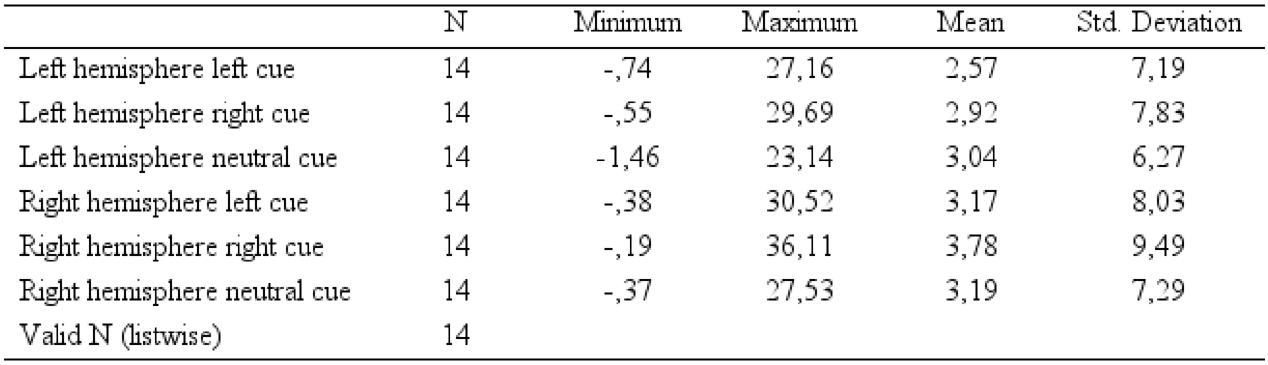
2.5. Statistical analysis of hemispheric asymmetry in occipital alpha

To make the interpretation of the statistical analyses easier, the maximum values of the amplitudes of alpha oscillation were multiplied by the value 10^{22}. Analysis of these values for the time window from 1000 ms to 2000 ms post-retro-cue revealed outliers (see figure 3), originating from a single participant. Descriptive statistics with this outlier included showed mean amplitudes ranging from 2.57 to 3.19, and standard deviations from 6.27 to 9.49 (Table 1).

A repeated measures ANOVA (rANOVA) was conducted to evaluate the effects of cue type on alpha power in each hemisphere. Two factors were included in the model: hemisphere and cue type. The factor of hemisphere had two levels, left and right, and the factor of cue type had three levels, right cue, left cue, and neutral cue. The rANOVA was chosen because of the within-subject experiment design, interest in interaction effects and the method's ability to handle inter-subject variability. We performed Mauchly's test for sphericity, applying the Greenhouse-Geisser correction if needed. Effect sizes were examined using partial eta squared. As outliers can skew results, we performed the rANOVA for both datasets (including and excluding the outlier participant) to confirm the robustness of the analysis.

Before proceeding with the rANOVA, the normality of the residuals was tested by Kolmogorov-Smirnov and Shapiro-Wilk tests and by visual inspection of the histograms and Q-Q plots. For all conditions, the residuals were not normally distributed ($p < .001$ for both tests). Due to non-normal distributions, we also employed the non-parametric Friedman test to measure the interaction effect, which was central to our study.

Difference scores were calculated by subtracting the alpha power in the left hemisphere from the alpha power in the right hemisphere for each cue type, resulting in three difference variables. The Friedman test assessed if significant differences existed across the three cue types. Acknowledging the departure from the assumption of normality, post-hoc tests were conducted with both parametric (a paired-samples t-test) and non-parametric (a Wilcoxon signed ranks test) methods. In the post-hoc tests a Bonferroni correction was applied to adjust the level of significance to mitigate the risk of type 1 errors. For the t-test, effect sizes were measured using Cohen's d and adjusted for small sample bias using Hedge's g (Lin & Aloe, 2021), which weights standard deviations based on sample sizes to reduce the bias inherent in Cohen's d (Ellis, 2010, pp. 10). For the Wilcoxon test, effect sizes were measured with rank-biserial correlation (r) (Tomczak & Tomczak, 2014).



	N	Minimum	Maximum	Mean	Std. Deviation
Left hemisphere left cue	14	-,74	27,16	2,57	7,19
Left hemisphere right cue	14	-,55	29,69	2,92	7,83
Left hemisphere neutral cue	14	-1,46	23,14	3,04	6,27
Right hemisphere left cue	14	-,38	30,52	3,17	8,03
Right hemisphere right cue	14	-,19	36,11	3,78	9,49
Right hemisphere neutral cue	14	-,37	27,53	3,19	7,29
Valid N (listwise)	14				

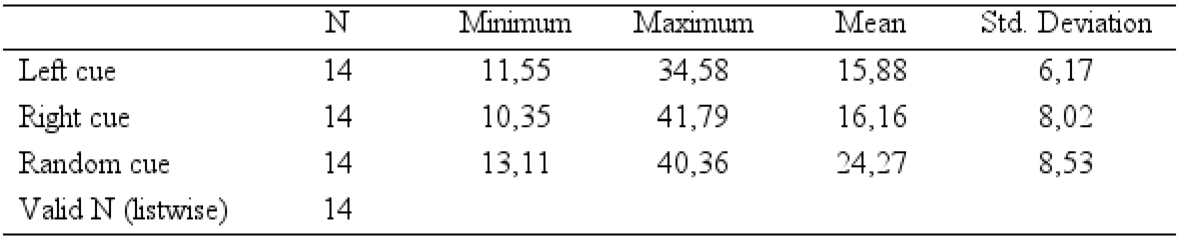
Table 1. The descriptive statistics for the maximum amplitude of alpha oscillation for each condition. Outlier participant included.

