Interchangeability of Virtual and Real: The Stable Vection Shifted Spatial Attention and New AR Technologies Improved Subjective Teaching Effects

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Interchangeability of Virtual and Real

--- The Stable Vection Shifted Spatial Attention and New AR Technologies Improved Subjective Teaching Effects

バーチャルとリアルの互換性

--- 安定ベクションによる空間的注意の変化と新しい AR テクノロジーによる主観的な教育効果の向上

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Abstract

Vection refers to the perception of self-motion illusion and can also be seen as the conscious and subjective experience of self-movement and movement in the metaverse space. Previous research has found that vection, rather than physical motion stimuli, can affect memory because as the participant's immersion time becomes longer, the virtual world will switch to the real world, at this time, the reality of the physical movement stimulus becomes weaker. Although both virtual and real environments impact human behavior, the boundaries between the virtual and real worlds have become blurred. However, the world perceived as more real at any given moment will have a greater influence on human cognition and behavior. To further investigate the impact of interchanging the virtual and real worlds on human behavior, this thesis also employed 3D augmented reality (AR) technology, which provides a more convincing approach. The vection experience and AR scene enable individuals to transition from the real world to the virtual world, and long-term virtual immersion brings them to the real world. Thus, Chapter 1 posed the question, “How are virtual and real realities connected and interchanged to affect human cognition and teaching and learning?” To address this, two studies were conducted. Firstly, this thesis examined the effect of self-motion illusion induced by 2D motion stimulation on attention (with a focus on whether vection affects other cognitive processes like spatial attention). Secondly, this thesis investigated the teaching effect of two new AR technologies in the 3D virtual world.

Chapter 2 utilized modified versions of Posner's classic spatial attention cueing paradigm to explore whether vection-direction could serve as an exogenous cue to spatial attention. Results showed that ‘vection-valid’ cues reduced reaction times compared to 'vection-invalid' cues. However, this vection-based cueing effect was observed only when the vection inducing grating motions were presented for 20 seconds (not 5 seconds) and when the target was visual (not audiovisual in nature). The vection cueing effects did not vary based on the experimental task (spatial orientation task and color discrimination go-no-go task). These findings indicate that vection-direction can direct spatial attention, but seemingly only when the vection is strong and reliable. Therefore, these four experimental results suggest that vection has a greater effect and successfully transforms the virtual into the real world.

Chapter 3 introduced two new augmented reality presentation technologies, Volumetric video Augmented Reality (VAR), and Avatar-based Augmented Reality (AAR), which facilitate the interchange of the virtual and real worlds in a more convincing manner. Four group behavior experiments were conducted: VAR, AAR, Face-to-face, and Zoom. The results indicated that the AAR and VAR groups reported significantly higher levels of 3D sensation and presence and perceived the teacher as more attractive compared to the Face-to-face and Zoom groups. The AR virtual teaching scene had a greater effect on subjective teaching outcomes.

Chapter 4 summarized the two main findings of this thesis: stable vection direction shifted spatial attention, and the new AR technologies improved the sense of presence and subjective teaching effects. In conclusion, these results affirm that vection and the virtual world can successfully interchange with the real world and have a greater impact on human cognition and teaching. Considering the limitations of this thesis, six potential research directions for the future are proposed, including further exploration of augmented reality technologies, vection effects, and other virtual scenes, as well as real-world effects.

Table of Contents

Chapter 1 Introduction

Summary

How to connect and transform into each other the virtual world and the real world is a topic worth studying. By studying this connection and transformation through vection and augmented reality, it is possible to further deepen the understanding of how virtual and real interactions affect human's daily cognition and learning behavior. This chapter introduced and elaborated on the concepts of vection and the metaverse world. The classical measurement methods of vection intensity and the low-level properties of the visual stimulus, as well as the higher-level cognitive factors affecting vection intensity, were summarized. The concept of vection was further enriched, considering it as the conscious and subjective experience of self-movement and movement in the metaverse space and it has the ability to transform the virtual world into the real world. The relationship between vection and attention was then discussed, highlighting the limited research on the effect of vection on spatial attention during cognitive tasks. To address this gap and examine whether vection greater effect on attention, this study examined whether vection direction could serve as an exogenous cue for spatial attention. Then the two new AR technologies were developed in this thesis as another way to interchange virtual and real more effectively and investigated their impact on cognitive processes (such as presence) and teaching and learning effects. Consequently, based on this background, the thesis aimed to explore the question: 'how virtual and reality are connected and interchanged to affect human cognition and teaching and learning?' If vection shifted spatial attention and the new AR technologies yielded better teaching effects, it would suggest that vection and the virtual world can successfully transform the virtual into the real world and greater effect on human cognition and teaching.

Chapter 1 Introduction

The advancement of technology has blurred the boundaries between the virtual and real worlds. Rather than being opposites, they interact and merge, influencing our daily behavior. The virtual world, also known as the metaverse, is an illusional and virtual creation that combines sensory information from various modalities. The term "metaverse" refers to a virtual space that connects multiple virtual spaces with each other (Damar, 2021; Mystakidis, 2022). Despite being simulated, the virtual world has real effects. A key feature of the metaverse is providing users with an enhanced sense of presence. This sense of presence refers to the feeling of complete immersion in the virtual world, fostering a deep connection and profound experience of the virtual environment, akin to the real world (Han, Bergs, & Moorhouse, 2022). Various virtual reality technologies, such as virtual reality headsets and spatial audio, create a sense of space and sensory presence for users (Servotte et al., 2020).

The study of how to connect and transform the virtual and real worlds is a worthwhile topic. Investigating this connection and transformation can deepen our understanding of how virtual and real interactions impact human cognition and learning behavior. Therefore, this thesis examines the effectiveness of two aspects: vection and augmented reality technology (AR) as means of connection and transformation. Within virtual worlds, motion grating-induced vection contributes to a sense of presence. Vection is not merely an illusion of self-movement but also a conscious subjective experience of self-movement. In the virtual environment, this subjective experience significantly enhances the sense of presence in virtual reality. It is generally accepted that vection and presence are positively correlated, meaning stronger vection intensity leads to a stronger sense of presence (Kim et al., 2022). This positive relationship remains unaffected even by visual-induced motion sickness, known as cybersickness (Kooijman et al., 2022). Due to their close relationship and mutual influence, researchers often examine vection and sense of presence together. For example, studies involving forward self-motion simulation in virtual reality using Oculus Rift head-mounted display demonstrated consistent trends in both vection and sense of presence across participants with different sequential yaw head movements. This positive relationship persists despite varying head-to-display lags (Kim et al., 2022), further supporting vection's role in enhancing the sense of presence in the virtual world. On the other hand, AR combines real-world and virtual stimuli, making it well-suited for connect and interchange between the real and virtual worlds. Both vection and AR technology blur the boundary between the real and virtual worlds. The following sections will further elaborate on whether vection and AR technology are suitable for connecting and interchanging virtual and real worlds, and how they may impact human cognition, teaching, and learning behavior.

1.1 Vection

Vection is a prevalent phenomenon in everyday life, and a classic example is the train illusion, where perceiving the movement of adjacent trains can create the illusion that the stationary train you are on is also moving. Scientific reports on vection date back to the late 19th century, with one of the earliest studies conducted by Wood (1895). Since then, researchers exploring the neural mechanisms involved in perceiving and controlling self-motion have frequently investigated vection (e.g., Brandt, Dichgans, & Koenig, 1973; Kirollos, Allison, Palmisano, 2017; Kleinschmidt et al., 2002; Palmisano et al., 2016; Pitzalis et al., 2013). The most studied types of vection are visually induced illusions of self-motion (please also see Palmisano et al. (2015) for alternative self-motion related definitions of the term 'vection'). When a large area of their visual field is filled with coherent motion, stationary observers often perceive the illusion that their body is moving in the opposite direction to the visual motion. As can be seen from Figure 1 a, vection is almost always perceived to occur in the opposite direction to the visual stimulus motion (Seno, Ito, & Sunaga, 2009) (i.e., the optic flow). However, when the observer's visual foreground moves (slowly) in a different direction to their visual background, it is possible to experience 'inverted vection' (Nakamura & Shimojo, 2000, 2003) – where vection is induced in the same, rather than the opposite, direction as the visual foreground motion. In addition, there tends to be a finite delay between the start of this visual motion and the onset of vection (e.g., Bubka, Bonato and Palmisano, 2008; Dichgans and Brandt, 1978; Keshavarz et al., 2017; Palmisano et al., 2015; Seno et al., 2017). After its onset, observers typically perceive a mixture of self-motion and object-motion, before eventually experiencing exclusive self-motion (known as vection saturation—see Dichgans and Brandt, 1978). Studying such compelling illusions can provide us with important basic information about the visual processing responsible for active navigation and passive locomotion. It can also provide useful information for vection implementing more effectively and efficiently in applied (e.g., when vection is used to compensate for missing or non-ecological forces in vehicle simulators, or to generate attention-grabbing effects in motion pictures, or to enhance amusement rides).

The measurement of vection intensity typically relies on subjective self-report measures, which encompass three key indicators: latency times, duration, and subjective ratings of vection strength (Palmisano et al., 2015; Seno et al., 2017). Latency time refers to the duration it takes for participants to initially experience the illusory sensation of self-motion when exposed to visual motion stimuli. Previous research has suggested that the existence of latency time, during which vection is not immediately evoked, may be attributed to initial intersensory cue conflicts between visual stimuli and vestibular cues during the acceleration phase (Keshavarz et al., 2015; Johnson, Sunahara, & Landolt, 1999). Duration denotes the total time participants experience vection when the visual motion stimulus is presented. Studies have shown that participants' ratings of vection strength increase as the duration of the visual motion stimulus increases (Seno et al., 2018). Latency and duration are typically recorded using keypress times, such as the time of the first press of the space bar and the total time of the space bar presses. The subjective vection score's strength is typically represented by a numerical range, such as 0 to 10 or 0 to 100. Generally, a score of 0 indicates no vection experience, while a score of 10 or 100 represents the strongest vection experience.

Vection can be induced when stationary observers are exposed to a large/global visual motion stimulus (Gibson, 1950; Brandt, Dichgans, & Koenig, 1973; Palmisano et al., 2015; Seno et al., 2012; Seno, Palmisano, Ito, & Sunaga, 2012). The experience of vection can be influenced by manipulating a variety of physical properties (Berthoz, Pavard, and Young, 1975; Brandt, Wist, & Dichgans, 1975) of the visual inducing stimulus, such as its frame rate - vection strength increased with 3D content frame rate (Fujii et al., 2019), luminance contrast (Patterson and York, 2009), its spatial frequency (Sauvan and Bonnet, 1993, 1995; Palmisano & Gillam, 1998), its optical/retinal size - vection strength increased with the increase size of visual stimuli (Brandt, Dichgans, & Koenig, 1973; Nakamura, 2006), its optical speed - vection strength tends to increase within a certain range stimulus speed (Brandt, Dichgans, & Koenig, 1973; Fujii et al., 2019), its oscillation of visual motion stimuli - oscillatory motion simulations can enhance vection and it can also improve the observers' perception of the distance travelled in comparison with a purely translational flow (e.g., Palmisano & Kim, 2009;

Palmisano et al., 2011; Bossard, Goulon, & Mestre, 2016, 2020; Bossard & Mestre, 2018), its surface properties of materials (Morimoto et al., 2019), its position in the visual field (Kawakita et al., 2000; Nakamura and Shimojo, 1998), its color/s - multiple colored dots inhibit vection whereas gray dots did not (Ogawa and Seno, 2016; Bonato and Bubka, 2006), its smoothness (Fujii, Seno, & Allison, 2018) and so on. Previous studies have found that these visual properties may affect the intensity of vection through human subjective perception, for example, a number of studies have shown that vection is not only affected by physical features of the visual inducer but also by its perceptual properties, such as perceived luminance, perceived rigidity, semantic meaning and auditory perception (e.g., Nakamura, 2019; Nakamura et al., 2013; Seno et al., 2012a, b; Ogawa and Seno, 2014). From the above studies, it can be seen that visual modality information processing plays an important role in the perception of self-motion illusion. In addition, the vestibular system may also play an important role in vection. The vestibular system is a sensory system in the inner ear that detects changes in head position and motion as well as changes in linear and rotational acceleration. For example, studies have found the vestibular system plays an important role in the postural response, attention, multisensory motion perception, body self-consciousness, navigation and vection, and so on (Berthoz, 1996; Brandt, Strupp, & Dieterich, 2014; Johnson, Sunahara, & Landolt, 1999; Lopez et al., 2007).

However, the experience of vection is not only determined by above low-level properties of the visual stimulus (please also see Dichgans and Brandt, 1978; Riecke, 2011 for reviews of these effects). Research has shown that there are also higher-level cognitive (e.g., attention, memory and so on) influences on observer experiences of vection (D'Amour, et al., 2021; Guterman & Allison, 2019; Palmisano & Chan, 2004; Miles, et al., 2010; Riecke, 2011; Riecke, et al., 2006; Seno, Ihaya, Yamada, 2013). For example, it was found that expectation changed vection strength and vection strength are positively correlated with field dependence etc., suggesting that vection is also affected by top-down mechanisms (D'Amour, et al., 2021). In addition, it has been shown that vection strength can be altered simply by changing the semantic meaning of the inducing stimulus (Seno & Fukuda, 2012). However, such interactions are not one-way – as the experience of vection can also alter our cognitions, modify our mood, and change the emotional valence of our episodic memories (e.g., Seno, et al., 2011; Seno, et al., 2013). For example, Seno, Kawabe, Ito and Sunaga (2013) found that people recollected more positive memories when perceiving upward (as opposed to downward or no) vection (see also Väljamäe & Seno, 2016).

Vection is typically a subjective illusory experience triggered by visual grating motion stimuli presented in a 2D display environment. Previous research has demonstrated that vection experiences can also be induced by auditory and tactile stimuli. For instance, similar to visually-induced vection, auditorily-induced vection can be evoked by real or virtual sound fields moving relative to the listener's point of audition (Väljamäe, 2009). Generally, auditory vection tends to be less intense than visual vection. Additionally, tactile stimulation can also elicit vection experiences. Researchers have successfully induced vection through wind stimulation on the face, application of force to the body, and vibration stimulation on various body parts (Kooijman et al., 2022). These findings indicate that vection involves different mechanisms and that the vividness of the vection sensation may be modulated by the context of motion simulation (Wright, DiZio, & Lackner, 2006). Furthermore, a study examining audiovisual interactive stimuli found that the simultaneous presentation of auditory cues, such as matching fountain sounds with visual landmarks, enhanced the vection experience and presence (Riecke, Väljamäe, & Schulte-Pelkum, 2009).

In other words, these different sensory modalities stimuli successfully induce the vection experience, so in this case, the elements of vection cannot be clearly defined, so the traditional visually induced vection can be understood as the self-motion experience through vision. With this multisensory modality vection experience, the concept of vection can be extended to the conscious and subjective experience of self-movement (or the movement of the metaverse world). This shows that although vection is a kind of illusion virtual experience if the immersion time is longer, human beings will feel that this illusion experience is no longer virtual but real like in the physical space. In the context of this thesis, a space with a physical body is referred to as the "physical space." However, the possibility of seamlessly replacing the physical space with the location of an avatar, as depicted in the movie "Avatar," has been considered. If individuals start perceiving a stronger sense of reality in the avatar body within the metaverse space, the argument that "there is no physicality in the metaverse space" could be refuted. This suggests that humans possess the ability to entrust the material world to virtual entities and perceive non-physical entities as real. As the sense of vection experienced in the metaverse space diminishes, it may indicate that our bodies are gradually being entrusted to that world. In essence, the bodies human believes to exist may not be essential. It leads us to an understanding that they might be ephemeral, regardless of their existence or absence. With frequent movement occurring in the metaverse space, the term "vection" will become a higher-level concept encompassing the idea of "self-motion." In other words, vection transcends movement facilitated by the physical body and represents a more fundamental form of motion. Vection is not merely a small word; it encompasses the very essence of human existence and the movement required to acquire information. Our bodies were merely vehicles of vection. At its core, vection defined our sense of being driven by something. Therefore, a longer vection experience will make human beings feel that the self-motion illusion world at this moment is real.

In addition, as mentioned earlier, vection can improve the sense of presence in the virtual world. If the stimulus could be performed in multiple sensory modalities, with a longer sense of presence and immersion, and also combine some virtual technology (VR) (Adam, 1993), could the vection experience at this time successfully transform this illusionary virtual world into the real world? In this case, the boundary between the virtual and real worlds has become more blurred, which once again shows that the virtual and real worlds are not opposed but unified with each other. In this case, it might be moving just like reality, thereby losing the illusion of motion, it is real self-moving. In other words, the vection at this time is not the self-motion illusion experience usually understand, it can be considered as the movement in the virtual space world and then the longer vection experience makes people feel like they have reentered the real world. In this way, the concept of vection is further enriched, that is to say, vection effectively connects and interchange the virtual world and the real world. At this time, the vection becomes the conscious and subjective experience of self-movement. Based on these ideas, humans who live in the real world (physical world) are forced to spend time in a subjective illusion or virtual space and adapt to the metaverse space. With the update of the concept of vection, it can be used as an effective connection and interchangeability between the virtual world and the real physical world. The vection experience can be induced to bring humans into the virtual world by observing physical motion stimuli, and then this virtual world can be interchanged into the real world if humans have long-term immersion in this illusion virtual world.

1.2 The Relationship Between Vection and Spatial Attention

How does the interaction between the virtual and the real world affect human behavior? Since vection is the conscious and subjective experience of self-movement and can also effectively connect and exchange the virtual and real worlds, does vection have a greater impact than objective physical motion stimuli? Because based on the previous discussion, vection has the ability to convert an illusory virtual world into a real world. As a result, this vection experience might have an effect on human cognition, more than physical motion stimulus. For instance, Seno, Kawabe, Ito, and Sunaga (2013) discovered that individuals recalled more positive memories when experiencing upward vection compared to downward or no vection. This implies that this subjective illusion experience has an impact on our memory performance, possibly because participants immersed in the vection experience induced by physical motion stimulation for a long time, will be transformed into the real world at this time and had a greater impact on memory. Could this effect of vection also extend to other cognitive processes, such as attention? It is unclear and further research is needed.

Research on attention has a rich history, encompassing its theoretical foundations, its role in higher cognitive processes, and its practical applications (Wickens, McCarley, & Gutzwiller, 2022). Within human information processing, attention serves as a fundamental psychological state, enabling us to selectively focus on desired information while filtering out irrelevant stimuli (Anderson & Crawford, 1980). This process involves directing and concentrating our focus on specific objects. Attention is not solely an automatic process; it can also be actively controlled (Pashler, Johnston, & Ruthruff, 2001). As one of the basic functions of human cognition, attention plays a vital role in key processes such as memory and decision-making. For instance, the "cocktail party effect" demonstrates the remarkable ability of humans to focus their attention on a specific auditory stimulus or conversation in a noisy environment, like a crowded party (Cherry, 1953; Shinn-Cunningham, 2008). This example highlights the crucial role of attention in human daily life, allowing us to selectively focus attention on specific regions or objects in the visual field, akin to a spotlight effect. Subsequently, researchers proposed the feature integration theory, suggesting that visual perception comprises two stages: the pre-attention stage (where basic features such as color, shape, and movement are automatically processed in the visual field) and the attention concentration stage (which corresponds to the spotlight effect) (Treisman & Gormican, 1988). Attentional control typically operates in a top-down and bottom-up manner within these two stages, although recent studies argue that such a dichotomy is oversimplified, and more comprehensive models are needed (Awh, Belopolsky, & Theeuwes, 2012). The latest attention schema theory suggests that attention mechanisms may be linked to internal control and the theory of mind, offering a fresh perspective on the relationship between attention and consciousness (Wilterson et al., 2020). While many attention phenomena are induced by visual stimuli, attention can be classified into visual attention and auditory attention based on sensory modality. Visual attention involves using our eyes to fixate on specific objects, forming the foundation for visual perception (Allport, 1989). Several key research questions arise within the field of visual attention, including visual stimulus salience, the inhibition of the return effect, and the interaction between attention and eye movement processes (Itti & Koch, 2001). For example, visual attention is crucial in guiding eye movements, as eye movements without a corresponding shift of attention would seem implausible (Shepherd, Findlay, & Hockey, 1986; Moore & Fallah, 2001). On the other hand, auditory attention refers to our ability to receive sound stimuli from various directions through our ears at any given time, in contrast to the selective focus of the eyes on stimuli in specific directions (Styles, 2006).

Most of the above-mentioned attention rules and phenomena are discovered through behavioral response time tasks. Such as, Posner (1980) proposed the cue-target paradigm to facilitate the investigation of spatial attention mechanisms through behavioral experiments. In earlier experimental paradigms, participants were presented with a central cue, such as an arrow, which provided information about the location where a target stimulus would appear. Different conditions were then created by manipulating the validity of the cue. For instance, in the valid condition, the cue accurately predicted the target stimulus position, while in the neutral condition, no cue stimulus was presented. In the invalid condition, the cue arrow pointed in the opposite direction to the target stimulus position, leading to a misleading cue. Participants' response times under different conditions were used to assess the validity of the cues. Generally, reaction times for valid cues conditions were significantly faster than those for invalid cues. Subsequently, Posner and Cohen (1984) employed sudden brightness or darkness changes to cue a specific position in space, resulting in accelerated participant responses to immediately appearing target stimuli at that position. This cue-target paradigm primarily investigates the function of visuospatial orienting attention. Recently, research has examined the role of top-down control in attentional allocation, highlighting the impact of task demands, cognitive load, attention's functions and individual differences on attentional processes (Posner, 2016). For example, based on attention's functions, the human brain's attention system is divided into three networks: the alerting network (associated with maintaining an alert state), the orienting network (responsible for directing attention to specific locations), and the executive control network (resolving conflicts and inhibiting irrelevant information) (Posner & Petersen, 1990; Petersen and Posner, 2012). Researchers then combined the cue-target paradigm with the inhibitory control task to propose an attention network experimental paradigm, aiming to examine attentional efficiency (Fan et al., 2002). The Posner cue-target experiment paradigm has significantly advanced our understanding of the mechanisms and functional significance of spatial attention. Through the application of various paradigms and methodologies, these studies have elucidated the time course of attentional orienting, neural correlates of attention, attentional networks, and clinical applications (Doricchi et al., 2010; Caldani et al., 2020).

Attention plays an important role in the process of task-related target information and filtering irrelevant stimuli, spatial location, etc. According to the processing method of attention, attention can be divided into exogenous spatial attention and endogenous spatial attention. Exogenous spatial attention is stimulus-driven and a bottom-up process, while endogenous spatial attention is goal-driven and a top-down process (Carrasco, 2011; Tang, Wu, & Shen, 2016; Theeuwes, 1991). Typically, these two kinds of attention can be evoked by different cue types in the cue-target paradigm. For example, in the cue-target paradigm, participants fixate on the center of the display, and a target appears in one of two boxes (located to the left and right of the center respectively) after the cue. In some studies, this cue is endogenous - e.g., it could be a centrally-placed arrow pointing either to the left or right (see Figure 1b). In other studies, the cue is exogenous – e.g., the outline of one of the two peripherally located boxes could be brightened (see Figure 1c). In both cases, trials are classified as 'valid' if the target subsequently appears on the side originally indicated by the cue, 'invalid' if it appears on the opposite side, and 'neutral' if no cue was provided. Participants typically press arrow keys or buttons (as quickly as possible) to indicate which side the target appears to be on (e.g., on the left). By comparing reaction times and task accuracy on valid, invalid, and neutral trails, one can determine whether such cues are capable of directing spatial attention (to either benefit or hinder performance).

Furthermore, there are various types of cues that can elicit both endogenous and exogenous spatial attention. For instance, studies have utilized semantic cues to induce endogenous spatial attention. These cues are often associated with specific concepts, such as object names or their associated sounds (Ho & Spence, 2005), as well as memory- or emotion-based cues like familiar faces, threats, and fears (Mohanty & Sussman, 2013). On the other hand, exogenous spatial attention is typically triggered by peripheral cues, such as the sudden appearance of a figure's outline. For example, researchers have used two small circles as exogenous attention cues, unrelated to the experimental task. The results demonstrate that such cues can successfully induce exogenous attention and impact learning efficiency (Szpiro & Carrasco, 2015). Another common cue that elicits exogenous spatial attention is a physiological movement cue or dynamic cue. For instance, Skarrat, Cole, and Gellatly (2009) found that both looming and receding movements received more attention compared to static stimuli. Researchers believe that the effect of looming movement is more pronounced than that of movement alone. This notion is supported by correlational evidence from neurological studies using the Event-related potentials (ERPs) approach, which found that early components of the ERPs (P1p and N2po) prior to 300 ms showed enhanced capture of exogenous attention in response to looming positive disruptors (Fernández-Folgueiras et al., 2022). Additionally, the size of exogenous spatial cues, the type of experimental tasks, and the contrast level of the cues also influence the magnitude of the cue effect (Burnett, d'Avossa, & Sapir, 2013; Fuller, Park, & Carrasco, 2009).

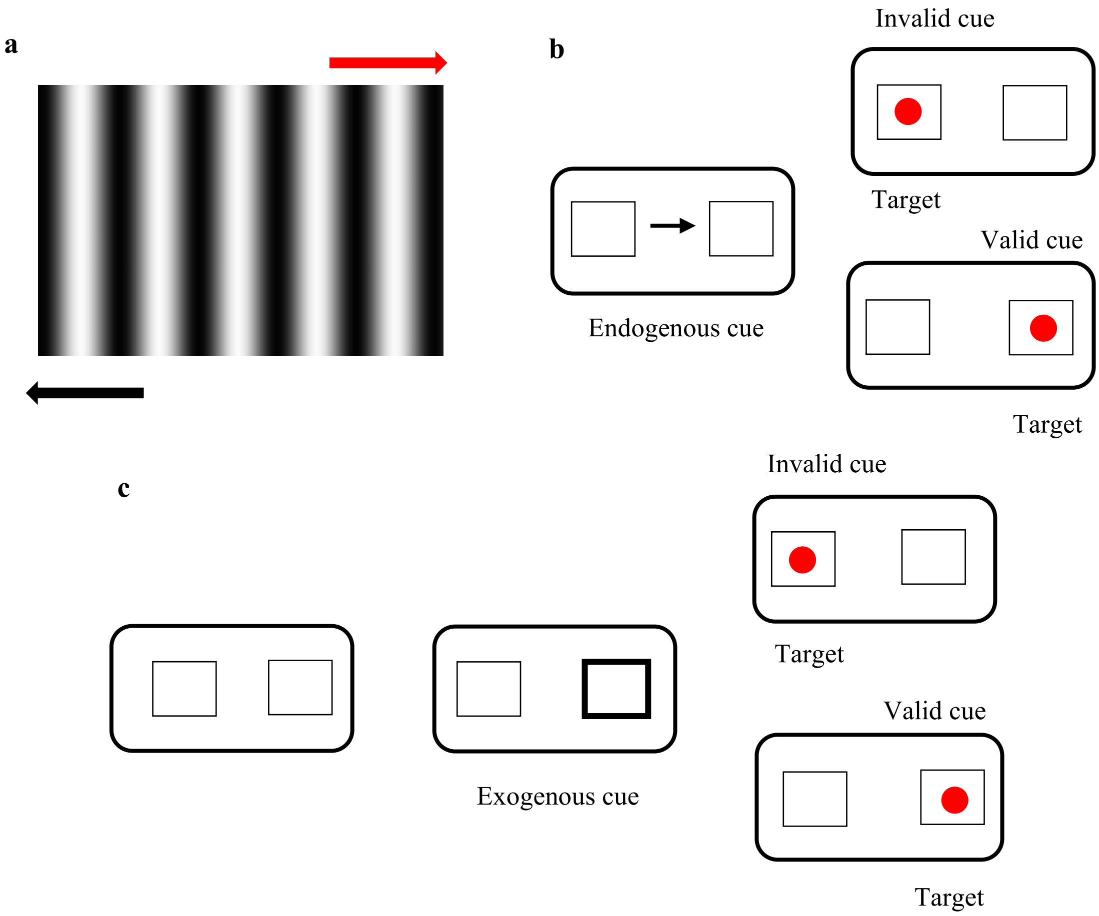

Figure 1. Schematic diagram of vection and endogenous and exogenous attention.

a) Vection direction (black arrow) and the inducing visual stimulus motion (red arrow) are almost always opposite.

b) Example of spatial cueing of attention using endogenous cues, the shift in spatial attention is induced by the centrally placed arrow.

c) Example of spatial cueing of attention using exogenous cues- the shifted in spatial attention is induced by the outline of one of the two boxes being brightened.

Thus, does vection affect spatial attention in the same way it affects memory? Previous studies have found that the relationship between attention and vection is complex, and different studies have produced different results (Seno, Ito & Sunaga, 2011; Kooijman et al., 2022). Thus, the relationship between vection and attention needs further investigation. To date, only a handful of studies have examined the relationship between vection and attention. This research initially suggested that vection induction was facilitated when observers paid less attention to their visual motion stimulation. For example, when Kitazaki and Sato (2003) instructed their participants to pay attention to only one (of two visible) competing directions of global display motion, they found that vection was dominated by the non-attended motion. Similarly, Trutoiu et al. (2008) reported that vection onsets were shorter when additional cognitive/attentional tasks were performed while viewing the visually simulated self-motion (e.g., counting the occurrence of a specific target or pressing a button every time it appeared). By contrast, Seno, Ito, and Sunaga (2011) found that (compared to control conditions) vection was impaired by performing additional cognitive tasks – either a rapid serial visual presentation (RSVP) task in their first experiment or a multiple-object tracking (MOT) task in their second experiment. Specifically, participants' subjective vection strength scores decreased under the RSVP task, while under the MOT task, not only the subjective vection strength scores but also the duration of vection experience decreased. Fujita (2004) also found that performing an additional memory task modestly reduced vection. The findings of these two studies suggest that vection does require attentional resources, and that excessive demands on these resources can delay vection onset and reduce vection intensity. The researchers further counted the number of times the participants pressed the vection experience response keys under the passive and task conditions and found no significant difference, so these results seem to rule out the effect of task difficulty on vection intensity.

However, other studies have found that attention may have no effect on vection experience. Specifically, the researchers combined virtual reality (VR) technology and a secondary visual discrimination response task and found that the participants' ability vection experience was not affected when performing the attention response task (Kooijman et al., 2022). It would appear then that the relationship between attention and vection is rather complex. This view is supported by the findings of several recent studies. In one of these, Wei et al. (2018) examined *sustained attention to response test* (SART) performance during display motions that were either consistent or inconsistent with self-motion. They found evidence that SART performance was impaired in central vision, but enhanced in the peripheral visual field, during vection. Additionally, the results found that participants experienced more stable vection when trained to redistribute attention from the central to the peripheral vision. Therefore, the vection experience will be changed when completing the visual cognition task. They concluded that vection triggers an eccentricity-based reallocation of attention, where more attention is directed to the periphery (compared to non-vection control conditions). This is consistent with previous research showing that when individuals experience vection, they pay more attention to their peripheral vision and less attention to their central vision (Brandt et al., 2002). Thus far, studies have focused mainly on the influence of spatial attention on vection.

At present, only two studies have examined the possible influence of vection on attention. Based on their Event-related potentials (ERPs) and behavioral data, Stróżak et al. (2016) concluded that vection appears to slow reaction times and disrupt electrophysiological responses to targets during an oddball task. Specifically, the behavioral results found that vection experienced most frequently under both the central and peripheral stripes of moving and central stationary peripheral stripes moving. However, there is basically no vection experience under the condition that both the center and the periphery are stationary, but the averaged reaction time under this condition is significantly faster than that under the condition that both the center and the periphery are moving. ERPs results found that the amplitude of P1, N2, and P3 event-related potentials of targets in cognitive tasks was reduced under the condition of vection experience compared with no vection experience. In a similar study, Stróżak et al. (2019) found that vection had little effect on performance on a complex visual change detection task (suggesting that attentional resources were not required to induced vection – similar to Kitizaki and Sato's, 2003 proposal). Specifically, under the condition of moving visual stimulation pattern, there was no significant difference in the accuracy and response time of the participants under the condition of vection experience and the condition of non-vection experience. However, there was psychophysiological evidence of attentional disruptions – with reductions in N400 event-related potentials (as well as P3a and P3b amplitudes) in the most vection prone participants.

1.3 The AR technologies improved Presence

Vection could successfully interchange the virtual and real worlds if vection also had a greater effect on spatial attention rather than motion stimuli. It refers to the virtual illusion experience caused by physical motion stimulation, and the longer immersive vection experience brings people to the real world and greatly affects the human attention response. By using 3D virtual reality technology to connect and interchangeability virtual and real world will be a more effective method. For example, previous studies have used head-mounted displays (HMD) and head-tracking systems to create a multisensory environment that more realistically immerses participants in this virtual world. This more realistic stimulation makes participants feel more real, which has a certain real and effective effect in psychotherapy. For example, exposure therapy is difficult to implement due to the limitations of the real environment. At this time, the virtual world is a valuable choice for exposure therapy, and it turns out that VR exposure is a better treatment (Li et al., 2017). And many previous studies have also found that participants have a high sense of presence after using virtual reality technology. According to these studies, subjective vection experiences and virtual worlds can transform into the real world, rather than completely virtual. Thus, the virtual and real world can be interchangeable. This shows that the illusion and virtual reality are not completely virtual, they may be connected and transformed to the real world.

In addition to the aforementioned VR technologies, numerous new VR technologies are currently being developed. As mentioned earlier, the virtual world may no longer be truly virtual when immersion is heightened, and the boundary between virtual reality and the real world becomes blurred, effectively transforming the virtual world into a real experience. To further explore the relationship between the virtual and real worlds, researchers have been developing novel virtual reality technologies aimed at enhancing the sense of presence and immersion. For instance, some recent studies have combined 360° panorama technology to create videos and pictures of both real and virtual environments, comparing them to computer-simulated environments to assess their effectiveness in generating a sense of personal presence, emotion, and relaxation. Interestingly, no significant differences between the simulation and VR environments were found, indicating the feasibility of using the new 360° realistic panoramic VR, especially for passive tasks that do not require active exploration of the environment (Brivio et al., 2021). As these new technologies are still in their early stages, researchers have initially applied them in various domains, such as movies, stage performances, games, medical procedures, and educational settings, to assess their preliminary effects (Slater & Sanchez-Vives, 2016). Based on these findings, it becomes evident that the interaction between virtual reality and reality profoundly affects human cognition and learning behavior. For instance, combining game-based methods with virtual reality (VR) environments has been found to enhance learning and training effectiveness, with promising potential for the future. In such environments, users are not passive observers but active participants, fostering an exploration-based learning paradigm (Checa & Bustillo, 2020). At this point, for users, the virtual world becomes indistinguishable from the real world.

Thus, besides the vection experience induced by 2D display motion stimulation, which might affect human cognition (attention), another notable example is the stimulation of more realistic stimuli in virtual scenes using 3D virtual technology might also influence human cognition and teaching and learning. Such as, with the development of 3D virtual technology, AR and other new methods are gradually used in the teaching process and found to improve the teaching effect and other entertainment activities. AR technology is based on a virtual overlay of real-world stimuli, so connecting and interchangeability virtual and real world from this technology is a viable start. AR technology was first developed by Sutherland using head-mounted devices, and currently, it is mainly composed of three parts: a display system; a 3D registration system, and a human-computer interaction system (Berryman, 2012; Chen et al., 2019). AR is the process of combining some virtual data, such as information, and real scenes with three-dimensional interaction (Azuma, 1997; Carmigniani, Furht, Anisetti, Ceravolo, Damiani, & Ivkovic, 2011; O'Shea, 2011).

In many augmented reality studies, the sense of presence is a very important subjective perception, and it is applied to some games. Previous studies have used different applications and strategies to study presence. Due to different technical equipment and virtual scenes, there may also be differences in the sense of presence (Marto, & Gonçalves, 2022). Another important application scenario is in teaching activities. For example, in science education courses, students used augmented reality technology, and it was found that the presence of these students affected their attention, and the focus of attention and sense of presence further affected their flow experience (Salar et al., 2020). Previous studies have also demonstrated the genuine and effective application of other AR technologies in educational environments, such as 3D anatomy simulations and the like (Garzón, 2021).

Most AR technologies are implemented by computers, whether it is to develop applications or systems in the teaching process (Chytas et al., 2020; Chen & Liu, 2020). There are still some limitations in the application of these AR technologies to practical teachings, such as rarely presenting the face or overall behavior changes of teachers in a comprehensive and three-dimensional way (Alalwan, Cheng, Al-Samarraie, Yousef, Alzahrani, & Sarsam, 2020; Sırakaya & Alsancak, 2020). Although, some researchers have developed AR technology that can fully capture the movement of people (volume video) and faces (virtual avatars) in a scene (Vera, Gimeno, Coma, & Fernández, 2011). Volumetric video allows individuals to observe the captured content from many directions, also an avatar representation can give participants a more enjoyable and immersive experience (Yoon, Kim, Lee, Billinghurst, & Woo, 2019; Zerman O'Dwyer, Young, & Smolic, 2020). However, it is unclear how volume video and virtual avatar technology will affect sense of presence and attention in the teaching process. Also, this study further maximizes the teaching effect and present teachers' activities in three-dimensions while realizing the real-time capture of the teacher's face movement in the teaching process. Thus, we developed two new present methods to present stimuli more real, namely: Volumetric video Augmented Reality (VAR) and Avatar based Augmented Reality (AAR), for a detailed description refer to the Chapter 4 Methods section below. These new systems can present the teachers' activities in three-dimensions and comprehensively bring participants into the AR experience, more easily and immersive. By using these two new VAR and AAR technologies to record courses and presenting them, participants' sense of presence and attention, memory in courses under different teaching conditions can be accurately compared.