2.6. Statistical analysis of retro-cue benefit and memory performance

Table 2 presents the descriptive statistics for each cue type. A repeated measures ANOVA was conducted to assess the main effect of cue type on memory performance. The rANOVA was chosen due to the within-subject design of our experiment and its ability to handle inter-subject variability effectively. One factor, the cue type, was included in the model with three levels, left cue, right cue, and neutral cue.

We first performed Mauchly's test to verify the assumption of sphericity. If any violations were found, the Greenhouse-Geisser correction was applied. Effect sizes were examined using partial eta squared. Before proceeding with the rANOVA, the normality of the residuals was tested by Kolmogorov-Smirnov and Shapiro-Wilk tests and by visual inspection of the histograms and Q-Q plots. The inspection showed that the residuals of the variable "left cue" (Kolmogorov-Smirnov $p = .01$ and Shapiro-Wilk $p < .001$) and "right cue" ($p < .001$ for both tests) were not normally distributed, while the residuals of the variable "neutral cue" was close to being normally distributed (Kolmogorov-Smirnov $p = .03$ and Shapiro-Wilk $p = .131$). Given these deviations from normality, we performed post-hoc analyses using both parametric (paired-samples t-test) and non-parametric (Wilcoxon signed ranks test) methods. In the post-hoc tests, a Bonferroni correction was applied to adjust the level of significance to mitigate the risk of type 1 errors. Effect sizes were measured using Cohen's d, with Hedge's g employed to correct for small sample bias (see 2.5). For the Wilcoxon test, effect sizes were measured with rank-biserial correlation (r).

Given that outliers (see figure 5) can distort findings, we carried out the rANOVA again with and without the outlier participant. Correlations in the difference values between different cue types were also measured to evaluate the consistency of response patterns and to assess how participants' performance with the direction cues related to a baseline – the neutral cue condition.



	N	Minimum	Maximum	Mean	Std. Deviation
Left cue	14	11,55	34,58	15,88	6,17
Right cue	14	10,35	41,79	16,16	8,02
Random cue	14	13,11	40,36	24,27	8,53
Valid N (listwise)	14				

Table 2. The descriptive statistics for the averages of the difference scores for each cue type.

3. RESULTS

3.1. Hemispheric asymmetry in occipital alpha

3.1.1. Time-frequency representations

The time-frequency representations (figure 2) created from the basis of the MEG data were inspected visually for differences in the frequencies between the occipital lobes for each cue type. In the left cue condition, a notable asymmetry was observed, with the right hemisphere displaying stronger activation in the alpha band. A similar trend was observed in the right cue condition, where the right hemisphere again showed more pronounced alpha band activation (note that the scales of the strength of activation vary in the figure). In the random cue condition, no noticeable differences between the hemispheres were evident.