1.4 The Purpose of Present Thesis

Firstly, previous research has established that vection can influence memory because it effectively connects and interchanges the virtual and real worlds. The boundaries between these two realms have become increasingly blurred, and both virtual and real experiences impact human behavior. At any given moment, the world perceived as more real may exert a greater influence on human cognition and behavior. However, the extent to which vection affects other cognitive processes, such as spatial attention, remains unclear. Secondly, prior studies have revealed a complex relationship between attention and vection. Yet, the specific impact of vection on spatial attention during cognitive tasks remains unexplored. Cognitive tasks often involve attention shifts, which can be either voluntary and goal-driven (endogenous) or involuntary and stimulus-driven (exogenous) (Hopfinger & West, 2006; Macaluso, 2010). In this thesis, investigated whether vection direction could serve as an exogenous cue for spatial attention, utilizing a modified version of Posner's classic cueing paradigm (Posner, 1980; Posner and Cohen, 1984; Chica, Bartolomeo, & Lupiáñez, 2013; Hopfinger & West, 2006; Macaluso, 2010; Tang, Wu, & Shen, 2016). Unlike previous studies that employed exogenous cues such as the brightening of stimulus borders around the visual field, this research aimed to replace them with the direction of vection experience evoked by the motion grating stimulus. Since the induction of vection experience is typically a passive or automatic illusion, this study set an equal ratio of left or up vection direction, right or down vection direction, and a control static condition to ensure non-predictive, it is more likely exogenous cues. Building on previous findings that vection direction can significantly impact memory task performance, this thesis hypothesized that vection direction could serve as a valid cue for spatial attention, ultimately enhancing cognitive task performance.

Besides the vection experience induced by 2D display motion stimulation which may impact human cognition (attention), there is another noteworthy and effective method. The presentation of stimuli more immersion through 3D virtual technology in virtual scenes also affects human cognition and teaching and learning. The level of realism and immersion in the virtual world determines the extent of its influence on cognition and learning. Thus, at this point, vection and the virtual world are not merely virtual. The boundaries between the virtual and real worlds are blurred, and interactions affect human behavior. 3D visual AR scenes are usually combining real-life stimuli and might have a better effect to connect and interchange virtual and real, so this thesis wanted to use AR technology to present teaching scenes instead of just computer screens and to improve the ecological nature of the experiment and better transformation of the virtual world into the real world. Since these technologies are still emerging, this thesis initially employed them in a teaching scenario to measure their initial effects. Moreover, considering the different types of visual stimuli, this study needs to examine various subjective perceptual characteristics and different tasks to better understand how AR impacts our sense of presence and teaching outcomes. Furthermore, vection may play a significant role in augmented reality, affecting subjective perceptions such as presence. Thus, investigating the impact of more ecologically valid scenes, such as teaching scenarios in augmented reality, on the sense of presence and cognitive processes, will provide technical data and test evidence supporting the combination of vection and augmented reality. In conclusion, if subjective vection and the virtual world experience longer immersion, it can transform virtually into the real. It is worthwhile to further investigate whether virtual interchange with the real world affects human daily cognitive processes and teaching efficiency.

Hence, based on these findings, this thesis aims to address the question: 'how virtual and reality are connected and interchanged to affect human cognition and teaching and learning.' To answer this question, two studies were conducted. The vection experience and AR scene will bring human beings from the real world to the virtual world, and the long-term virtual immersion experience will bring human beings from the virtual world to the real world. The first study examined the effect of self-motion illusion experiences induced by 2D motion stimulation on attention (see Chapter 2). To further investigate whether the virtual world can be interchanged with the real world, the second study investigated the educational impact of two new AR technologies in a 3D virtual world (see Chapter 3). In summary, stable and longer vection experience may not be a virtual illusion, and its influence on memory might also be discovered in spatial attention. If the new augmented reality technologies prove effective in educational scenarios, it will establish a foundation for these emerging technologies to interchange virtual and reality in the future. When vection and AR world can effectively transform the virtual world into the real world, exploring the effectiveness of vection and AR in human cognition (such as spatial attention) and teaching can help humans further deepen their understanding of the virtual world. The level of realism and immersion achieved in the virtual world determines the magnitude of its impact on cognition and teaching. This thesis holds significant value, particularly in the connecting virtual and real worlds, as it will shed light on whether the virtual and real worlds are interchangeable. Based on the conclusions drawn from this thesis, further research interact about virtual worlds and reality effects on human behavior can be conducted. Consequently, this thesis serves as a meaningful foundation for future experimental investigations.

1.5 Overview of This Thesis

Therefore, the purpose of this thesis is to examine how virtual and reality are connected and interchange to affect human cognition and teaching, and learning. Through subjective vection induced by grating motion stimuli and using two AR new technologies present the real teaching scenes try to answer this question. First, in Chapter 2 this thesis induced a stable vection experience by using grating motion stimuli. Then examined whether vection direction can be used as an effective cue of exogenous attention under different motion directions and target modality and experiment tasks. And examine the vection whether vection has a real and effective diversion in spatial attention. Second, in Chapter 3, two new AR technologies are used and compared with traditional teaching methods to examine whether the virtual teaching effect is better, that is, whether the longer immersion in the virtual world transforms into the real world and affects human cognition and teaching and learning.

Chapter 1 Introduction

Chapter 1 provides an introduction to the concept of vection, explores the factors influencing vection intensity, and discusses the impact of vection on higher-level cognitive processes. Furthermore, the chapter expands on the concept of vection by considering it as the conscious and subjective experience of self-movement and perception of movement within a metaverse space and has the ability to transform the virtual world into the real world. Subsequently, visual attention was introduced, followed by a summary of Posner's Cue paradigms, including endogenous and exogenous spatial attention, as well as the common types of cues that induce these two types of attention. The relationship between vection and attention was then discussed, highlighting the limited research on the effect of vection on spatial attention during cognitive tasks. To address this gap and vection effect on attention, this study examined whether vection direction could serve as an exogenous cue for spatial attention using a modified version of Posner's classic cueing paradigm.

Besides the vection experience induced by 2D display motion stimulation, which might affect human cognition (attention), the longer and more immersion in virtual scenes using 3D virtual technology might better interchange of the virtual world into the real world and also influence human cognition (presence) and teaching and learning. However, previous technologies may have lacked a sense of three-dimensionality and the engaging aspects of avatars. Therefore, two new technologies were developed in this thesis to make more immersion and investigated their impact on cognitive processes (such as presence) and teaching effects. Consequently, based on this background, the thesis aimed to explore the question: 'how virtual and reality are connected and interchange to affect human cognition and teaching and learning by investigating the potential effects of vection on spatial attention and the teaching effects of two new AR technologies.' The vection experience and AR scene will bring human beings from the real world to the virtual world, and the long-term virtual immersion experience will bring human beings from the virtual world to the real world. If vection shifted spatial attention and the new AR technologies yielded better teaching effects, it would suggest that vection and the virtual world can successfully transform the virtual into the real world. The notion of vection and the virtual world being purely virtual may need to be reconsidered and rethink the relationship between virtual and real then what world is real at this moment. Finally, the chapter concludes with a brief overview of the thesis's purpose and content.

Chapter 2 comprises four behavioral experiments. It begins by inducing a stable vection experience using grating motion stimuli. The chapter then delves into a detailed examination and measurement of the effectiveness of vection direction as a cue in exogenous spatial attention, comparing different vection directions (left, right, up, and down), task modalities (visual and audiovisual target modalities), and task types (positioning task and color discrimination Go-Ngo task). The results are explained and illustrated using the two-stage theory of attention, vection, and embodied cognition theory. A stable and reliable vection experience can indeed serve as an effective cue and indicates that vection has greater effects and successfully transform the virtual to the real world.

Chapter 3 presents four group behavioral experiments. To further investigate whether the virtual world is truly virtual or like the self-motion illusion experienced in Chapter 2 successfully transforms the virtual to the real world, Chapter 3 explores the teaching effects and sense of presence under four different conditions, specifically focusing on two new AR technologies: Zoom and Face to Face. The findings indicate that these AR technologies yield superior teaching effects and higher levels of presence and engagement. The AR virtual teaching scene had a greater effect on subjective teaching effects.

Chapter 4 summarizes the findings, highlighting how subjective vection and virtual teaching serve as more real and effective stimuli, influencing the attention and improving teaching outcomes. The thesis concludes that stable and longer immersion in vection and AR virtual worlds can transform into the real world, affecting attention and teaching effect and learning behaviors. Furthermore, it suggests future research directions involving the combination of visual properties, cognitive factors, and augmented reality technologies to investigate similar levels of realism and effects in more virtual scenarios and vection as a good perspective to understand human and the world.

Chapter 2 Evidence of exogenous shifts in spatial attention produced by vection

Summary

In Chapter 2, four behavioral experiments were conducted to explore the effects of stable vection induced by grating motion stimuli. Experiment 1 investigated whether the vection direction induced by left and right motion grating stimulation could serve as an effective cue in the exogenous spatial orientation task. It was observed that vection led to a general slowing down of response times, but the direction of vection served as an effective cue, confirming our expectations. Building upon this finding, similar to other induced exogenous attention cues, Experiment 2 also examined whether the sensory modality of the target stimulus would impact the vection cue effect. Interestingly, it was found that the presence of an audiovisual target stimulus eliminated the vection cue effect.

Based on the results of the initial experiments, further investigations were conducted to replicate the vection cue effect using up and down motion gratings. Experiment 3 and Experiment 4 successfully replicated the vection cue effect in both the spatial orientation task and the color discrimination go-no-go task. However, it should be noted that this vection cue effect was only observed when the grating motion stimulus lasted for 20 seconds, and not for 5 seconds. These findings suggest that a stable and reliable vection experience can indeed serve as an effective cue and greater effect, which may irrelated to the grating motion or eye movement stimulation. This effect on spatial attention, similar to its effect on memory, indicates that vection has greater effects and successfully transforms the virtual into the real world.

2.1 Background

Based on previous studies, this study selected appropriate stimulus presentation time, grating motion speed, and stimulus size. In addition, previous research found that participants would have motion sickness when the spatial frequency was too high (Hu et al., 1997). Therefore, a lower spatial frequency value was used in this study. Thus, this study induced a stable vection experience with grating motion stimuli.

In **Experiment 1** of this study, this experiment examined whether vection could serve as an exogenous cue to direct our participants' spatial attention towards (or away from) future target locations (i.e., in a similar fashion to a centrally presented arrow and changes to the peripherally located boxes). Exogenous spatial attention refers to situations where a stimulus in the external display automatically attracts the observer's attention to the target location (Tang, Wu, & Shen, 2016). On each trial, vection was induced by the global leftward or rightward motion of a background surface (always a vertically oriented grating stimulus - see Figure 2 left). With these grating stimuli, vection should occur in the opposite direction to the display motion (e.g., Seno et al., 2013). Thus, if vection can serve as an exogenous cue for future target location, trials should be 'vection-valid' when 1) leftward display motion occurs before a right-side target; and 2) rightward display motion occurs before a left-side target. However, under these specific conditions, it is possible that the display motion itself (rather than the vection) might serve as the dominant cue for spatial attention. Thus, in order to assess whether either vection direction or motion direction serve as the cue for future target location, we tested equal numbers of 'vection-valid' (i.e., 'motion-invalid'), 'vection-invalid' (i.e., 'motion-valid') and 'vection-neutral' (static background) conditions. We also confirmed whether vection had been induced (or not) on each trial in order to direct their spatial attention.

To foreshadow the results of Experiment 1, vection-valid direction cues were found to significantly reduce reaction times on the modified Posner task. However, several other factors are known to alter cuing effects on spatial attention, such as the modality of the cue and the modality of the target (Mazza et al., 2007; Van der Burg et al., 2008). For example, studies have reported that: 1) multisensory cues are required to produce significant spatial cuing effects under conditions of high attention load (Barrett & Krumbholz, 2012); and 2) spatial cuing effects are reduced with a multimodal target (i.e., audiovisual compared to auditory-only or visual-only targets – Tang et al., 2019). Therefore, we also conducted a second experiment (**Experiment 2)** to examine whether vection-based cuing effects on spatial attention generalize beyond situations with visual-only targets. This experiment examined the influence of (left/right) vection direction on spatial attention when an auditory cue was combined with the visual target.

Experiment 3 was aimed at replicating and extending the original vection direction cueing effect. In our first two experiments, we presented participants with leftwards or rightwards vection/grating motion, and then we placed their visual target for that trial on either the left or the right side of the screen. In this third experiment, we instead presented them with upwards or downward vection/grating motion (see Seya, Shinoda, & Nakaura, 2015; Fujii, & Seno, 2020), and then placed their target either above or below the center of the screen. This up/down vection cueing was expected to be just as effective in directing spatial attention as the left/right vection cueing used in Experiment 1. In this third experiment, we also examined whether the strength of the induced vection affected these spatial cuing effects. Previous studies have found that the longer the motion is presented, the stronger the vection (Seno et al., 2018). Therefore, we also examined the effects of using two different grating presentation durations in Experiment 3 (5 and 20 seconds – with the latter duration being more likely to reliably induce vection).

In addition to the target stimulus and the sensory channel of the cue will affect the size of the cue effect, the type and difficulty of the task will also affect the size of the

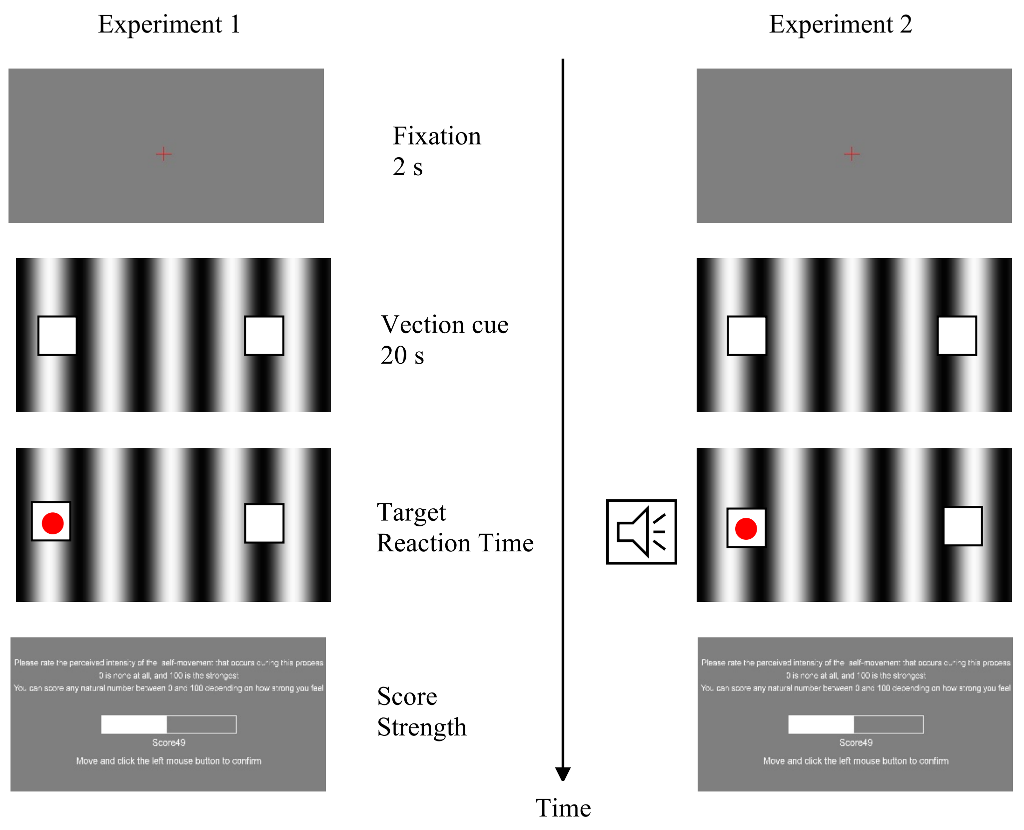

Figure 2. Schematic representation of the general experimental phases and procedures for each trial in Experiments 1 (on the left) and 2 (on the right). In both experiments, a target in the right (or left) box should be responded to by pressing the right (or left) key. In Experiment 2, a pure tone stimulus was often presented at the same time as the red visual target stimulus. When this sound was presented, it either came from the same, or the opposite, direction as the visual target.

cue effect (Chen et al., 2021; Gregory & Jackson, 2021). For example, studies have reported that: 1) the size of the gaze cue effect is not only affected by the cue-target stimulus onset asynchrony (SOA), but also by the type of task such as detection, localization, or categorize targets (McKay et al., 2021); and 2) the gaze cue effect increased when the task required participants to assess the valence of the target word, but not when only distinguishing between uppercase and lowercase of these same words (Pecchinenda, et al., 2008). Therefore, we also conducted a fourth experiment

(**Experiment 4)** to examine whether vection-based cuing effects on spatial attention generalize beyond situations with spatial orientation task-only targets. This experiment examined the influence of (up/down) vection direction on spatial attention when spatial orientation task was compared with the color discrimination go-no-go task.

In summary, this study examined the following questions: 1) Can left/right vection direction serve as an exogenous cue for spatial attention? (**Experiment 1** – which used visual-only targets in a modified Posner task); 2) Does the presentation of a pure-tone auditory stimulus at the same time as the visual target affect these vection cuing effects? (**Experiment 2** – which combined an auditory cue with the visual target in a modified Posner task); and 3) Does up/down vection direction also serve as an exogenous cue for spatial attention? And does the strength of the induced vection alter this size of these cueing effects? (**Experiment 3** – which used visual-only targets in another modified Posner task); 4) Does the task type as the visual target affect these vection cuing effects? (**Experiment 4** – spatial orientation task was compared with color discrimination go-no-go task).

2.2 Experiment 1: Can left/right vection serve as an exogenous cue?

This experiment examined whether vection (or motion) direction could serve as an exogenous cue to direct our participants' spatial attention towards (or away from) target locations. It had a fully within-subjects design. Visual targets were presented on either the left or the right of the display after participants had been exposed to either leftwards, rightwards, or no, global display motion for 20 seconds.