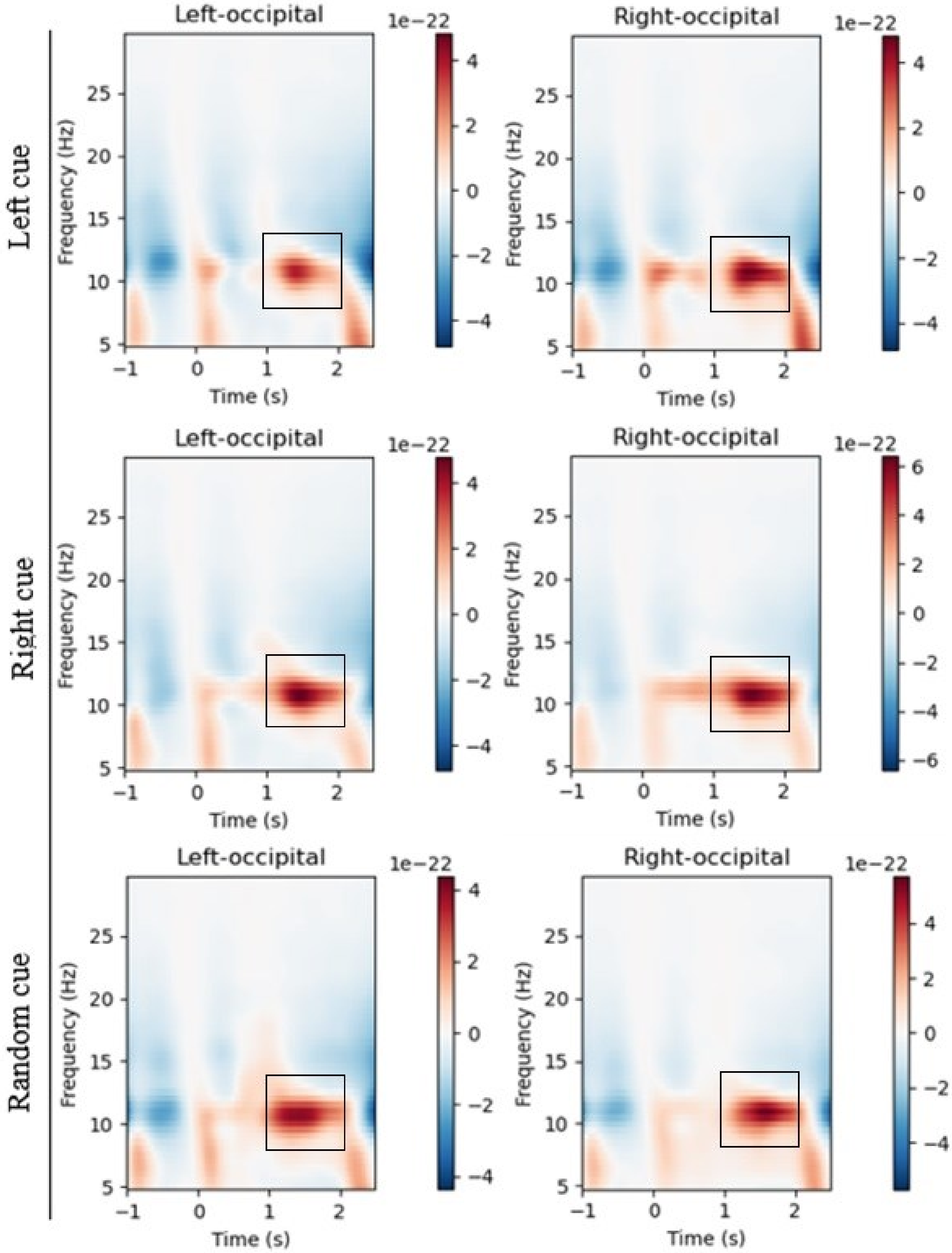


Figure 2. Time frequency representations (TFRs) for each cue type for the frequency range of 5-30 Hz and for both occipital hemispheres as measured using gradiometer sensors. The zero point is the retro-cue onset. Note that the scales of the strength of activation vary. The black rectangles show the time period (1000 ms – 2000 ms from the onset of the cue) and the frequency (8-13 Hz) that was further analysed.

3.1.2. Statistical results

A repeated measures ANOVA was performed for both datasets – including and excluding the outlier participant. As the results were essentially the same, the dataset including the outlier was used for further analyses and is reported here.

There was no significant main effect of hemisphere ($F(1, 13) = 2.281$, $p = .155$, partial $\eta^2 = .149$). There was also no significant main effect of cue type ($F(2, 26) = .433$, $p = .653$, partial $\eta^2 = .032$). The interaction between hemisphere and cue type approached significance but was not statistically significant ($F(2, 26) = 2.725$, $p = .084$, partial $\eta^2 = .173$). Figure 4 depicts the maximum alpha powers across different cue types for each occipital lobe.

Given our data's departure from normality, an additional non-parametric test was conducted for more robust analysis. The Friedman test was used to evaluate interactions between hemisphere and cue type, revealing no statistically significant effects ($\chi2 = 0.571$, $p = .751$). The mean ranks for the three difference variables created were as follows: left cue difference variable (2.00), right cue difference variable (2.14), and neutral cue difference variable (1.86).

Although conducting post-hoc tests is typically not recommended when no significant main effects are found with rANOVA, simple effects were assessed, because the rANOVA seemed to indicate that the alpha amplitude was consistently higher in the right hemisphere (see figure 4). This was done with both a paired-samples t-test and a Wilcoxon signed ranks test, given the violation of the assumption of normality. A Bonferroni correction was applied for multiple comparisons by dividing the significance value of 0.05 with the number of tests performed ($\alpha=0.05/3=0.0167$).

In the paired-samples t-test, no significant differences were found in the mean alpha power value between the hemispheres even before the Bonferroni correction. In the Wilcoxon signed ranks test, the median alpha power in the right hemisphere was higher than in the left for the left cue condition ($Z = -2.040$, $p = .041$, $r = -0.54$), and similarly for the right cue condition ($Z = -2.166$, $p = .030$, $r = -0.58$). However, these differences did not reach statistical significance after the Bonferroni correction. For the neutral cue, there was no significant difference in the alpha power values between the hemispheres ($Z = -.220$, $p = .826$, $r = -0.06$) even before applying the Bonferroni correction.

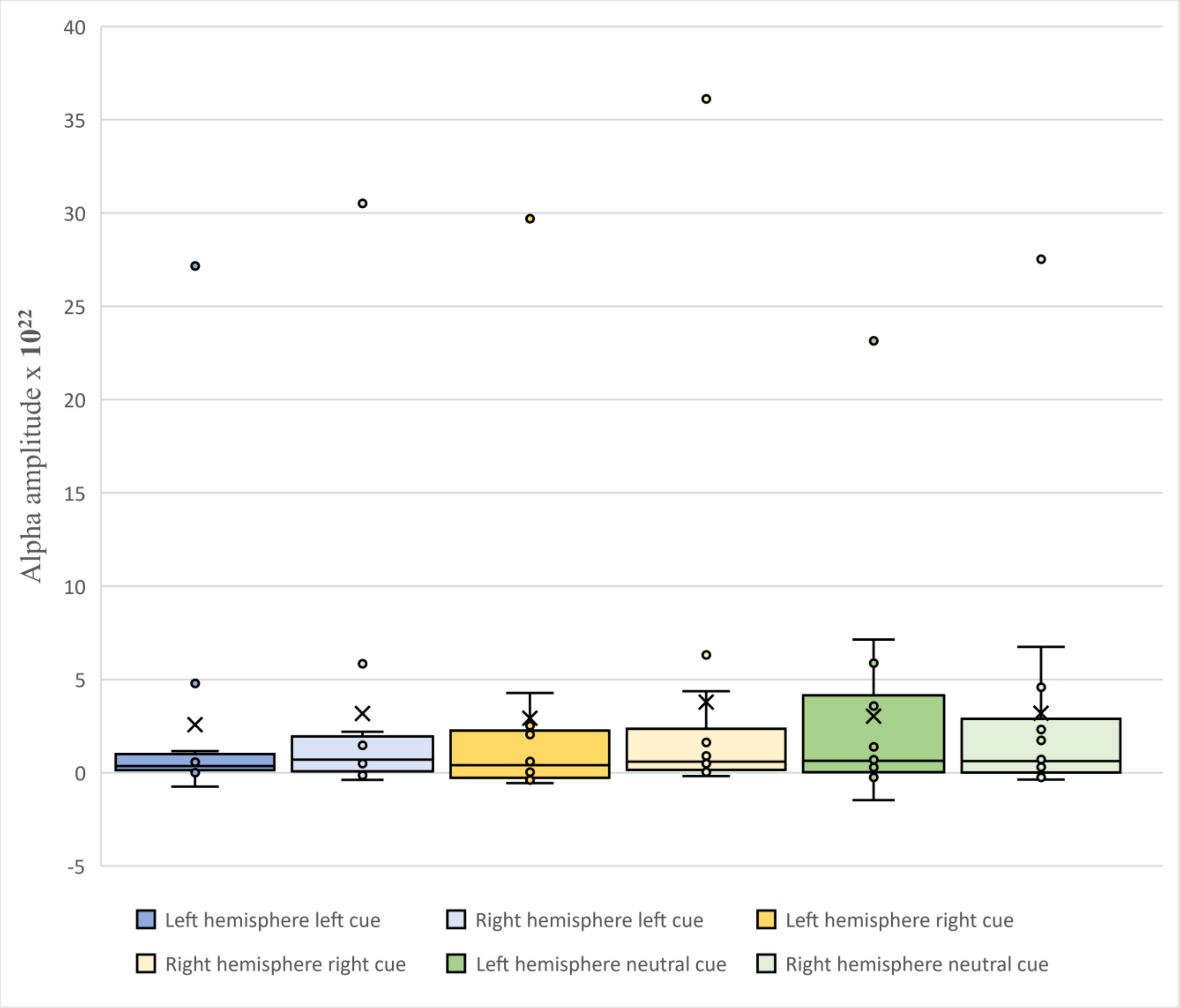


Figure 3. Maximum amplitude values of alpha oscillations for each cue type. Each dot represents the maximum alpha amplitude value of one participant for the time window of 1000 ms to 2000 ms after the presentation of the retro-cue. Central line in each box represents the median difference score. The top and bottom borders of the box show the third and first quartiles, respectively. Lines above and below the box indicate the range of scores within the data, excluding potential outliers (1.5 times or over the interquartile range), which are plotted as individual points. The X represents the mean difference score.

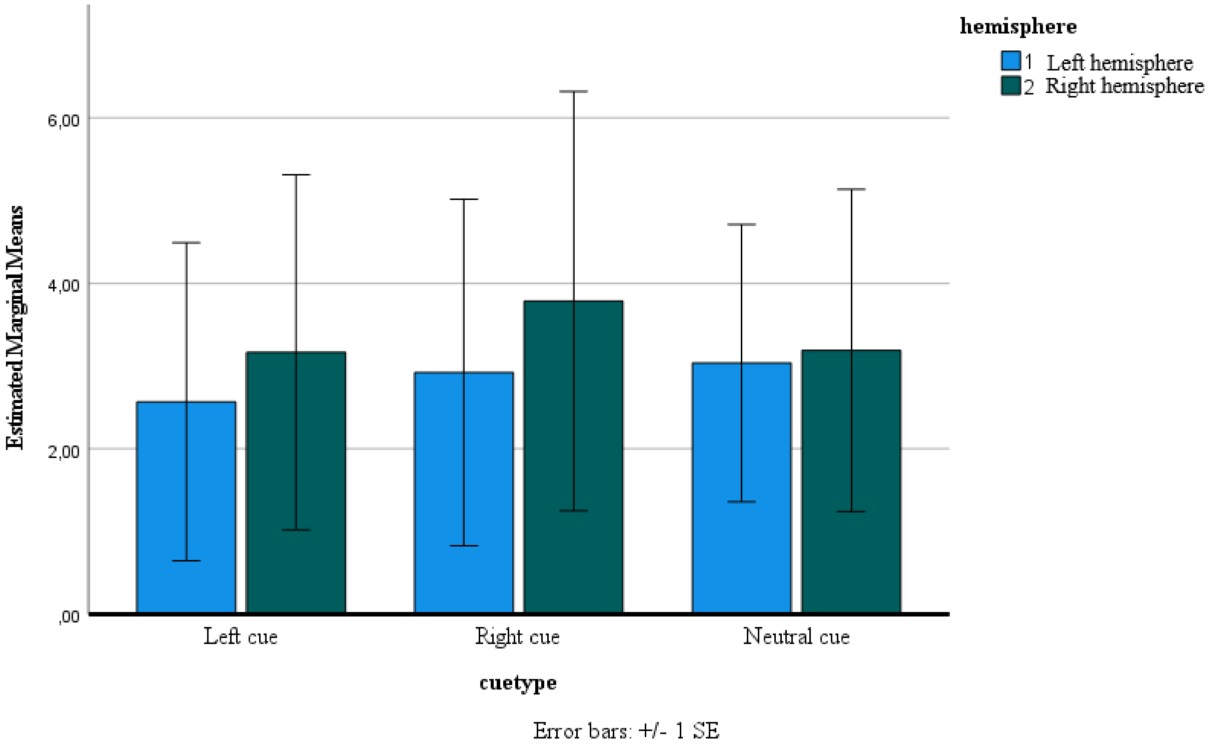


Figure 4. Maximum alpha amplitude across different cue types for both left and right occipital hemispheres. The x-axis represents the type of cue, while the y-axis indicates the maximum alpha power. Separate bars represent the responses for the left and right hemispheres. Error bars are included indicating the standard errors of the means.

3.2. Retro-cue benefit and memory performance

The Mauchly's test of sphericity indicated that the assumption of sphericity was not met, so Greenhouse-Geisser correction was used. There was a significant main effect of cue type (F(2,26) = 13.615, p < .001, partial $\eta^2 = .512$). The distributions of difference scores as well as their means can be seen from figure 5. With the application of the Bonferroni correction, the significance threshold was adjusted to $\alpha = 0.0167$ (α=0.05/3=0.0167). The paired-samples t-test and the Wilcoxon signed ranks test settled upon the same results, so only the results from the t-test are reported here.