2.2.1 Methods

Participants and ethics statement. Nineteen adult volunteers (9 females and 10 males), who were either graduate or undergraduate students at Kyushu University, participated in this experiment. Their ages ranged from 21 to 37 years (M = 25.47, SD = 3.95). All were healthy and had either normal or corrected normal vision. This study was pre-approved by the Ethics Committee of Kyushu University and informed consent was obtained from all participants before commencing the experiment.

Apparatus and stimulus. The stimuli were presented on a Plasma display (3D Viera 65-inch, Panasonic, Japan, with 1920 × 1080 pixels resolution at a 60-Hz refresh rate) and controlled by a computer (ALIENWARE 17R1, Dell USA). The experimental software was developed using MATLAB R2014a (Mathworks, Natick, MA) and PsychToolbox-3. Experiments were conducted in a darkened room. The viewing distance was approximately 57 cm. At this distance, the plasma display subtended a visual area of 103.23 degrees (horizontal) by 70.72 degrees (vertical). Each trial started with a red fixation cross (2° diameter; 25.72 cd/m^2) being presented on an otherwise gray background (21.84 cd/m^2). This scene was then replaced with a vertically-oriented grating, which filled the entire the plasma display. The luminance contrast of this black and white grating stimulus was 0.99, and its spatial frequency was 0.16 c/deg (the averaged luminance of the grating was SLmean = 21.76 cd/m^2 (SLmax = 43.48 cd/m^2; SLmin = 0.03 cd/m^2) (SLmean: average luminance of the screen presenting the stimuli; SLmax: maximum luminance of the screen presenting the stimuli; SLmin: minimum luminance of the screen presenting the stimuli). When the grating moved (either to the left or the right), its speed was always constant (20 degree/sec). A red circular target object (1° in diameter, 22.62 cd/m^2) subsequently appeared inside one of laterally displaced boxes. Each box was 2° high x 2° wide. These boxes were located 18° to the left or the right of the display's center respectively. They each had a black border (15.56 cd/m^2) and a white interior (41.66 cd/m^2).

Procedure. The procedure for this experiment is shown in Figure 2 left. Each trial started with a red fixation cross being presented on a gray background for 2 seconds. Then this scene (including the fixation cross) disappeared and was replaced by a vertically orientated black and white grating stimulus, which was stationary or moving rightward or leftward. Irrespective of whether it was moving or stationary, the grating stimulus always completely filled the plasma display. After 20s exposure to the grating stimulus, a circular red target appeared in the one of the two boxes superimposed on the grating display. When the target appeared, participants pressed either the F (left) or J (right) key on the keyboard to indicate its location. After completing this spatial attention location task, they then rated the perceived strength of their vection experience for that trial (scores ranged from 0 to 100, with 0 corresponding to "no vection" and 100 corresponding to "very strong vection"). The experiment consisted of a total 10 blocks of trials – with 6 trials per block. That is, each of the 6 experimental conditions was repeated 10 times, and thus each participant underwent 60 experimental trials in a randomized order (10 repetitions of each of the 6 different stimulus conditions). The experiment took approximately 25 minutes for each participant to complete.

Data processing and analysis. Three dependent variables were recorded for each trial using custom code written for MATLAB R2014a [task accuracy, task reaction time (RT) and vection strength ratings]. As each condition was repeated 10 times per participant, these values were averaged prior to being subjected to statistical analysis. Note: the reaction time data for a trial was excluded from analysis if there was either no response, an incorrect response, or it was deemed to be an outlier (i.e., if it exceeded the standard value plus or minus 3 standard deviations during the all RTs). Based on these criteria, we excluded 4% of the total RT data. Repeated measures ANOVAs were conducted as the initial statistical tests on each dependent variable (i.e., task accuracy, RT and vection strength ratings). Greenhouse-Geisser corrections were applied when required to account for violations of sphericity. Partial eta-squared (η_p^2) measures of effect size were also calculated for these ANOVAs. When multiple post hoc comparisons were required for follow-up testing, we also applied Bonferroni-corrections. A linear mixed model analysis was then used to examine the possible relationship between vection strength ratings and RTs (with participants being used as a cluster variable – since the study had a within-subjects design).

2.2.2 Results

Task Accuracy. The average response accuracy rate for the target location task was 98.1% in this experiment. This experiment first performed a 3 (Grating motion direction) x 2 (Target direction) repeated-measures ANOVA on these response accuracy data. None of the main effects or interactions were found to be significant ($p > 0.05$ in all cases) – indicating that vection/motion direction did not alter participants' task performance accuracy.

Reaction Time (RT). Then next conducted a 3 (Grating motion direction) x 2 (Target direction) repeated-measures ANOVA on the mean RT data (followed by post-hoc multiple comparisons when required). A significant main effect of grating motion direction was found for RT (F (1.378, 24.806) = 6.974, p = 0.008, η_p^2 = 0.279) (see Figure 3a). On average the RTs for the static grating condition (M = 553.2 ms) were faster than those for both the leftwards (M = 581.5 ms) and rightwards (M = 577.1 ms) grating motion conditions. The main effects of target direction (F (1, 18) = 0.997, p = 0.662, η_p^2 = 0.011) on RTs were not significant. However, we did find a significant two-way interaction between grating motion direction and target direction (F (2, 36) = 3.816, p = 0.031, η_p^2 = 0.175). To investigate this further, then calculated the average RTs separately for each participant in their 'vection invalid' (i.e., 'motion right + target right' as well as 'motion left + target left') and 'vection valid' conditions (i.e., 'motion right + target left' as well as 'motion left + target right') (see Figure 3b). Then conducted a paired sample t- test on these data, which revealed that RTs for the 'vection valid'

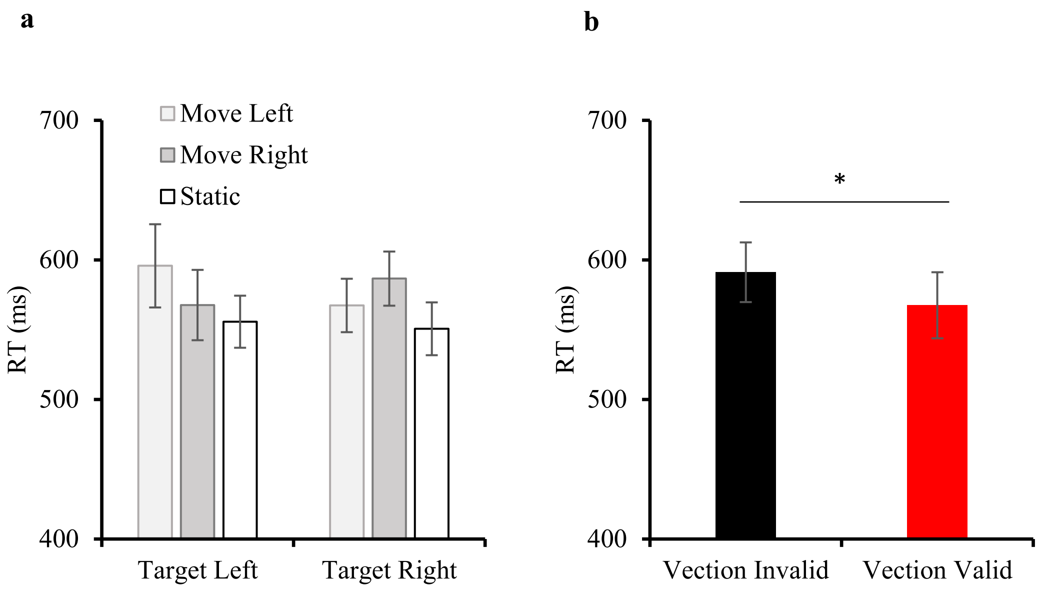

Figure 3. The reaction time (RT) results in Experiment 1.

a) Mean RTs in the 3 different motion direction and target direction conditions.

b) Average of RTs in the 'Vection Valid' and 'Vection Invalid' conditions (all error bars are standard errors).

conditions (*M* = 567.5 ms, *SD* = 95.8) were significantly faster those for the 'vection invalid' conditions (*M* = 591.2 ms, *SD* = 106) (t (18) = 2.726, p = 0.014, 95% *CI* = [5.42, 4.19]).

Vection Strength. There were 1140 motion trials in total (19 participants each completing 60 trials). Four percent of these trials were excluded from analysis (Vection Strength data were deleted according to the result of the reaction time for a trial was excluded from analysis if there was either no response, incorrect response, or it was deemed to be an outlier (i.e., if it exceeded the standard value plus or minus 3 standard deviations during the all RTs)). Of the remaining 1094 trials, 824 were vection trials (75.3%) and 270 were non-vection trials (vection trials refer to the trials' subjective vection strength was not 0, and the non-vection trials refer to the trials' subjective vection strength were 0). Then next performed a 3 (Grating motion direction) x 2 (Target direction) repeated-measures ANOVA on the vection strength rating data. Then found significant main effects of grating motion direction (F (1.073, 19.311) = 308.025, $p < 0.001$, $\eta_p^2 = 0.945$). As expected, pairwise comparisons revealed that vection strength ratings were significantly lower for the static grating condition (*M* = 5.33) compared to the leftward (*M* =71.15) and rightward grating motion (*M* = 71.06) conditions (see Figure 3a). The main effect of target direction was not significant (F (1, 18) = 0.017, p = 0.897, η_p^2 = 0.001). The two-way interaction between grating motion direction and target direction was also not significant for vection strength (F (1.346, 24.221) = 0.554, p = 0.514, η_p^2 = 0.03).

Relationship between RT and Vection Strength. Based on observations of Figure 3a and Figure 4a, it was possible that there might have been a relationship between vection strength and RTs. Then used a linear mixed model (LMM, jamovi 2.3.18, GAMLj package) to examine this possible relationship. This model – which included both fixed and random effects – was found to account for 83% of the variance in our participants' RT (ms) data:

RT ~ 1 + VectionStrength + (1/Participants) [1]

Compared to models with random slopes, the above model had lower Bayesian Information Criteria (BIC). According to the model, RT was significantly predicted by

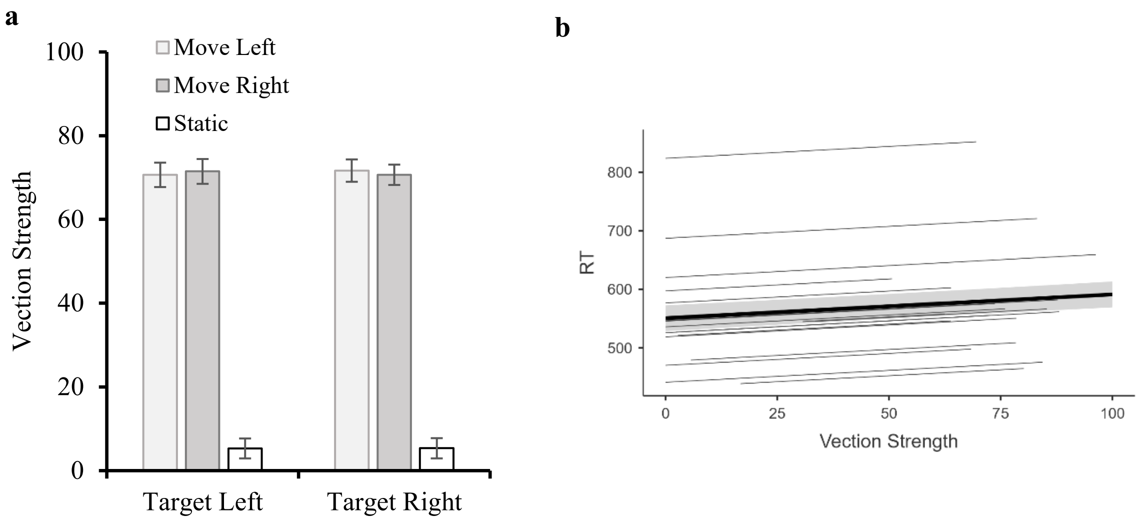

Figure 4. The vection strength results for Experiment 1.

a) Mean vection strength for each of the different motion direction and target direction conditions (all error bars are standard errors).

b) The relationship between the vection strength and RTs. This figure shows the mean slope (bold line) of the relationships between vection strength and RTs for the 19 participants. The random effects are also plotted by participant (all other lines).

the vection strength [F (1, 94.4) = 11.0, $p < 0.001$]. There was a significant positive relationship between vection strength and RT - see Figure 4b. The mean slope of this relationship was 0.407 and the standard error was 0.123. On average, an increase of 1 in vection strength resulted in 0.407 ms increase in our participants' RT.

2.2.3 Discussion

While grating motion did not significantly alter target location performance accuracy in the modified Posner spatial attention task, it did significantly increase overall reaction times (compared to the static grating conditions). These findings appear to be consistent with of those of several past studies (e.g., Seno, Ito, & Sunaga, 2011; Stróżak et al., 2016), which concluded that vection requires attentional resources. These findings suggest that the vection in the grating motion trials increased our participants' attentional load and slowed their overall performance on the modified Posner task (compared to static grating conditions). Interestingly, the size of this effect on reaction times appeared to depend on the strength of the vection (not simply on whether it was or was not induced). In general, stronger vection experience was associated with slower reaction times.

While vection generally increased reaction times, 'vection-valid' conditions were found to produce significant faster reaction times than the 'vection-invalid' conditions. That is, reaction times were faster in vection inducing (as opposed to static) conditions when the vertical grating moved in the opposite horizontal direction to the future target location (e.g., the grating moved to the left, before a target appeared on the right). This reaction time advantage occurred in the same direction as the induced vection, but in the opposite direction to the object/scene motion. Thus, it appears then that vection direction can be used as a valid cue for exogenous spatial attention. This finding appears to be similar to other research findings on the influence of motion direction on cognition - for example, research which shows that moving upward and downward modulated people to think more positive and negative thoughts (Casasanto, & Dijkstra, 2010).

The current reaction time results could conceivably have been caused by the effects of the global optic flow on our participants' optokinetic/visually induced eye movements. During the grating motion phase, their eyes likely performed repetitive tracking movements – alternating between smoothly pursuing/tracking the grating pattern (slow-phase) and making rapid saccadic jumps back in the opposite direction (Büttner & Kremmyda, 2007; Tanaka, Yoshida, & Fukushima, 1998; Lencer & Trillenberg, 2008). It is possible that our participants might have been biased to respond in the direction of the latter saccadic eye-movement. However, contrary to this notion, recent research has shown that exogenous visual attention appears preserved during such optokinetic eye-movements, even though these eye-movements do appear to increase performance reaction times (relative to stationary fixation conditions - Mastropasqua, Vural, & Taylor, 2022). Thus, this experiment appears to show that spatial attention was influenced by the vection direction (rather than the direction of the visual object/scene motion).

2.3 Experiment 2: Are vection cueing effects altered by target modality?

Target modality (e.g., visual, auditory, audiovisual) is known to be an important factor in spatial attentional cuing effects (e.g., Mazza, et al., 2007; Van der Burg, et al., 2008). For example, researchers found that simultaneous bilateral auditory stimuli with visual target reduced the alerting and orienting cue effects (Fu, et al., 2021). Therefore, Experiment 2 investigated whether the use of audiovisual targets would alter the effects of the vection-valid cues on reaction times (as found previously with visual-only targets in Experiment 1).

2.3.1 Methods

Eighteen college students (10 females and 8 males), volunteered to participate in this experiment. Their ages ranged from 24 to 36 years (M = 26.84, SD =3.26). In this experiment, the apparatus, visual stimulus, procedure, and data processing were the same as Experiment 1. The only difference was that under some conditions in Experiment 2, the red visual target was presented simultaneously with an external auditory stimulus, which was located on either the left or right side of the screen (depending on the trial - see Figure 2 right). The speakers were located 50 cm to the left or the right of the center of the screen. The sound stimulus (65 dB, 44.1khz sampling rate, 16 bits) was presented for 60 ms. One-third of the trials were classified as 'sound consistent' (i.e., the sound was presented in the same side – left or right - as the red visual target stimulus). Another third of the trials were classified as 'sound inconsistent' (the sound was presented on the opposite side to the red visual target stimulus). The remaining trials did not present any sound during the visual target (i.e., 'without sound'). Thus, there were 18 different stimulus conditions in our 3 (Grating motion direction) x 2 (Target direction) x 3 (Sound type) design. Each of these 18 experimental conditions was repeated ten times, and thus each participant underwent 180 experimental trials in a randomized order. This experiment had a total of 10 blocks with18 trials/block. The entire experiment lasted about 60 minutes.

2.3.2 Results

Task Accuracy. The average response accuracy rate for the target location task was 97.3% in this experiment. This experiment first performed a 3 (Grating motion direction) x 2 (Target direction) x 3 (Sound type) repeated-measures ANOVA on these response accuracy data. The main effect of the sound type was significant (F (2, 34) = 30.536, p < 0.001, η_p^2 = 0.642). Accuracy was lower for the 'sound consistent' conditions (M =

94.2%) compared to the 'sound inconsistent' (M = 98.7%) and 'without sound' conditions (M = 99.2%). However, the main effects of motion direction and target direction, and all of the interactions, were non-significant.