The paired-samples t-test did not reveal a significant difference between the scores for the left cue and right cue conditions (t(13) = -.281, p = .783, g = 0.073). There was a significant difference between the scores for the left cue and neutral cue conditions (t(13) = -4.315, p < .001, g = -1.120). Similarly, a significant difference was observed between the scores for the right cue and neutral cue conditions (t(13) = -3.545, p = .004, g = -0.920). A positive correlation was found between scores from the left and right cue conditions (r = .894, p < .001). Positive correlations were observed also between the left cue and neutral cue conditions (r = .550, p = .042) and between the right cue and neutral cue conditions (r = .466, p = .093).

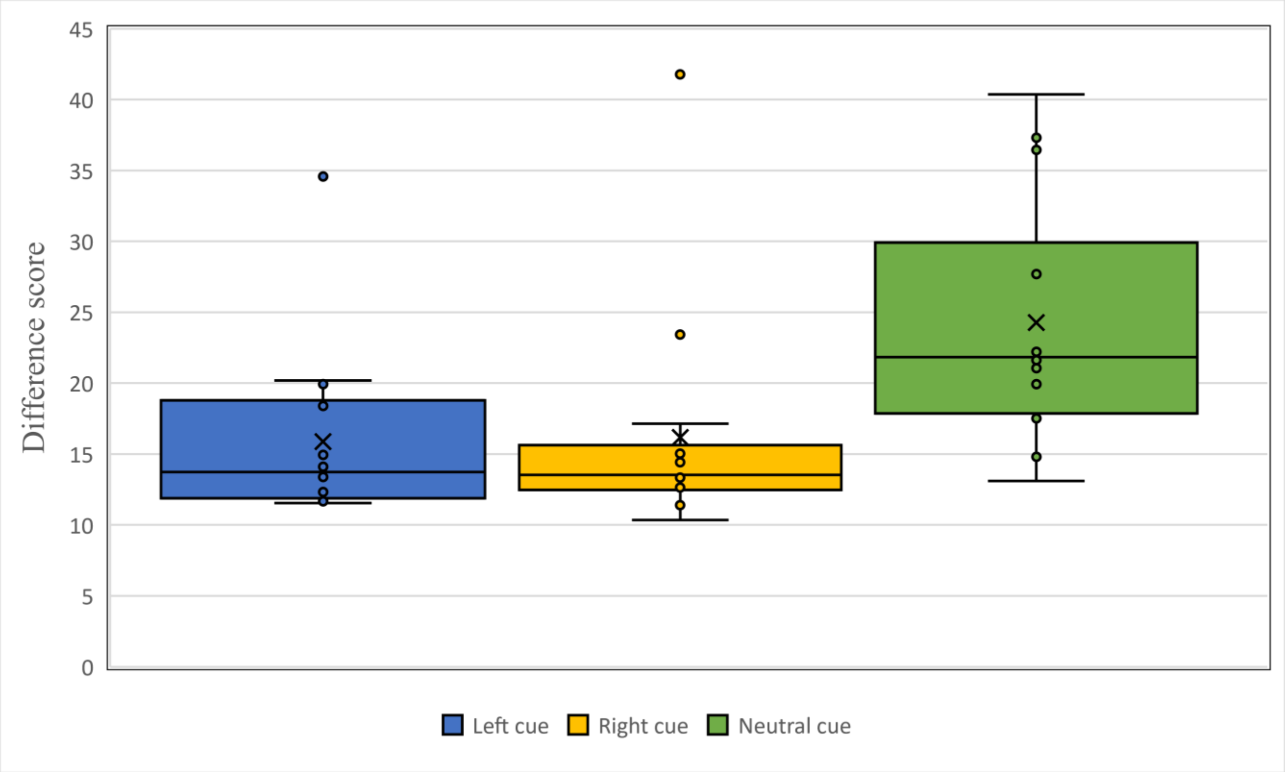


Figure 5. The distribution of difference scores for each cue type. Each dot represents the difference score of one participant. Central line in each box represents the median difference score. The top and bottom borders of the box show the third and first quartiles, respectively. Lines above and below the box indicate the range of scores within the data, excluding potential outliers (over 1.5 times interquartile range), which are plotted as individual points. The X represents the mean difference score.