Reaction Time (RT). As in Experiment 1, RT data for a trial was excluded from analysis if there was either no response, an incorrect response, or it was deemed to be an outlier (i.e., if it exceeded the standard value plus or minus 3 standard deviations during the all RTs). Based on these criteria, we excluded 4.5% of the total RT data. Then conducted a 3 (Grating motion direction) x 2 (Target direction) x 3 (Sound type) repeated-measures ANOVAs on the mean RT data (followed by post-hoc multiple comparisons when required). A significant main effect of motion direction was found for the RT data (F (1.388, 23.591) = 23.096, $p < 0.001$, $\eta_p^2 = 0.576$). On average, RTs for the static grating condition (M = 531.7.4 ms) were faster than those for left (M = 562.5 ms) and right (M = 564.4 ms) grating motion conditions. A main significant effect of sound type was also found (F (2, 34) = 135.42, $p < 0.001$, $\eta_p^2 = 0.888$) (see Figure 5a). On average, RTs were significantly slower for the 'without sound' condition (M = 596.3 ms) compared to the 'consistent sound' (M = 542.7 ms) and 'inconsistent sound' (M = 519.5 ms) conditions (see Figure 5b). The main effect of target direction was not significant (F (1, 17) = 1.601, $p = 0.223$, $\eta_p^2 = 0.086$). However, a significant two-way interaction was found for grating motion direction and target direction (F (2, 34) = 3.759, $p = 0.033$, $\eta_p^2 = 0.181$). There was significant difference between the left grating motion direction and the static grating when the target appeared on the leftwards (compared to the right). Similar to Experiment 1, then we calculated the average RTs for each participant in their 'vection invalid' and 'vection valid' conditions and then conducted a paired sample t-tests on these data. Unlike Experiment 1, this revealed that the RTs for the 'vection valid' conditions (M = 563.2 ms, SD = 72.8) were not significantly

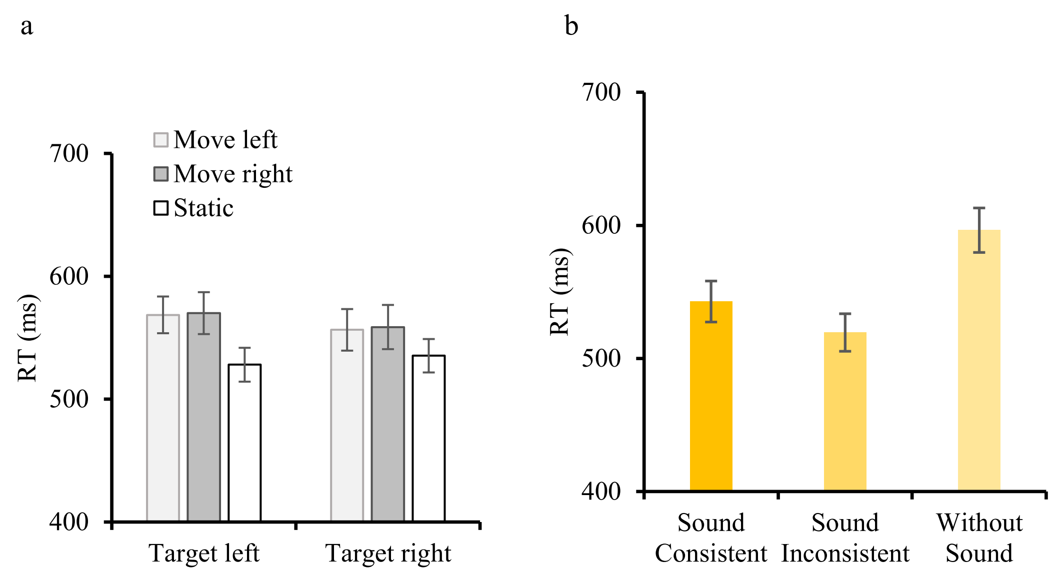

Figure 5. The reaction time (RT) results in Experiment 2.

a) Mean RTs in the 3 different motion direction and target direction conditions.

b) Mean RTs in the 3 different sound type conditions (all error bars are standard errors).

different to those for the 'vection invalid' conditions (M = 563. 6 ms, SD = 70.7, t (17) = 0.12, p = 0.906, 95% CI = [-7.19, 8.06]). No other two-way or three-way interactions were found to be significant (F (2.884, 49.036) = 0.259, p = 0.847, η_p^2 = 0.015).

Vection Strength. There were 3240 trials in total (18 participants each completing 180 trials). 4.5% of these trials were excluded from analysis (Vection Strength data were deleted according to the result of the reaction time for a trial was excluded from analysis if there was either no response, incorrect response, or it was deemed to be an outlier (i.e., if it exceeded the standard value plus or minus 3 standard deviations during the all RTs)). Of the 3096 valid trials remaining, 2191 vection trials (70.8%) and 905 were non-vection trials. Then this experiment also conducted 3 (Grating motion direction) x 2 (Target direction) x 3 (Sound type) repeated-measures ANOVAs on the vection strength rating data (followed by post-hoc multiple comparisons when required). Then found significant main effects of grating motion direction on vection strength (F (1.031, 17.521) = 195.474, $p < 0.001$, $\eta_p^2 = 0.920$). As expected, pairwise comparisons revealed that vection strength was significantly lower for the static grating condition (M = 1.5) compared to the leftwards (M = 71.3) and rightwards (M = 71.9) grating motion conditions (see Figure 6a). Significant two-way interactions were found for grating

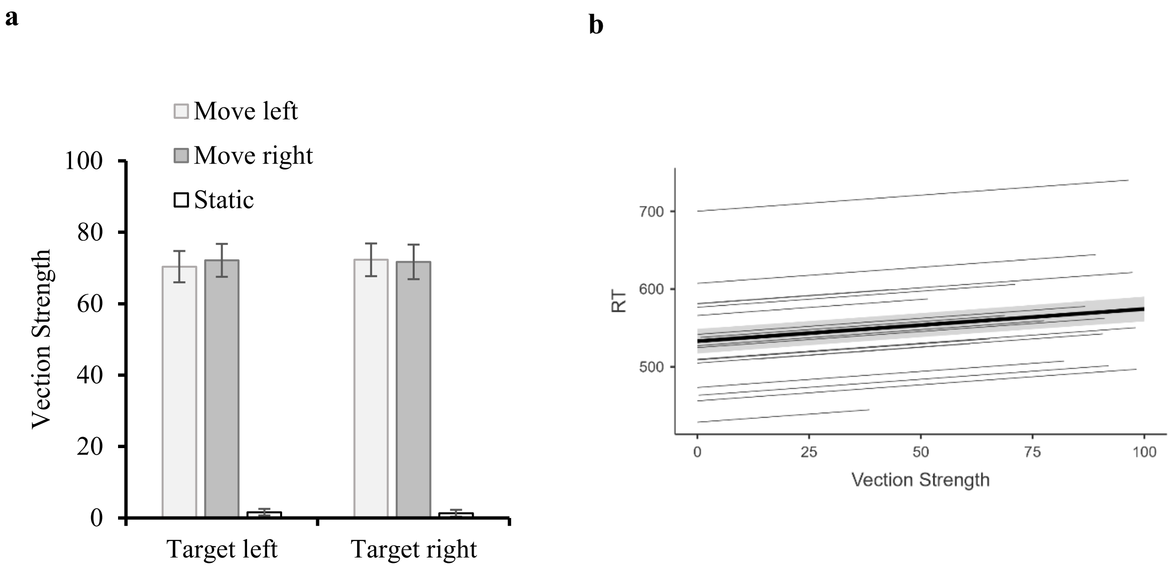

Figure 6. The vection strength results in Experiment 2.

a) Mean vection strength in the different motion direction and target direction conditions (all error bars are standard errors).

b) The relationship between the vection strength and RTs in Experiment 6. This figure shows the mean slope (bold line) of the relationships between vection strength and RTs for the 18 participants. The random effects are also plotted by participant (all other lines).

motion direction and target direction (F (2, 34) = 3.768, p = 0.033, η_p^2 = 0.181). No other main effects, two-way, three-way or four-way interactions were found to be significant.

Relationship between RT and Vection Strength. Based on the findings of Experiment 1, this experiment examined whether there was a relationship between vection strength and RTs. Then used a linear mixed model (LMM, jamovi 2.3.18, GAMLj package) to examine this possible relationship. The same simple model used in Experiment 1 (see Equation 1) – which included both fixed and random effects – was again found to account for 85% of the variance in our participants' RT (ms) data. According to that model, RT was significantly predicted by the vection strength [F (1, 307) = 32.0, p < 0.001]. There was a significant positive relationship between vection strength and RT - see Figure 6b. The mean slope of this relationship was 0.414 and the standard error was 0.0732. On average, an increase of 1 in the vection strength resulted in 0.414 ms increase in our participants' RT.

2.3.3 Discussion

As expected, the sound type manipulation was found to alter performance on this modified Posner spatial attention task. On average, task accuracy was significantly poorer in the 'sound consistent', compared to the 'sound inconsistent' and 'without sound' conditions. In addition, reaction times were found to be significantly slower for the 'without sound', compared to the 'consistent sound' and 'inconsistent sound', conditions. Similar to Experiment 1, this experiment again found that grating motion conditions increased the overall reaction times (compared to static grating conditions). As in that experiment, the size of this effect on reaction times depended on the strength of the vection (not simply on whether it was or was not induced). In general, stronger vection experiences again were associated with slower reaction times. However, vection direction did not appear to serve as a reliable exogenous cue in Experiment 2. It appears that the auditory stimuli reduced the benefits/effects provided by ‘vection valid’ cues (consistent with previous research which found that the inclusion of an audiovisual target reduced spatial cueing effects - Tang et al., 2019). It would appear that the simultaneously presented auditory stimuli altered the participants’ attention to the target stimulus task, and completely obscured the potential influence of ‘vection valid’ cueing effects.

2.4 Experiment 3: Can up/down vection serve as an exogenous cue?

In Experiment 1 (but not Experiment 2), results found that the left and right vection direction could serve as a valid exogenous cue for shifting spatial attention. However, the effectiveness of this visual vection cue appeared to be destroyed by the inclusion of an additional auditory cue. Thus, in Experiment 3, then wanted replicate and extend the original findings of Experiment 1 – looking again at vection cueing effects under visual-only target conditions. This experiment explored whether these vection-direction cueing effects generalized to a different vection direction (up/down – as opposed to left/right – vection).

2.4.1 Methods

Sixteen adult volunteers (9 females and 7 males), students and researchers, participated in this experiment. Their ages ranged from 23 to 36 years (M = 26.25, SD = 3.07) years old. In this experiment, the apparatus, visual stimulus, procedure, and data processing were the same as Experiment 1. However, in this experiment, the motion duration was 5 seconds for half of the trials, and 20 seconds (the same as was used in all of the trials in Experiments 1 and 2) for the remaining trials. Another difference was that the background grating motion – used to induce the vection – was changed from left or right to up or down. When the target appeared, participants pressed either the Y (up) or B (down) key on the keyboard to indicate its location within 2 seconds. Each box was 2° high x 2° wide - they were located either 12° above or below the center of the display respectively (see Figure 7 up). Thus, there were 12 different stimulus conditions: resulting in a 3 (Grating motion direction: up, down or static) x 2 (Target direction: up or down) x 2 (Grating presentation duration: 5s or 20s) design. Each of the 12 experimental conditions was repeated ten times, and thus each participant underwent 120 experimental trials in a randomized order. This experiment had a total of 10 blocks, with 12 trials/block. Thus, the entire experiment lasted about 40 minutes.

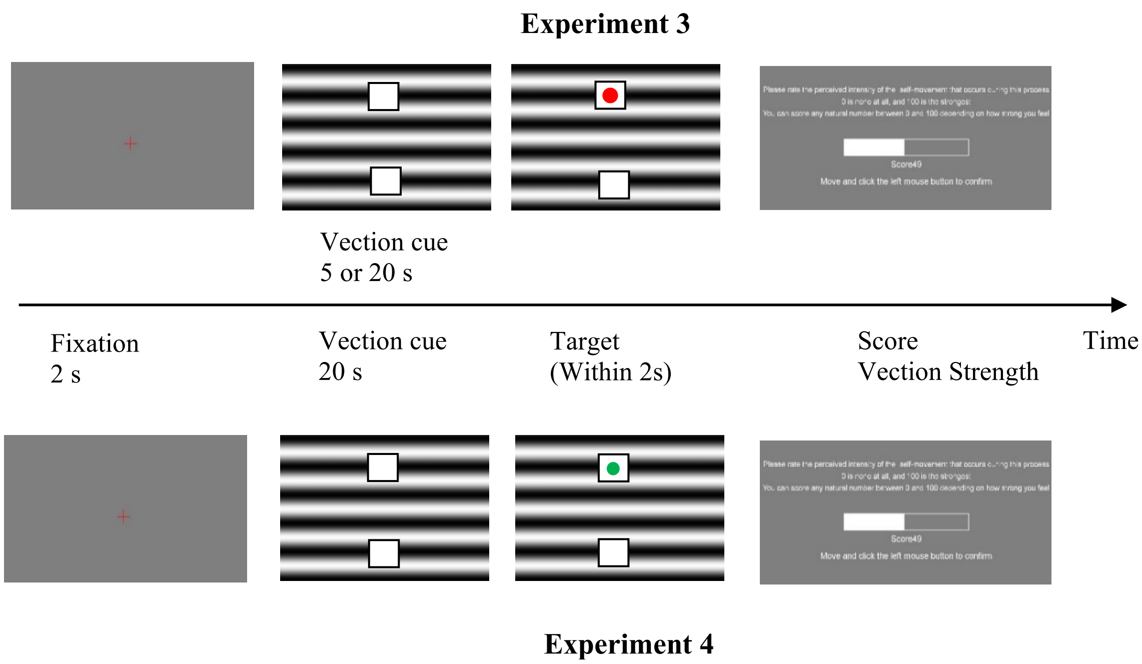

Figure 7. Schematic representation of the general experimental phases and procedures for each trial in Experiments 3 (on the up) and 4 (on the down).

In both experiments, a red target in the up (or down) box should be responded to by pressing the up (or down) key. In Experiment 4, a green target in the up (or down) box no need to respond it, and it will automatically enter the scoring page after 2 seconds.

2.4.2 Results

Task Accuracy. The average response accuracy rate for the target location task was 97.7% in this experiment. Then first performed a 3 (Grating motion direction) x 2 (Grating presentation duration) x 2 (Target direction) repeated-measures ANOVA on these response accuracy data. No main effects or interactions were found to be significant – indicating that vection/motion direction did not significant alter our participants' task performance accuracy (as was found in Experiment 1).

Reaction Time (RT). As in Experiments 1 and 2, RT data for a trial was excluded from analysis if there was either no response, an incorrect response, or it was deemed to be an outlier (i.e., if it exceeded the standard value plus or minus 3 standard deviations during the all RTs). Based on these criteria, this experiment excluded 4% of the total reaction time data. We next conducted a 3 (Grating motion direction) x 2 (Grating presentation duration) x 2 (Target direction) repeated-measures ANOVA on the mean RT data (followed by post-hoc multiple comparisons when required). A significant main effect of grating motion direction was found for RT (F (2, 30) = 3.551, $p = 0.041$, $\eta_p^2 = 0.191$). Then also found a two-way interaction between grating motion direction and grating presentation duration (F (1.263, 18.949) = 7.888, $p = 0.008$, $\eta_p^2 = 0.345$) (see Figure 8a). Mean RTs was significantly slower during grating motion compared to the static grating presentations in the 20 s grating duration conditions. However, RTs were not significantly different for the 3 different grating motion directions during the 5 s grating duration conditions. There was also significant two-way interaction between grating presentation duration and target direction (F (1, 15) = 5.305, $p = 0.036$, $\eta_p^2 = 0.261$).

Similar to Experiments 1 and 2, then also calculated the average RTs for each participant in their 'vection invalid' and 'vection valid' conditions under each of the different grating presentation duration conditions. We next conducted a 2 (Grating presentation duration) x 2 (Vection type: invalid and valid) repeated-measures ANOVA on these data. This experiment found a significant two-way interaction for grating presentation duration and vection type (F (1, 15) = 6.578, p = 0.022, η_p^2 = 0.305) − see Figure 8b. In the 20 s grating presentation duration conditions, RTs in the 'vection valid' conditions were found to be significantly faster than those in the 'vection invalid' conditions. However, RTs did not differ significantly as a function of vection type during the 5 s grating conditions. The main effects and other interactions were not found to be significant.

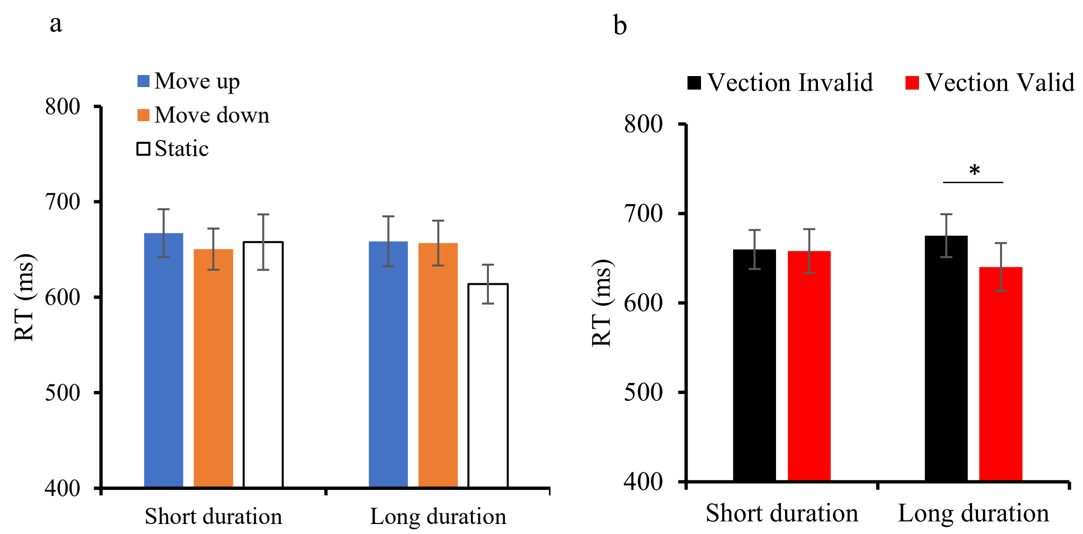

Figure 8. The reaction time (RT) results for Experiment 3.

a) Mean RTs for the different motion direction and grating presentation duration conditions.

b) The average of RTs in the 'Vection Valid' and 'Vection Invalid' conditions under different grating presentation duration conditions (all error bars are standard errors).