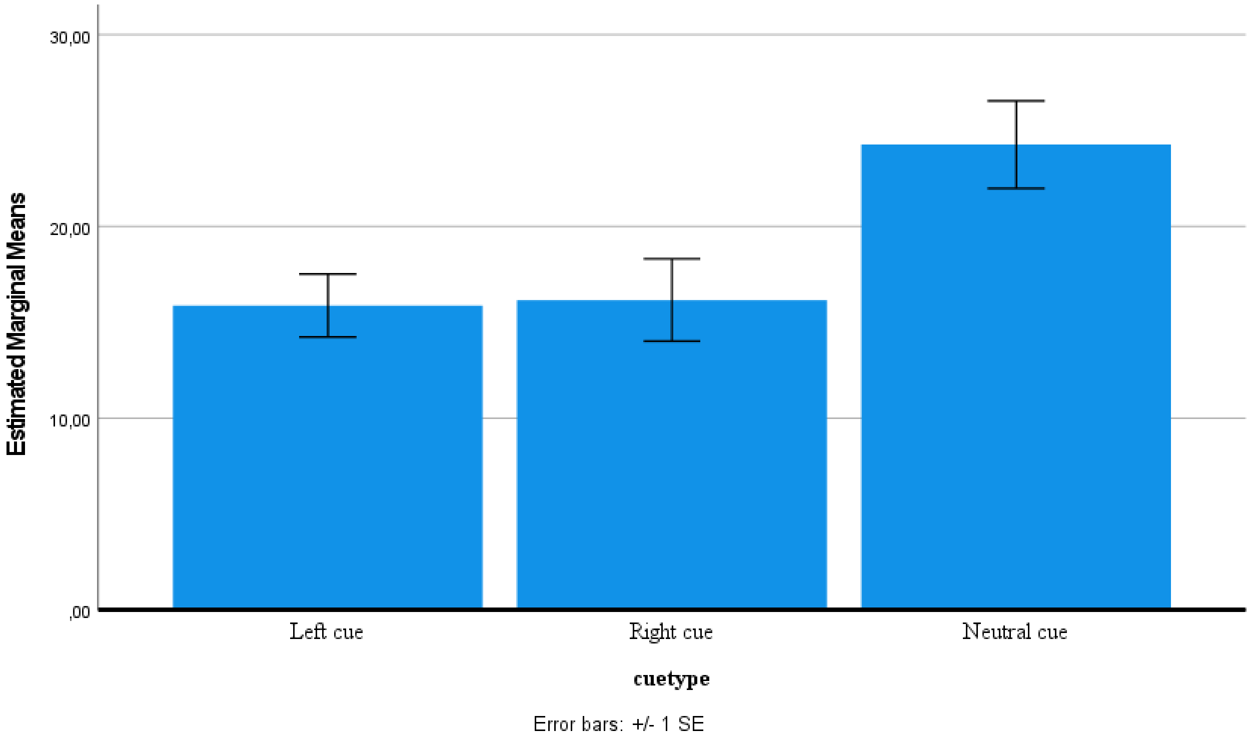


Figure 6. Difference scores for each cue type. Error bars are included indicating the standard errors of the means.

4. DISCUSSION

The primary objective of the study was to explore whether verbal (abstract) cues influence the neural (oscillatory) processes of internal attention during a visual working memory task. Previous research has predominantly focused on symbolic cues (Berryhill et al., 2012; for a review see Souza & Oberauer, 2016), which motivated us to study how using verbal cues might affect these processes.

To study this, two research questions were posed. Firstly, we asked whether focusing internal attention to a VWM representation with verbal cues elicits a similar neural response as has been demonstrated with symbolic cues. To examine this, we used MEG to assess whether hemispheric asymmetry in occipital alpha is evident in a retro-cue task with directional word cues. Specifically, we compared the maximum amplitude of alpha oscillations between the occipital hemispheres in response to different cue types. We predicted that hemispheric alpha asymmetry would be evident with alpha amplitude being decreased contralaterally to the cue. Secondly, we wanted to know whether this novel type of retro-cue could elicit a retro-cue benefit. We asked specifically whether the presentation of a valid direction word retro-cue leads to better memory performance in the retro-cue task than the presentation of a verbal neutral retro-cue.

4.1. Internal attention and hemispheric asymmetry in occipital alpha

Multiple studies have identified hemispheric alpha asymmetry to be a correlate of internal attention orienting to VWM representations (e.g., Poch et al., 2017). Specifically, alpha amplitude has been found to decrease contralaterally to the cued stimulus (e.g., Myers et al., 2015; Mössing & Busch, 2020; Poch et al., 2014; Poch, Capilla, Hinojosa, & Campo, 2017; Schneider et al., 2015, 2019). This was the hypothesis of our study as well, especially since previous research has indicated that directional word cues can direct visual attention to the designated location approximately as well as symbolic arrow cues (Hommel et al., 2001).

Our study did not, however, concur with these findings. The TFRs seemed to indicate that alpha amplitude increased in the right occipital hemisphere in relation to the left occipital hemisphere in both right and left cue conditions. While our statistical results were not entirely definitive, they seemed to suggestively support these visual observations.

The repeated measures ANOVA did not find statistically significant effects for either the main effects of cue type and hemisphere or their interaction, though the latter approached significance. This suggests that no individual cue predominantly influenced brain response when accounting for hemisphere differences, and conversely, no hemisphere showed consistently heightened activity when controlling for cue type. However, the interaction effect pointed to the possibility of cue-specific hemispheric responses, although not statistically significantly. This was of central interest for the purposes of this thesis. Notably, the effect size of the main effect of hemisphere was large, as was the interaction effect between hemisphere and cue type (Cohen, 1988). The effect size of the main effect of cue type was small (Cohen, 1988).

Post-hoc analyses are generally not recommended when no statistically significant effects are found in an rANOVA. We, however, proceeded with subsequent analyses to study further the curious trend that seemed to show the alpha amplitude to be higher in the right occipital hemisphere in both valid cue types. These analyses did not result in statistically significant results after a Bonferroni correction was used. The non-parametric Wilcoxon signed ranks test however indicated, although sub-significantly, that for both valid cue types, the alpha amplitude indeed seemed to be more pronounced in the right occipital lobe. This effect was slightly stronger in the right cue condition. For both conditions, the effect size was large (Ellis, 2010, pp. 41). The neutral cue condition showed the least alpha asymmetry, with a higher alpha amplitude in the right occipital lobe, although this was far from statistically significant, and the effect size was less than small (Ellis, 2010, pp. 41). A paired-samples t-test did not result in any significant results even before the Bonferroni correction, but it too indicated that alpha seemed to be more pronounced in the right hemisphere. It can be concluded that our study observed a consistent trend in which the right occipital lobe displayed increased alpha power across different cue conditions. While this trend did not achieve statistical significance, its repeated appearance across conditions suggests a potential underlying phenomenon worthy of further exploration.