Vection Strength. There were 1920 trials in total (16 participants each completing 120 trials). As noted above, 4% of these trials were excluded (Vection Strength data were deleted according to the result of the reaction time for a trial was excluded from analysis if there was either no response, incorrect response, or it was deemed to be an outlier (i.e., if it exceeded the standard value plus or minus 3 standard deviations during the all RTs)). Of the 1843 trials remaining, 1324 were vection trials (71.8%) and 519 were non-vection trials (39.2%). Then next performed a 2 (Grating presentation duration) x 3 (Grating motion direction) x 2 (Target direction) repeated-measures ANOVA on the vection strength rating data. Then found a significant main effect of grating motion direction (F (1.418, 21.263) = 416.015, p < 0.001, η_p^2 = 0.965). As expected, pairwise

a **b**

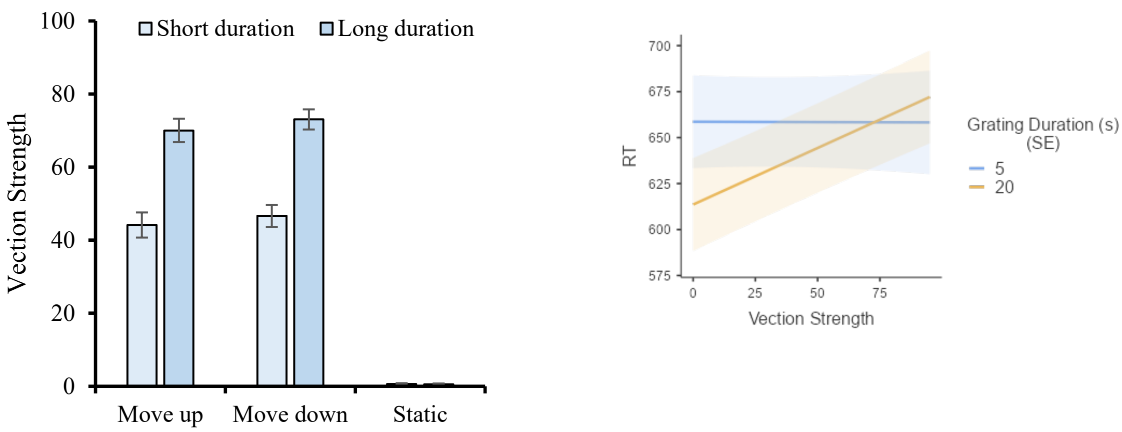

Figure 9. The strength results in Experiment 3.

a) Mean vection strength on the different motion direction and grating presentation duration conditions (all error bars are standard errors).

b) The relationship between the vection strength and RTs. This figure shows the mean slope (bold line) of the relationships between vection strength and RTs for the 16 participants. The random effects are also plotted by participant (all other lines).

comparisons revealed that vection strength was significantly lower for the static grating condition (M = 0.6) compared to the upward (M = 57.1) and downward grating motion (M = 59.9) conditions. The main effect of grating presentation duration (F (1, 15) = 53.425, $p < 0.001$, $\eta_p^2 = 0.781$) was also significant. Pairwise comparisons revealed that vection strength for 5 s grating motion condition (M = 30.5) was significantly lower than that for the 20 s grating motion condition (M = 47.9). There was also a significant 2-way interaction between grating motion direction and grating presentation duration (F (1.237, 18.562) = 49.566, $p < 0.001$, $\eta_p^2 = 0.768$) (see Figure 9a). This indicated that grating duration only influenced vection strength in the moving (rather than the static) grating conditions. other main effects or interactions were found to be no significant. None of the other main effects and interactions were significant.

Relationship between RT and Vection Strength. Based on the findings of Experiments 1 and 2, this experiment examined whether there was a relationship between vection strength and RTs. We were also interested in the influence of grating duration on RTs. We used a linear mixed model (LMM, jamovi 2.3.18, GAMLj package) to examine these possible relationships. This model – which included both fixed and random effects – was found to account for 79% of the variance in our participants' RT data:

RT ~ 1 + GratingDuration + VectionStrength + GratingDuration:VectionStrength + (1/Participants) [2]

There was a significant positive relationship between vection strength and RT (F (1, 174) = 6.85, $p < 0.01$) - see Figure 9b. On average, an increase of 1 in the vection strength resulted in 0.32 ms increase in our participants' RT. There was also a significant negative relationship between grating duration and RT (F (1, 173) = 13.96, p < 0.001) – on average, as grating duration increased from 5 to 20 seconds, RT decreased. However, our analysis also revealed a significant interaction between grating duration and vection strength (see Figure 9b). Simple effects analysis subsequently revealed that RT: 1) was independent of vection strength during the 5 s grating duration conditions (F (1, 174) = 0.0, p = 0.987); 2) increased significantly with vection strength during the 20 s grating duration conditions (F (1, 173) = 17.6, p < 0.001).

2.4.3 Discussion

While grating motion did not significantly alter target location performance accuracy in this modified Posner spatial attention task, it did significantly increase overall reaction times (compared to the static grating conditions). Similar to Experiments 1 and 2, this experiment found that grating motion increased reaction times in the 20 s grating presentation duration conditions (compared to static grating conditions). However, this effect of grating motion on RTs was not found in the 5 s grating presentation duration conditions. These findings suggest that the stronger/more reliable experiences of vection in the 20 s (as opposed to 5 s presentation conditions) were required to significantly delay RTs (the vection in the 5 s conditions was not sufficient). This proposal is supported by the findings of our LMM, which revealed a significant positive correlation between vection strength and RTs. Taken together, these findings are consistent with the notion that vection requires extra attention resources (as proposed by Seno, Ito, & Sunaga, 2011). They suggest that stronger experiences of vection increased our participants' attentional load and generally slowed their overall performance on the modified Posner task (similar to the results of Experiments 1 and 2).

In this experiment, also found that 'vection-valid' conditions produced significant faster RTs than the 'vection-invalid' conditions during the 20 s grating presentations – importantly this replicated our earlier vection-direction cueing findings from Experiment 1. However, the effect of vection direction on RTs was not found to remain significant when the grating presentation durations were reduced from 20 s to 5 s. Thus, it appears then when conditions are favorable for vection, vection direction can serve as a valid cue for exogenous spatial attention.

2.5 Experiment 4: Are vection cueing effects altered by experiment task?

In Experiments 1 and 3 (but not Experiment 2), results found that the left and right and up and down vection directions could serve as a valid exogenous cue for shifting spatial attention. However, the effectiveness of this visual vection cue appeared to be destroyed by the inclusion of an additional auditory cue. In addition to target modality affecting attention cue effects, previous studies have also found task difficulty affects cueing effects (Gregory & Jackson, 2021). Specifically, when the individual consumed more attention resources by increasing the difficulty of tasks and the degree of distraction, they found that the orientation effect of effective cues was stronger. Similarly, it has been found that gaze cues for neutral faces are less effective in discrimination tasks relative to orientation tasks (Chen et al., 2021). Thus, it can be speculated that the consumption of attentional resources weakens the effect of cues of invalid or no emotional value. Therefore, in Experiment 4, investigated whether the visual target task difficulty (color discrimination go-no-go task) would alter the effects of the vection-valid cues on reaction times (as found previously with visual-only exogenous spatial attention localization task in Experiment 3).

2.5.1 Methods

Seventeen adult volunteers (11 females and 6 males), students and researchers, participated in this experiment. Their ages ranged from 23 to 36 years (*M* = 26.24, *SD* = 3.08) years old. In this experiment, the apparatus, visual stimulus, procedure, and data processing were the same as Experiment 3. However, in this experiment, we added the task difficulty this factor, in order to prevent the participants from being prone to fatigue in order to prevent the experiment time from being too long. Thus, we only keep the motion duration of 20 seconds, deleted the motion duration was 5 seconds. In Experiment 8, we used half of trails are green target stimuli and other half of trails red target stimuli two targets. The green stimuli were the same size and position as the red stimuli appeared in Experiment 3. Participants were tasked with pressing a button in response to a red stimulus (as a go stimuli) and not in response to a green stimulus (as a No-go stimulus - see Figure 7 down). Thus, there were 12 different stimulus conditions in our 3 (Grating motion direction) x 2 (Target direction) x 2 (Task type) design. Each of these 12 experimental conditions was repeated ten times, and thus each participant underwent 120 experimental trials in a randomized order. This experiment had a total of 10 blocks with 12 trials/block. The entire experiment lasted about 40 minutes.

2.5.2 Results

Task Accuracy. The average response accuracy rate for the target location task was 98.7% in this experiment. This experiment first performed a 3 (Grating motion direction) x 2 (Target direction) x 2 (Task type) repeated-measures ANOVA on these response accuracy data. No main effects or interactions were found to be significant – indicating that vection/motion direction did not significant alter our participants' task performance accuracy (as was found in Experiment 3).

Reaction Time (RT). As in Experiments 1-3, RT data for a trial was excluded from analysis if there was either no response, an incorrect response, or it was deemed to be an outlier (i.e., if it exceeded the standard value plus or minus 3 standard deviations during the all RTs). Based on these criteria, this experiment excluded 2% of the total reaction time data. Due to the no response time data for the green target stimulus condition, and only performed further analysis for the red target stimulus response time. Then next conducted a 3 (Grating motion direction) x 2 (Target direction) repeated-measures ANOVA on the mean RT data (followed by post-hoc multiple comparisons when required). Unlike Experiment 3, this experiment did not find a main effect of grating motion direction (F (2, 32) = 1.647, p = 0.209, η_p^2 = 0.093)). No main effect of target direction (F (1, 16) = 3.744, p = 0.071, η_p^2 = 0.190)) and two-way interactions (F (2, 32) = 3.068, p = 0.06, η_p^2 = 0.161)) were found to be significant.

Similar to Experiments 1-3, then also calculated the average RTs for each participant in their 'vection invalid' and 'vection valid' conditions and then conducted a paired sample t-tests on these data. Similarly Experiment 3, this revealed that the RTs

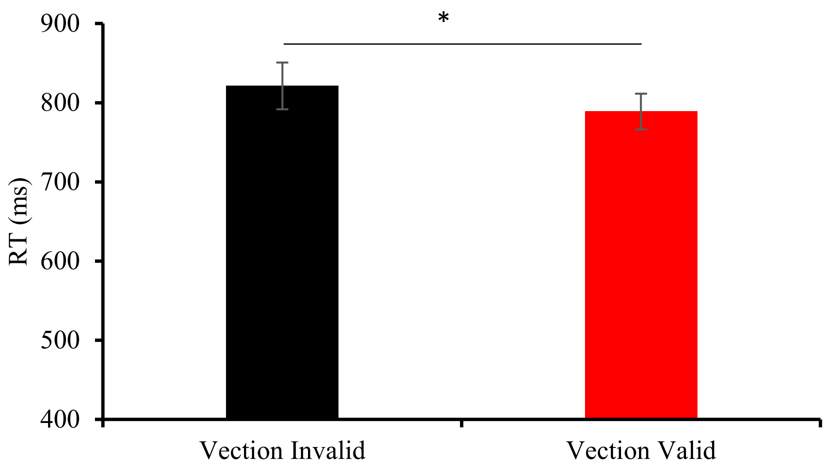

Figure 10. The reaction time (RT) results in Experiment 4.

Average of RTs in the 'Vection Valid' and 'Vection Invalid' conditions (all error bars are standard errors).

for the 'vection valid' conditions (M = 788.8 ms, SD = 96.01) were significantly faster than those for the 'vection invalid' conditions (M = 821.2 ms, SD = 125.41, t (16) = 2.337, p = 0.033, 95% CI = [3.008, 61.845]) (see Figure 10).

Vection Strength. There were 2040 trials in total (17 participants each completing 120 trials). As noted above, 2% of these trials were excluded (Vection Strength data were deleted according to the result of the reaction time for a trial was excluded from analysis if there was either no response, incorrect response, or it was deemed to be an outlier (i.e., if it exceeded the standard value plus or minus 3 standard deviations during the all RTs)). Of the 2000 trials remaining, 1357 were vection trials (67.8%) and 643 were non-vection trials (32.2%). Then next performed a 3 (Grating motion direction) x 2 (Target direction) x 2 (Task type) repeated-measures ANOVA on the vection strength rating data. Then found a significant main effect of grating motion direction (F (1.077, 17.238) = 356.306, $p < 0.001$, $\eta_p^2 = 0.957$). As expected, pairwise comparisons revealed that vection strength was significantly lower for the static grating condition (M = 0.4) compared to the upward (M = 69.4) and downward grating motion (M = 71.2) conditions (see Figure 11 a). The other main effects or interactions were found to be no significant.

Signal detection theory. For the color discrimination go-no-go task, signal detection theory is used, and there are two stimuli, whether or not the red target was present. Statistically analyze the regularity of the following 4 patterns: Hit (H, correct answer rate - the red target stimulus appears, and the participant correctly judges the position and responds to the button); Miss (the red target stimulus was presented, and the participant did not perform a keypress response); Correct rejection (participants did not perform a key press response when the green stimulus was presented); False Alarm

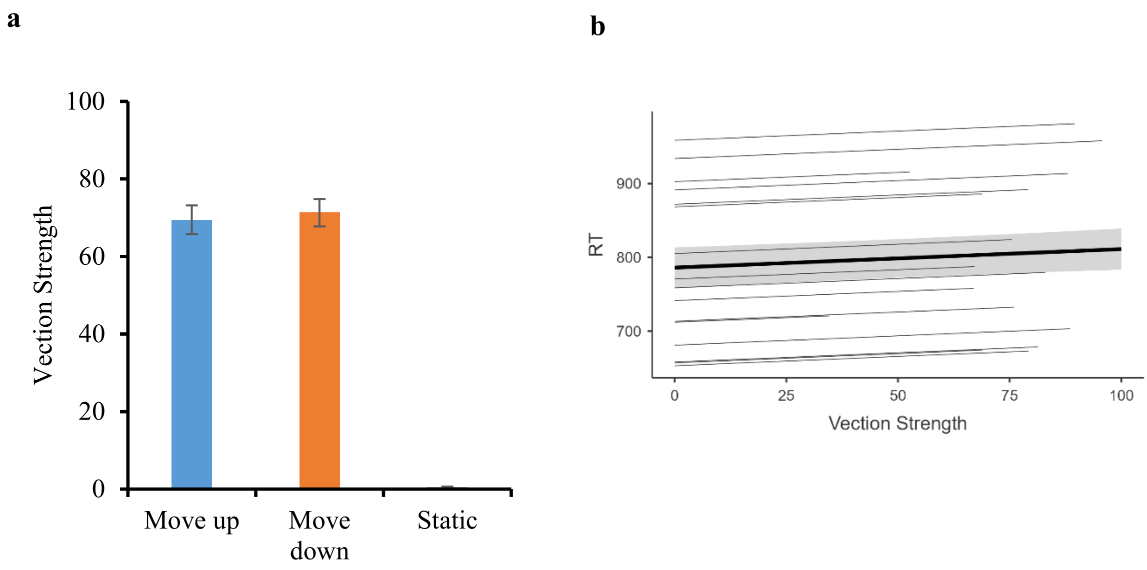

Figure 11. The vection strength results in Experiment 4.

a) Mean vection strength on the different motion direction conditions (all error bars are standard errors).

b) The relationship between the vection strength and RTs. This figure shows the mean slope (bold line) of the relationships between vection strength and RTs for the 17 participants. The random effects are also plotted by participant (all other lines).

(FA, false alarm rate, when the green stimulus was presented, participants performed a keypress response, regardless of whether the position judgment task was correct). Participants were calculated to have an overall average hit rate of 0.99 and an overall average false alarm rate of 0.04. Some participants had a hit rate of 1 and a false alarm rate of 0, so we did not calculate further discrimination metrics (d' = z(H) – z(FA), c = - (Z(H) + Z(FA)) / 2). Then, the false alarm rates under the conditions of vection valid (0.015), vection invalid (0.029) and static (0.068) condition were further calculated, but no significant difference was found among the three conditions.

Relationship between RT and Vection Strength. Based on the findings of Experiments 1-3, this experiment examined whether there was a relationship between vection strength and RTs. We used a linear mixed model (LMM, jamovi 2.3.18, GAMLj package) to examine this possible relationship. The same simple model used in Experiment 4 (see Equation 1) – which included both fixed and random effects – was again found to account for 74% of the variance in our participants' RT data. However, according to that model, RT was no significantly predicted by the vection strength [F (1, 84.8) = 1.92, p = 0.169]. There was a significant positive relationship between vection strength and RT - see Figure 11b. The mean slope of this relationship was 0.25 and the standard error was 0.182. On average, an increase of 1 in the vection strength resulted in 0.25 ms increase in our participants' RT.

2.5.3 Discussion

This experiment revealed that manipulating the task type did not significantly impact performance on the modified Posner spatial attention task. On average, task accuracy did not differ between Go and No-go stimuli. However, unlike Experiments 1-3, this experiment did not observe an increase in overall reaction times in the grating motion conditions compared to the static grating conditions. This finding suggests that although vection experience consumes attentional resources (as reaction times were slower in Experiments 1-3), it does not play a dominant role in attentional resource consumption when compared to task types. Participants were required to respond quickly and accurately, which necessitated their disengagement from the vection experience as quickly as possible (within 2 seconds). Consequently, there was no significant difference in average response times between grating motion and static conditions. While previous experiments showed that stronger vection experiences were associated with slower reaction times, this experiment did not find a significant relationship, although a trend was observed.

Additionally, this experiment found that "vection-valid" conditions resulted in significantly faster reaction times than "vection-invalid" conditions, replicating the vection-direction cueing findings from Experiments 1 and 3. It appears that the task type did not influence the vection cue effect. This observation may be attributed to the similar difficulty levels of the experimental tasks. Although the experiment included a color discrimination Go No-go task in addition to the spatial positioning task, there was no significant difference in difficulty between the two tasks (as evident from the average hit rate and false alarm rate). However, the difference between vection-valid and vection-invalid conditions in this experiment was 32 ms, whereas in Experiment 7 it was only 18 ms. This finding is consistent with previous studies (Chen et al., 2021; Gregory & Jackson, 2021), suggesting that increasing task difficulty enhances the effectiveness of cues in prompting attention.

2.6 General Discussion

2.6.1 Summary of the experiment findings

The main goals of this chapter were to examine whether: 1) vection direction (left/right; up/down) could serve used as an exogenous cue for spatial attention, and 2) these vection direction cue effects would be altered by the presence of auditory cues or the strength of the vection experience or the task type. To do this, we examined our participants' performance on modified versions of Posner's cueing task. While vection was not found to alter response accuracy on these tasks, it generally slowed participant reaction times across the first three experiments (relative to the static grating conditions), but not for Experiment 4. However, the experience of vection could sometimes benefit task performance. While vection generally slowed participant reaction times, Experiments 1, 3, and 4 found that valid vection direction cues also sped up response times (relative to trials with invalid vection direction cues). When grating motions were shown for 20 s in Experiment 1, reaction times were found to be significantly shorter when vection was induced in the same (as opposed to the opposite) direction as the future target location. These findings were replicated in Experiments 3 and 4 (with up/down – as opposed to left/right – vection directions and target locations) whether spatial orientation task or the color discrimination go-no-go task. However, in Experiment 3, also found that these benefits disappeared when only 5 s (as opposed to 20 s) of grating motion was provided. Of interest, the benefits of vection cueing also disappeared in Experiment 2 when the cueing task used audiovisual (instead of visual-only) targets.

2.6.2 Strong vection generally led to slower RTs in spatial orientation task

Across all first three Experiments 1-3, found that average response times were slower in the grating motion (up/down/left/right), compared to the static grating, conditions. We interpreted these results as indicating that grating motion often induced experiences of vection that required extra attentional resources. In these grating motion conditions, participants typically perceived self-motion while they were performing their spatial orientation task – with all of these different types of visual (and sometimes auditory) processing engaged competing for their finite attentional resources. Then found that participants' reaction times were faster in the static grating conditions, which this study assumed was because these extra attentional resources were not required for visually processing self- (or object/scene) motion in those conditions. This explanation was supported by the strong positive relationships found between vection strength and reaction time in this study. When the static and moving gratings were presented for 20 s, participant response times slowed as the vection strength increased across all first 3 experiments. These findings were (at least partially) consistent with the results of several previous studies, where vection appeared to increase the response times, and reduce the performance accuracy, of their participants (e.g., Seno, Ito, & Sunaga, 2011; Trutoiu, et al., 2008). However, the relationship between grating motion and reaction time was also found to depend on the duration of the grating motion. Vection is more likely to be induced, and generally stronger, with longer durations grating motion. So, while vection was sometimes induced by 5 s exposures to grating motion, it did not appear to be sufficiently compelling or attention-grabbing to alter task performance. Thus, as can be seen in Figure 9b (blue line), reaction time performance was largely independent of vection strength when gratings were presented for only 5 s. By contrast, reaction times can be seen to increase markedly with vection strength when gratings were presented for 20 s (see Figures 4b, 6b and 9b black/orange lines). Thus, the current results suggest that vection has to be both reliable and compelling, in order for it to significantly slow reaction times (at least on our particular variants of Posner's cueing spatial orientation task).