The implications of our use of the Bonferroni correction should be noted. While the Bonferroni correction ensured rigorous control for type I error, it also increases the risk of type II errors, where true effects might go undetected. Without the correction, the Wilcoxon test results for higher alpha amplitude in the right occipital hemisphere for both valid cue types would have been significant. However, caution is advised in interpreting these post-hoc results, given the lack of significant findings in the initial rANOVA.

4.2. Retro-cue benefit and memory performance

In addition to the analysis on occipital alpha, the second key objective of this thesis was to explore the potential retro-cue benefit using novel verbal cues. The literature surrounding retro-cue benefits, predominantly with symbolic cues, has shown enhanced memory performance upon the presentation of valid cues (Griffin & Nobre, 2003; Hajonides et al., 2020; Mössing & Busch, 2020; Rerko et al., 2014; Schneider et al., 2019; for reviews, see Gressmann & Janczyk, 2016; Souza & Oberauer, 2016). We wanted to know, whether a similar enhancement in memory performance could be observed with verbal direction word cues. We assumed to find a clear retro-cue benefit.

Here our findings supported the hypothesis: A significant distinction emerged when the valid direction word cues were compared to the neutral cue. Both the left and right cue conditions demonstrated markedly better performance than the neutral cue condition. These differences were not only statistically significant but also substantial in effect size (Ellis, 2010, pp. 41). When studying further the relationship between the cues, a highly robust positive correlation (Ellis, 2010, pp. 41) was identified between scores from the left and right cue conditions. This finding indicates a consistent benefit across both valid cue types, suggesting that participants who benefited from one valid cue type also benefited from the other, and vice-versa. Weaker, but still robust positive correlations (Ellis, 2010, pp. 41) were present between the directional cue conditions and the neutral cue condition. This suggests that while directional cues provide clear advantages, inherent memory abilities of the participants, as indicated by performance in the neutral cue condition, still play a role in their overall performance.

4.3. Dissociation between hemispheric asymmetry in occipital alpha and memory performance

Our results offer an intriguing puzzle. A clear retro-cue benefit was evident, but this was not accompanied by the expected hemispheric asymmetry in occipital alpha. What should be made of this? First, it is important to consider the potential impact of hemispheric lateralization on these results, particularly given that the core topics of this thesis – hemispheric asymmetry in occipital alpha and the shifting of internal attention to VWM representations using verbal cues – are intrinsically lateralized phenomena.

One of the most well-established aspects of hemispheric lateralization is that for most, especially right-handed, individuals, the left hemisphere is dominant for language processing (for reviews, see Gazzaniga, 2002; Damasio & Geschwind, 1984; Damasio, 1992). Similarly, the processing of words is thought to be generally mediated by the left hemisphere (e. g., Baker et al., 2007; Cohen et al., 2002; McCandliss, Cohen, & Dehaene, 2003). As all our participants were right-handed, it is conceivable that the left hemisphere was more actively engaged in the task due to the verbal nature of the cues. This, paired with the fact that alpha oscillations have been suggested to reflect the active inhibition of cognitive processes during internally directed attentional tasks (Cooper et al., 2003; Myers et al., 2017), could explain why in our experiment alpha increased in the right hemisphere in relation to the left, as this could reflect the verbal processing demands of the cues. It might therefore be, that hemispheric asymmetry in occipital alpha in our research could reflect predominantly the inhibition of the cognitive processes in the right occipital lobe due to increased processing demands of the verbal nature of the cues in the left occipital hemisphere. This could have overridden the role of alpha oscillations in modulating internal attention orienting to the relevant stimulus, which has been found in many studies (e.g., Myers et al, 2015; Mössing & Busch, 2020; Poch et al., 2014; Poch et al., 2017; Schneider et al., 2015, 2019).

Alternatively, our results may indicate that effects of retro-cues on brain activity are domain-dependent. The use of arrow cues in previous studies (Berryhill et al., 2012; for a review, see Souza & Oberauer, 2016), has allowed for visual symbolic cues to prioritize processing of visual information. These studies have not crossed domain boundaries and have therefore not tapped into whether the effects of shifting internal attention to VWM representations is domain dependent or not. Our novel approach allowed us to study whether internal prioritization in visual processing occurs even though the cue indicating the prioritization must be interpreted through verbal understanding. As we found a solid retro-cue benefit in absence of the neural marker of hemispheric asymmetry in occipital alpha, it might be concluded that the improvement of memory performance caused by shifting internal attention to VWM representations is domain-independent, but the neural marker previously associated with it (e.g., Myers et al., 2015; Mössing & Busch, 2020; Poch et al., 2014; Schneider et al., 2015, 2016, 2019) is not.

More generally, this dissociation could imply that while occipital alpha asymmetry might be a prevalent marker for shifting internal attention to VWM representations, it is not an absolute prerequisite for enhanced memory performance. It can also be noted that the observed retro-cue benefit in the absence of alpha asymmetry may hint at the involvement of other neural mechanisms or pathways facilitating shifting of internal attention to VWM representations. For example, other frequency bands or brain regions could be more involved when verbal cues are presented. The findings could also suggest that the previously reported hemispheric asymmetry in occipital alpha is more specific to symbolic cues and may not generalize to all cue types, especially verbal ones.

Our surprising results could also be looked at from the point of view of the dual-coding theory proposed by Päiviö (1971), which posits that words and images are processed differently and can aid each other in memory recall. Participants might have processed not only the verbal information of the verbal retro-cue but also a mental image of the direction indicated by the word, as the theory would suggest (Päiviö, 1971). This dual encoding could partly explain the improved memory performance with valid verbal cues. Similarly, the neural findings might reflect the complexities introduced by the engagement of both verbal and imagery processing systems. For instance, the unexpected findings related to hemispheric asymmetry in occipital alpha could be a result of competing or overlapping neural activities stemming from these two systems. The verbal processing might have predominantly activated the left hemisphere due to language dominance, while the non-verbal imaginal processing, evoked by the direction word, could have engaged visual areas in both hemispheres.