However, as discussed in Experiment 4, vection experiences were not found to significantly slow participants' reaction times. This study speculates that although vection experience requires attentional resources, when encountering more complex color go no-go discrimination tasks, visual sensory passively induced vection experience cannot compete for attentional resources with visual processes that actively complete complex tasks, thus resulting those significant differences in the mean response times disappeared in grating motion and static conditions.

2.6.3 The direction of strong vection served as an exogenous cue for visuospatial attention

While prior exposure grating motion generally slowed task performance in the current study (compared to the static grating conditions), the effect of this grating motion also depended on its direction (as well its presentation duration). Of interest, in both Experiments 1, 3 and 4, reaction times were found to be faster if the grating motion occurred in the opposite direction to the future target location (compared to when it occurred in the same direction as the future target location). When vection was induced in this study it occurred in the opposite direction to the grating motion. So, this meant that reaction times were consistently shorter when the grating motions produced 'vection valid' (compared to the 'vection invalid') cueing conditions (i.e., vection occurs in the same direction as the future target location). However, the reaction time benefits of using 'vection valid' cueing conditions were only found when moving gratings were presented for 20 s (not 5 s) and when visual-only localized orientation and discriminate targets were used (not audiovisual targets).

The available evidence suggested that it was vection direction which was responsible for cueing attention in these experiments – not the direction of the grating motion or the participant's optokinetic eye-movements. These observed cueing effects occurred in the opposite direction to the actual grating motion, but in the same direction as the experienced vection. Furthermore, if these 'vection valid' cueing effects had been caused instead by the grating motion or optokinetic eye-movements (rather than by the vection), then should still have found similar cuing effects in the 5 s grating motion conditions of Experiment 3. However, the benefits of 'vection valid' cues were only found in 20 s grating motion conditions (of Experiments 1 and 3 and 4). Thus, we concluded that vection direction could serve as an exogenous cue for spatial attention.

The current findings also suggested that reliable vection induction and stronger experiences of vection are both crucial for these 'vection valid' cueing effects. As there is always a finite vection onset latency (which can last up to 10 s – Palmisano and Riecke, 2018), vection induction should have been more likely in the 20 s (as opposed to the 5 s) grating motion conditions of the current study. Also, as vection strength tends to build with increases in the duration of the stimulus motion (see Seno et al., 2018), vection should also have been stronger during the 20 s (as opposed to the 5 s) grating motion conditions. Consistent with these expectations, we found that ratings of vection strength were 60% higher in the 20 s (compared to the 5 s) grating motion conditions of Experiment 3.

Conceivably these longer 20 s durations of grating motion should also have increased the likelihood of both visual motion aftereffects (Chaudhuri, 1990) and vection aftereffects (see Seno, Palmisano & Ito, 2011). After prolonged exposure to visually moving stimulus, observers will often experience illusory object/scene motions in the opposite direction to the original motion (e.g., when they subsequently view a stationary stimulus - Winawer, Huk, & Boroditsky, 2010). Similar to these motion aftereffects, prolonged exposure to self-motion consistent optic flow can also induce illusions of self-motion (referred to as vection aftereffects – Brandt, Dichgans and Büchelle, 1974). While it is possible to produce very short motion aftereffects (1 s on average) with 20 s stimulus motion durations (see Seno, Palmisano, & Ito, 2011), the likelihood of inducing such effects depends critically on stationary fixation and the characteristics of the stationary test stimulus (they increase with the similarity of the inducing stimulus to the test stimulus). As a stationary fixation reference was not provided during the grating motion, the participants' eyes were free to move. Furthermore, the test screen (which consisted of the two stationary boxes placed either to the left and right, or above and below, the screen center) was quite different to the motion adaptation stimulus (either a horizontally or a vertically oriented grating). As the conditions in this study were not favorable for motion or vection aftereffects, and as none of our participants reported experiencing such aftereffects during their debriefing, they are unlikely to explain the 'vection valid' cueing results of the current study.

Instead, it would appear that when vection was sufficient compelling, participants' attention was attracted to where they were currently headed towards (rather than where they were heading away from). This served to speed up their responding to the Posner task when the target appears in direction they had been simulated to be moving. Sato and Hata (2015) have recently proposed a two-step model of the relationship between vection and attention. In the first stage of this model, the visual input (in this case, the moving grating stimulus) forms a bottom-up motion signal, and in the second stage, the observer's attention modulates the strength of the vection induced by the visual input by selectively modulating the processing of this motion signal. Based on this model, this study can explain the current results as follows. When participants first begin to experience vection, this consumes some of their attentional resources, which leads to an overall increase their reaction times to the Posner variant task. However, as the intensity of the vection increases, their attention will be progressively directed towards the direction of their simulated self-motion, which will thus decrease reaction times more when the target also appears in that same (as opposed to opposite) direction. This therefore explains how vection induction generally increased reaction times, and vection-direction sometimes decreased the reaction times, on the task used in the current study. Our results extend and deepen this previously proposed two-stage model of attention and vection.

This explanation of the current results appears to be quite compatible with other research findings on the influence of vection on cognition/emotion - for example, research which shows that upward vection can improve the participant's mood (Seno, et al., 2013), whereas downward vection can facilitate the recognition of negative images and inhibit the recognition of positive images (Väljamäe & Seno, 2016).

However, the benefits of vection-direction cues are obscured by the use of a multimodal target. When it was compelling, the direction of the visually induced vection (i.e., 'vection valid' versus 'vection invalid') was found to significantly influence reaction times in both Experiments 1, 3 and 4. However, the Posner task in those three experiments only presented a purely visual target. Similar vection direction cueing effects were not found in Experiment 2, where a pure-tone auditory stimulus was presented at the same time as the visual target. On each trial in this experiment, the auditory stimulus could either be consistent with the visual target location, inconsistent with the visual target location or absent. The presentation of a pure tone auditory stimulus at the same time as the visual target stimulus was found to speed up participant response times (compared to reaction times in 'without sound' conditions). These findings are consistent with those of a number of previous studies (e.g., Lunn, et al., 2019; Van der Stoep, et al., 2016). This is consistent with previous research, the concurrent visual task and auditory signal stimuli enhanced visual brightness and reduced visual contrast thresholds (Noesselt et al., 2010; Stein, et al., 1996).

However, presenting a sound at the same time as the visual target on two thirds of the experimental trials also must have significantly increased our participants' attentional load (compared to that in the visual-only target studies). While degrading effect of vection can still be seen in this experiment despite the inclusion of audio cues (due to the increased demand on the remaining attentional resources), the benefits of 'vection valid' (compared to 'vection invalid') conditions were not observed. That is, the use of an audiovisual target stimulus appears to have placed too high a demand on our participants' available attentional resources – and thus, these 'vection valid' cueing effects were obscured. So, for vection direction to serve as an exogenous cue for spatial attention, not only must the vection be strong and reliably induced, but the participant also needs to have sufficient attentional resources available (so they can extract the appropriate cue from their experience of that vection).

2.6.4 The vection direction cue possibility of influenced by embodied cognition

Embodied cognition research has shown that certain body postures, movements and vection can also affect our cognition (Klatzky et al., 1989), emotion (Riskind and Gotay, 1982), memory (Väljamäe & Seno, 2016) and so on. For example, stronger vection leads to faster mental rhythms and greater arousal levels (Ihaya, Seno, & Yamada, 2014) and downward vection direction favors the recognition of negative photos and inhibits the recognition of positive images. In addition, the way that we attend to and perceive objects in our visual field appears to be influenced by our body's position and its movements (Harris et al., 2015; Shapiro, 2019; Wilson, 2002). This suggests that our bodily experiences of motion can also affect our attention. Therefore, this study can infer that embodied cognition promotes the participant's self-motion illusion direction's attention and reference.

In the current study, compelling illusory self-motions might have generated embodied memories. Embodied memory research examines the impact of the body and sensorimotor processes on memory (Glenberg, 1997). From this perspective, memory is not a high-level cognitive process that is separate from human sensory processing, but rather it integrates information from human visual, auditory, and other sensory modalities via interactions with the environment. The relevant processes are activated, intensified and stored in the corresponding sensory modalities (Dutriaux, Dahiez, & Gyselinck, 2019). Thus, it is possible that embodied memories of vection direction were generated by 20 s grating motion conditions in this study - so that when the visual target eventually appeared in that same direction, participants reacted to it faster.

2.6.5 Comparing vection direction cues to other classical spatial attention cues

The past research has shown that there are many different ways to direct the observer's spatial attention towards (or away from) a target, such as the using a centered arrows (e.g., pointing either towards or away from the future target location), and presenting additional sound cues (located in either the same or a different direction to that target) and so on. In Experiments 1 and 3 and 4, these results found that the differences in reaction time between 'vection valid' and 'invalid cues' were 23.7 ms, 18.4 ms and 32.4 ms respectively. By contrast, in one recent study, where participants' visuospatial attention was directed by the use of either arrows or a face stimulus containing gaze cues, the average difference in valid versus invalid response times was 7.80 ms or 13.30 ms respectively (Stevens et al., 2008). Similarly, a more recent study, which examined the effectiveness of small and large exogenous cues, found that the difference in valid and invalid response times was 10.3 ms or 13.5 ms respectively (Burnett, d'Avossa, & Sapir, 2013). Thus, the effects of our vection-direction cues appeared to be larger than some other, more commonly used visuospatial attention cueing techniques. This might have been because our vection cueing required a long presentation time (of 20 s), whereas endogenous/exogenous cues are typically presented very briefly (e.g., for 300 ms) in most past studies. Consistent with this notion, previous studies have reported that the size of their cueing effects tend to increase with the time between the presentation of the cue and the presentation of the target (see Brignani et al., 2009). Another possible explanation for the size of our vection cueing effects, was that the cue for our study (the grating motion stimulus) covered the entire screen and occupied most of the participants' field of view. This stimulus was therefore considerably larger than the typically small, centrally located cues used in most attentional cueing studies.

The modalities of the stimulus and target presentation have also been shown to affect the size of cueing effects (e.g., the difference in reaction times for the valid versus invalid cueing conditions). For example, Santangelo and colleagues (2006) looked at the difference in reaction times for valid and invalid cues under both audiovisual and visual-only target conditions. They found that under the audiovisual conditions these differences appear to be much larger (e.g., 20.5 ms compared to 13.5 ms under visual-only conditions). However, by contrast, as noted above we failed to find a vection direction cueing effect in the current study under audiovisual conditions. This study only found our vection direction cueing effects under visual-only target conditions. The increase in the difficulty of the experimental task will also increase the prompting effect of the cue, which can be seen from the time difference between the vection valid and vection invalid responses in Experiment 4. This is consistent with previous studies (Chen et al., 2021; Gregory & Jackson, 2021), and again shows that the vection direction is indeed used as an effective cue for individuals to refer to rather than the direction of the grating motion direction.

There are of course many other differences in the experimental conditions, stimulation parameters, and experimental tasks used in each of the above-mentioned studies. Hence it is not really possible to make direct comparisons between these other cues and ours. These apparent differences in the sizes of their cueing effects will need to be examined and further clarified in future research. Taken together, Chapter 2 proved to a certain extent that vection experience had a greater effect on human spatial attention. When this virtual vection is experienced for a longer period of time and higher immersion, and the stimulation virtual illusion world becomes real, then the virtual experience is no longer virtual, and the virtual and real-world boundary become blurred. This effect on spatial attention, similar to its effect on memory, indicates that vection has greater effects and successfully transforms the virtual into the real world.

Chapter 3 The Sense of Presence between Volumetric-Video and Avatar-Based Augmented Reality in Teaching Activities

Summary

Based on the findings from Chapter 2, where four experiments were conducted using stimuli presented on a 2D display, it was demonstrated that vection can indeed shift spatial attention. This effect on spatial attention, similar to its effect on memory, indicates that vection has greater effects and successfully transforms the virtual into the real world. To further investigate whether the virtual world can be interchanged with the real world and has a similar influence on human behavior described in Chapter 2, this study employed 3D virtual reality technology to connect and interchange the virtual and real world, which is a more convincing approach. As a part of this exploration, two new augmented reality presentation technologies were developed to enhance the realism of the presented stimuli: Volumetric video Augmented Reality (VAR) and Avatar-based Augmented Reality (AAR). Subsequently, four group behavior experiments were conducted using these two new technologies and other traditional methods (e.g., Face-to-face, and Zoom). The results indicated that there were no significant differences in the effects of teaching among the four methods. However, the AAR and VAR groups exhibited significantly higher 3D sensation and presence, as well as teacher more attractiveness compared to the Face-to-face and Zoom groups. Taken together, Chapter 3 proved to a certain extent that the virtual teaching scene had a greater effect on subjective teaching effects.

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3.1 Background

Based on the findings presented in Chapter 2, the four experiments involved presenting stimuli on a 2D display, where the induced vection experience when participants viewed the moving stimuli served as valid direction cues for the spatial attention location task and the color discrimination Go No-go task. Chapter 2 demonstrated that vection has the ability to shift spatial attention, similar to its effect on memory, indicating that it has greater effects and successfully transforms the virtual to the real world. This suggests that vection is not merely an illusion or virtual experience; rather, it can provide valuable information for participants to complete cognitive tasks and enhance their performance. These results blur the distinction between the virtual and real worlds. To further investigate whether the virtual world can be interchanged with the real world and has a similar influence on human behavior described in Chapter 2, the use of 3D virtual reality technology to connect and interchange the virtual and real world would be a more convincing approach. Furthermore, Chapter 2 only established the effectiveness of vection in certain cognitive tasks, without exploring its impact on other mental processes such as teaching and learning. Therefore, in Chapter 3, two newly developed augmented reality technologies were employed to create educational scenarios and assess participants' subjective perceptions and teaching effects. Given the novelty of these presentation technologies, this study compared their teaching efficacy with traditional teaching methods, serving as a foundation for future investigations involving other types of visual stimuli (e.g., motion stimuli) within vection-related or alternative scenarios. The aim was to provide reliable technical data for future experiments and testing.

Various types of AR, such as in helmet displays, have been successfully applied to highly operable and spatial teaching courses in medicine, mathematics, chemistry, and so on (Abad-Segura, González-Zamar, Rosa, & Cevallos, 2020; O'Shea, 2011; Radu, 2014; Saltan & Arslan, 2016; Yilmaz, 2018). By using AR technologies, we can improve students' concentration, satisfaction, interest, and creativity in learning (Di Serio, Ibáñez, & Kloos, 2013; Mesia, Sanz, & Gorga, 2016; Wei, Weng, Liu, & Wang, 2015). Using AR systems and applications of mobile displays we can better train medical students (Leitritz et al., 2014). It can be used as an effective anatomical tool for students to have a better understanding and grasp of three-dimensional structures (Chytas et al., 2020). Some researchers used AR technology to develop math learning apps, and found that students' learning effect was improved and their understanding of volume and 3D content was effectively enhanced (Chao & Chang, 2018). However, in addition to these courses, it’s unclear whether these new technologies can offer similar advantages in non-highly operational or spatial disciplines, such as psychology. In addition, AR technology has been successfully used in psychological research and clinical treatment practice (Juan & Pérez, 2011). However, there is no study that have applied AR technology to a psychology course. By using AR technology in psychology courses, this study can further clarify the unique advantages of AR technology in the teaching process.

The advantages of these AR technologies are more obvious than those of traditional online and face-to-face courses. For example, Wang (2017) compared the AR system interaction by personal mobile devices group and an online learning group in a software programming course, and found that the AR group had more interaction in learning and strong interest of students. Some researchers also found that compared to face-to-face teaching, AR technology group’s students' chemistry performance improved significantly, especially for the students with poor foundation (Cai, Wang, & Chiang, 2014). This study used the method of pre-post testing, that is, the pre-test is based on the face-to-face learning process of the textbook, while the learning with the help of AR applications of computer is the post-test content. In addition, another study found that "Elements 4D" application of AR mobile device in this process can make the student learning effect stronger and the memory effect is improved (Chen & Liu, 2020).

Online courses are similar to AR technology, and these methods have advantages over traditional face-to-face courses. With the outbreak of COVID-19, a clear study of the differences between comparing face to face, and online courses such as Zoom or Teams meeting, will be helpful for later teaching work (Ali, 2020). Soffer and Nachmias (2018) found that online courses were just as effective or even more effective than face-to-face courses in many aspects, such as engagement, satisfaction, and learning content. Studies have shown that when students learn simple courses, they usually prefer online courses. For difficult courses, students think that the presence of teachers in online courses is too low, and it is difficult for students to understand complex contents (Jaggars, 2014). This indicates that the difference of teaching effects between the two teaching methods may be related to the difficulty of content. Therefore, in this study, in order to better compare the effects of the different teaching methods, we used a short psychology course with relatively simple content.

In summary, it is found that most of them compare the teaching or learning effects of the two of methods, and few of the four different teaching methods are put into the same research simultaneously. In addition, the teaching effect is closely related to the attractiveness of teachers themselves. This study should expect that the teaching effect of these new AR methods is not different from that of online courses and face-to-face courses, but participants with the new AR technology will find them more present and attractive. Therefore, this study compared four different teaching methods: VAR, AAR, Face to face, and the Zoom online. This study employed an introduction to psychology course as the teaching content. This study also surveyed participants' evaluation of teachers' attractiveness and course novelty and satisfaction, so as to comprehensively and systematically understand the teaching differences under different methods.

3.2 Methods

3.2.1 Participants

This study compared the differences of four different teaching methods, so four groups of experimental subjects were used as the between-subject deign. The first group was the VAR group, with a total of 10 subjects, ranging in age from 23 to 42 years ($M = 37.8$, $SD = 5.34$). The second group was the AAR group, with a total of 10 subjects, ranging in age from 22 to 49 years ($M = 38.2$, $SD = 7.29$). The third group was the face-to-face group, with a total of 12 subjects, ranging in age from 18 to 51 years ($M = 34.33$, $SD = 10.95$). The last group was the Zoom group, with a total of 12 subjects, ranging in age from 25 to 48 years ($M = 41$, $SD = 8.28$). All participants had a normal or corrected-to-normal vision and no reported history of attention deficit disorder, no mental illness, and no history of brain damage. Experimental procedure was approved in advance by the Ethics Committee of Kyushu University. Participants were informed about the experimental stimuli and procedures prior to the experiment, and informed consents were collected from all participants by questionnaire.