4.4. Limitations

While our study offers valuable insights into the interplay between verbal cues and their influence on shifting internal attention to VWM representations, it is important to acknowledge its limitations. A significant limitation is the potential confounding effect of the lateralized processing of verbal cues. The verbal cues were utilized to overcome the confounding variable of the lateralized processing of symbolic arrow cues, but, unfortunately, the novel verbal cues might have introduced another confounding factor. When considering the use of verbal cues, it is also important to acknowledge potential individual differences in reading speed and language proficiency, which could have influenced participants' performance.

Another thing to note is our selection of the baseline in analysis of the MEG data. The choice of baseline is pivotal in MEG analysis as it establishes the reference state against which changes in post-stimulus brain activity are measured (Gross et al., 2013). We selected a baseline period of 200 ms to 0 ms prior to the retro-cue presentation to isolate the effects of the cue from preceding stimuli. However, a mnemonically active state preceded the retro-cue onset, because at 200 ms to 0 ms before the onset of the retro-cue the participant had already been shown the objects to be remembered. This leaves open the possibility that the baseline state could reflect a state of already modified oscillatory pattern in alpha, since alpha oscillations might play a role in many kinds of memory functions (Klimesch, 1997). There is a possibility therefore, that our baseline was not neutral in reference to alpha activity. Additionally, the risk of anticipation effects, where participants anticipate the onset of the retro-cue, potentially altering the brain state before the cue, cannot be ruled out. Such effects could dilute or modify the true impact of the retro-cue on alpha activity.

Previous studies have used different kinds of baselines anywhere from 1200 ms to 1000 ms before the onset of the retro-cue (Myers et al., 2015) to 200 ms to 0 ms before the onset (Schneider et al., 2015). Given this, our baseline choice aligns with several other studies that have successfully identified hemispheric asymmetry in occipital alpha (Mössing & Busch, 2020; Poch et al., 2014; 2017; Schneider et al., 2015).

Another limitation is that this thesis did not include an arrow cue condition. To ensure a more rigorous analysis of the effects of the novel verbal cues, the verbal cue condition could have been accompanied by an arrow cue condition for comparison. Our reliance on comparisons with previous studies raises questions about the commensurability of findings. The study's sample size and lack of diversity also limit the generalizability of our findings. It should also be noted that, although both parametric and nonparametric methods were used to validate the results, the non-normal distribution of several of our variables might have impacted the robustness of our statistical inferences.

The lengthy and potentially monotonous nature of the retro-cue task should also be noted. This may have influenced the engagement levels of participants. For example, fatigue and reduced alertness could have interfered with participants' cognition. Further, it should be noted that we did not account for the individual memory strategies employed by participants, which might introduce variability in task performance.

4.5. Significance and future directions

Although this study has its shortcomings, it holds significance in several respects. First, it addressed a gap in the literature by investigating the neural mechanisms underlying the shifting of internal attention to VWM representations using object-based endogenous verbal retro-cues, an aspect that had not been previously explored. Second, by employing verbal cues, the study managed to eliminate a confounding variable associated with the use of spatial cues, thereby providing a new approach to studying the mechanisms involved in shifting internal attention to VWM representations. Lastly, this thesis sought to contribute to our understanding of the domain dependency of retro-cue effects on brain activity, which has broader implications for our understanding of cognitive processes involved in attention and memory. Our results highlight the importance of considering the subtle effects of different types of cues, inviting a reassessment of existing theories and models. This could possibly have implications even for practical applications like education or clinical settings.

Our novel research paradigm and surprising findings suggest the need for more research. Future research should dive deeper into the effects of verbal endogenous cues. A systematic comparison of verbal cues with other cue types is called for. This could teach us about the unique neural patterns associated with different cue types, enhancing our understanding of the nature of shifting internal attention to VWM representations. Given the speculations related to hemispheric lateralization in this study, subsequent research could specifically explore its influence. For instance, studies with left-handed participants or those with atypical brain lateralization might offer valuable information. Given the unexpected lack of alpha asymmetry despite clear retro-cue benefits, it might be worth investigating other potential neural markers, such as other frequency bands or activation in different brain regions when verbal cues are used. To ensure generalizability and more robust statistical inferences, further studies should use a larger and more diverse set of participants. Future research should also focus on studying internal attentional shifting to VWM representations with different MEG baselines.

Regarding the experimental paradigm, future studies might want to introduce longer and more frequent breaks to maintain high participant engagement and ensure the quality of collected data. Individual memory strategies in the task should also be examined. This would offer a better understanding of how different individuals engage with and benefit from verbal cues as well as retro-cues more generally.

4.6. Conclusions

Our study offers a unique and fresh perspective into the research concerned with internal attention and visual working memory. The investigation revealed that while verbal retro-cues do result in enhanced memory performance, they might not lead to the expected hemispheric asymmetry in occipital alpha – a marker associated with retro-cue benefit in previous studies. This disassociation between the retro-cue benefit and the neural marker challenges some of our existing conceptions and sets the stage for more detailed examination in the future.

We speculate that this unexpected pattern might be caused by the interplay between verbal processing, which is intrinsically lateralized, and the role of alpha oscillations in internally directed attentional tasks. Alternatively, our results might indicate that the neural mechanisms underlying shifts in internal attention to VWM representations are more domain-dependent than previously thought. The results indicate also that hemispheric asymmetry in occipital alpha, although significant in the context of symbolic cues, might not be a requisite for improved memory performance, suggesting the potential involvement of other neural pathways or mechanisms.

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