3.2.2 Apparatus and Stimulus

Figure 12(a) shows the outline of the system (developed by Steampunk Digital, 2021, Japan) for first group. This system enables remote communication in an environment where the appearance and behavior of teachers and subjects in remote areas are displayed three-dimensionally in front of them. Azure Kinect (Microsoft, USA, 2019) was used in this study to capture the user's appearance in real time. Information taken with Azure Kinect on the End Point ① side is compressed into an RGBD image that combines depth and color information in order to reduce the data size. WebRTC technology (Google, USA, 2010) is used for the remote video communications link and

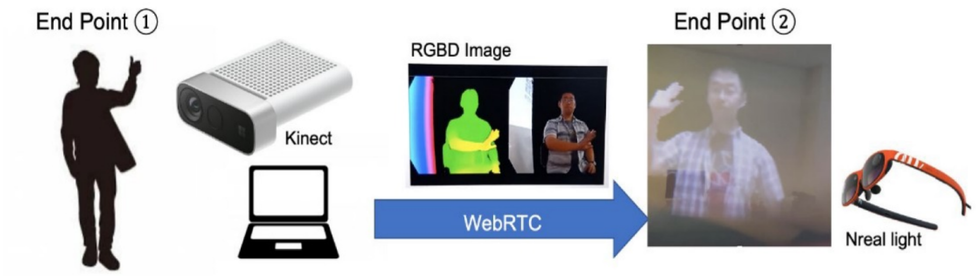

Figure 12(a): Volumetric video AR (VAR) equipment. Volumetric capture and transmissions system used Azure Kinect (Miscrosoft, USA, 2019) to record the movement and position of the teacher in 3D. Uses WebRTC technology (Google, USA, 2010) to present teacher's lecture video. Volumetric capture and transmission system at End Point 2 (the same as End Point 1) to convert back 3D information. AR visualization showing point cloud in Nreal light (Nreal, China, 2019) AR glass to users.

for distribution of the combined RGBD video. On the End Point ② side, the received RGBD image was converted back into 3D information in the colored Point Cloud format and displayed in front of the user through the Nreal Light of the AR glass (Nreal, 2019, China). Similarly, by installing Azure Kinect at End Point ② and Nreal Light at End Point ①, it is possible to have a bidirectional conversation in an environment whereby the other party's figure is three-dimensionally displayed in front of both end points. Figure 12(b) shows the outline of the system (developed by Steampunk Digital, 2021, Japan) for the second group. By measuring the movement of the user's face and linking it with the facial expression of the avatar in a remote location, this system realizes communication in an environment where the other party's figure is displayed, similar to the first group system. The TrueDepth camera in the iPhone 12 Pro (Apple, USA, 2020) was used to measure the movement of the face at End Point ①, and the

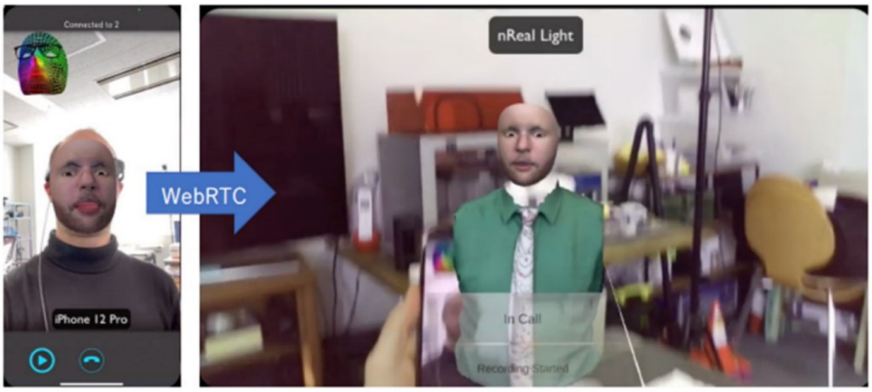

Figure 12(b): Avatar based AR (AAR) equipment. Developed by Steampunk Digital (2021 Japan): Face tracking and transmission system uses ARKit and TrueDepth camera (iPhone 12 Pro, Apple, 2020, USA) to track and measure the face movement. The record, present transmissions and AR visualization system are the same VAR group.

system was developed using the Face Tracking function utilizing ARKit (iPhone 12 Pro, Apple, 2020, USA). WebRTC was used as the communication technology to distribute the coordinates of each feature point on the face to remote locations. In End Point ②, the facial expression of the other party was reproduced by reflecting the received facial feature point coordinates on the avatar's face, and AR was displayed in front of the eyes using the Nreal Light. In addition, in order to prepare the experimental content for both two systems, the lecture content is recorded in advance as a time-series data of volumetric video information (VAR system) and facial movements (AAR system) synced with the audio recording.

For last online group, this study chose to use the Zoom online conference platform (like a TV phone online system). Similarly, this study recorded teaching videos on our iPhone 12 Pro. The same teaching was prerecorded in accordance with previous two conditions. This is shown in Figure 13 left. And for third Face-to-face group, we conducted them in the Takeharu Seno's (he is an associate professor) office of Kyushu University. This environment is shown in Figure 13 right. In this group, Takeharu Seno left the room immediately after the lesson was over to ensure the accuracy and memory of the participants. The contents of the questionnaires in this group are slightly different (see the "Appendix IV" for details). In addition, since it was face to face, there might be more irrelevant variables in this group, but this study tried our best to control them. For example, this study tried to keep the content of each speech basically the same, the speed of speech is basically moderate, and the time is basically the same as the first three groups.

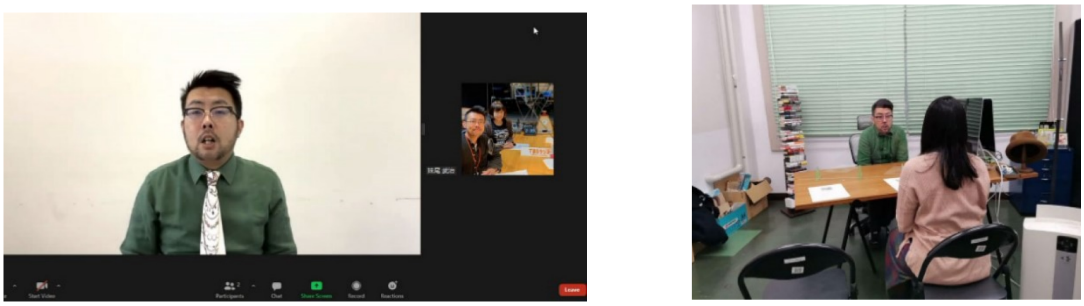

Figure 13: Zoom, Face-to-face Experimental diagram.

3.2.3 Procedure

After simple instructions at the start of the experiment under each group, the introduction to psychology contents were watched and taught. After taking the 5 minutes course, Takeharu Seno set up a time to answer short questions from the participants, and finally conducted a questionnaire. The questionnaire prepared 30 questions, including questions about teaching attractiveness, questions about teaching content, and questions about the Takeharu Seno's characteristics and so on, as shown in Japanese questionnaire, for the English version refer to the "Appendix". It took about 20 minutes for each participant to complete the experiment. In addition, except Face-to-face groups, for teaching content, recorded video was used to eliminate differences between experiments. The content was an introduction to psychology course, is Japanese language and for the English content refer to the "Appendix".

The thirty questions in the questionnaire have two indicators of these experiments. The first is where participants were asked questions based on the content of the teaching, the teacher's appearance features and self-introduction content and total numbers of four mistake types. Specially, a sum of all mistakes as total mistake numbers (all 10 questions), respectively self-introduction mistake numbers (three questions: Q5, Q6 and Q7), teaching content mistake numbers (four questions: Q8, Q9, Q10, Q11), and video mistake numbers (three questions: Q12, Q13, Q14). There is a correct answer for each of these questions. If it matches the content of the lecture, it is correct. The correct answers for each group are indicated in the Appendix IV for reference. Each wrong answer counts as a point, the correct answer does not count as a point. The second is 14 survey questions and used a 5 points scale. The higher the score, the more fun or novelty the course is. All subjective evaluation questions in the questionnaire were scored in a positive way. For better statistical analysis, then divide these 14 questions into five types, such as; (1) Course novelty: four questions: Q15, Q16, Q17, Q19; (2) 3D: two questions: Q20, Q21; (3) Video quality: three questions: Q18, Q23, Q24; (4) Teachers' attractiveness: two questions: Q25, Q26; and (5) Familiarity: two questions: Q27, Q28. Because the third face-to-face group is not on video, some questions in the questionnaire are different from those in the other three groups. These five types also fit into the face-to-face group. In the first 4 questions of the questionnaire, we investigated the name, age, gender of the participants and the questions about their consent to participate in the experiment. In addition, the last 2 questions in the questionnaire were about the familiarity with Takeharu Seno and the participants' feeling of freedom about the course.

3.3 Results

This study calculated the responses of participants to different questions in the questionnaire and compared the correct answers to get the number of errors per participant. All participants' total mistake rate is 31.4%. Figure 14 indicates the number of incorrect questions recalled by participants under different conditions. From Figure 14, can see that there is no significant difference in the recall accuracy of the four teaching methods with respect to the total mistake numbers. However, there are significant differences in some methods, such as video mistake numbers. Specially, One-way ANOVAs and post-hoc multiple comparisons were carried out for four different dependent variables. Then used the Greenhouse-Geisser corrections for violations of sphericity and Bonferroni-corrections when conducting multiple post hoc comparisons. All statistical levels were set to 0.05. Partial eta-squared (η_p^2) measures of effect size were also calculated for the ANOVAs. As for the total mistake numbers, there is no significant difference in four different teaching methods: F (3, 40) = 0.564, p = 0.642, η_p^2 = 0.041. As for the video mistake numbers, there is significant difference in four different teaching methods: F (3, 40) = 3.258, p = 0.031, η_p^2 = 0.196. Post-hoc analysis found significant differences between VAR and AAR: p = 0.019, that the number of errors in the VAR group was significantly higher than the AAR group.

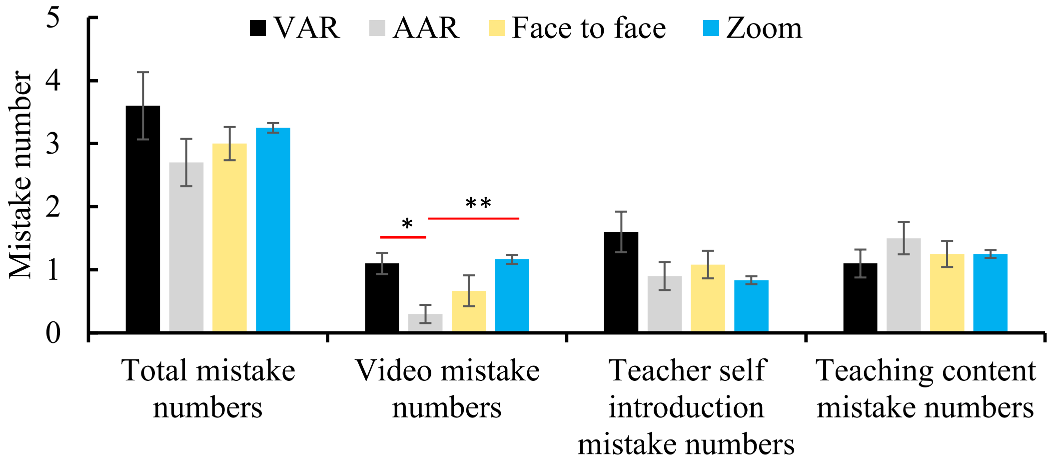

Figure 14: Number of falsely recalled questions in teaching or teacher's relevant content of four different teaching methods. * $p < 0.05$, ** $p < 0.01$.

Between AAR and Group Zoom, p = 0.008, that the number of errors in the Zoom group was significantly higher than the AAR group. As for the self-introduction mistake numbers, there is no significant difference in four different teaching methods: F (3, 40) = 1.675, p = 0.188, η_p^2 = 0.112. As for the content mistake numbers, there is no significant difference in four different teaching methods: F (3, 40) = 0.307, p = 0.820, η_p^2 = 0.023. This result indicates that different teaching methods do not affect the degree of individual recall, that is to say, there may be no difference in teaching effects under the four teaching methods. However, there are significant differences in video content, which may be caused by the fact that in VAR technology, when participants interact with teachers, the teacher present more three-dimensional and novel. Therefore, under this condition, participants were more likely to ignore the teacher's personal physical characteristics, and the error rate is high.

Figure 15 shows that: in the questionnaire conducted, each item was evaluated on a scale of 1 to 5. In general, we can see that the attractiveness of teachers, 3D and so on are higher under the new VAR and AAR technology as follows. The specific results

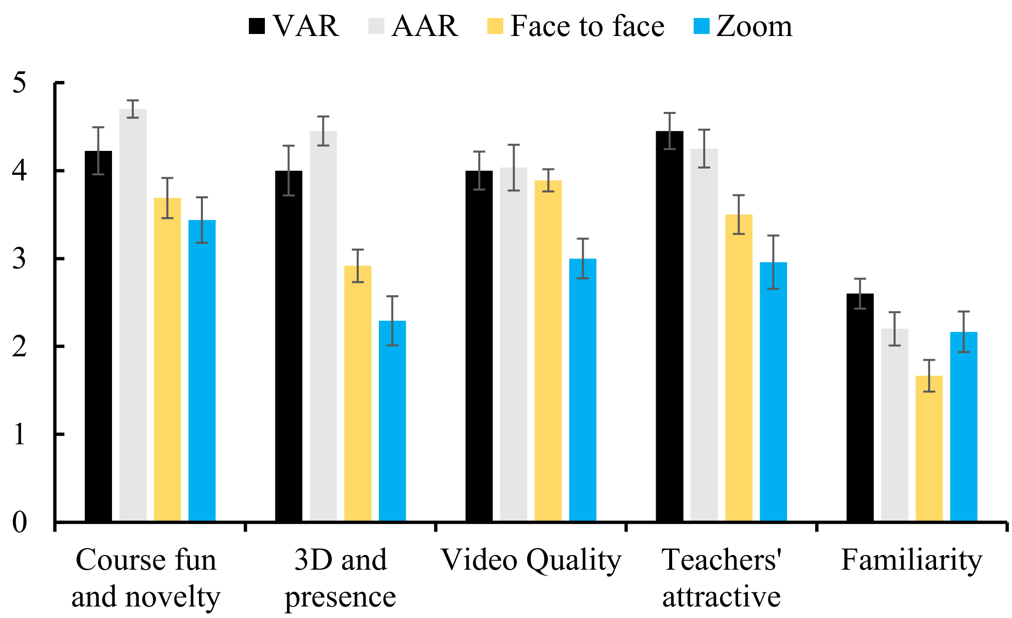

Figure 15: Five aspects of questionnaire result under four different teaching methods.

are shown in the analysis of variance below. One-way ANOVAs and post-hoc multiple comparisons were carried out for five different dependent variables. As for the fun and novelty of the course, there is significant difference in four different teaching methods: $F\,(3, 40) = 5.446$, $p = 0.003$, $\eta_p^{\,2} = 0.290$. Post-hoc analysis found significant differences between VAR and Zoom: $p = 0.026$, also significant difference between AAR and Face to face, $p = 0.005$, AAR and Zoom: $p = 0.001$, that participants in the AAR group felt the courses more fun and novel than those in the Face to face and Zoom groups, in the VAR group felt more fun and novel than those in the Zoom groups. As for the 3D and presence of the course, there is significant difference in four different teaching methods:

F (3, 40) = 15.886, $p < 0.001$, $\eta_p^2 = 0.544$. Post-hoc analysis found significant differences between VAR and face-to-face: $p = 0.004$, VAR and Zoom: $p < 0.001$, also significant difference between AAR and face-to-face, $p < 0.001$, AAR and Zoom: $p < 0.001$, that participants in the VAR and AAR group felt more sense of presence than those in the face-to-face and Zoom groups. As for the Video of the course, there is significant difference in four different teaching methods: F (3, 40) = 5.266, $p = 0.004$, $\eta_p^2 = 0.283$. Post-hoc analysis found significant differences between VAR and Zoom: $p = 0.001$, also significant difference between AAR and Zoom: $p = 0.002$, significant difference between face-to-face and Zoom: $p = 0.005$. Participants in the VAR, AAR and face-to-face group felt better video and communication quality than those in the Zoom groups. This result seems reasonable, according to the 18th question in the questionnaire about communication effects feedback, it was found that the quality of communication between participants and teachers of online Zoom courses was not well.

There will be no sense of timeliness and reality of face-to-face, as well as the three-dimensional presence sense of new VAR and AAR technology. As for the attractiveness of the teacher, there is significant difference in four different teaching methods: F (3, 40) = 7.183, $p = 0.001$, $\eta_p^2 = 0.35$. Post-hoc analysis found significant differences between VAR and face-to-face: $p = 0.013$, VAR and Zoom: $p < 0.001$, also significant difference between AAR and face-to-face, $p = 0.047$, AAR and Zoom: $p = 0.001$, that participants in the VAR and AAR group felt the teacher was more attractive than those in the face-to-face and Zoom groups. As for the familiarity of the VAR, AAR and psychology, there is significant difference in four different teaching methods: F (3, 40) = 3.433, $p = 0.026$, $\eta_p^2 = 0.205$. Post-hoc analysis found significant differences between VAR and face-to-face: $p = 0.003$, that participants in the VAR group more familiar of the VAR, AAR and psychology than those in the face-to-face groups. Finally, we also investigated the participants' familiarity with the teacher (Takeharu Seno). The results showed that 68.75% participants did not know Takeharu Seno, and 20.75% participants only knew Takeharu Seno's name, but were not familiar with Takeharu Seno. The

Table 1: Pearson correlation coefficients between the five aspects of questionnaire.

	Fun and novelty	3D and presence	Video quality	Attractiveness
VAR				
3D and presence	0.825^{**}			
Video quality	0.561	0.682^{*}		
Attractiveness	0.406	0.430	0.075	
Familiarity	-0.214	-0.571	-0.362	-0.486
AAR				
3D and presence	0.521			
Video quality	0.720^{*}	0.703^{*}		
Attractiveness	-0.294	0.176	0.194	
Familiarity	-0.280	-0.128	0.02	0.613
Face to face				
3D and presence	0.442			
Video quality	0.582^{*}	0.116		
Attractiveness	0.414	0.639^{*}	-0.166	
Familiarity	0.295	-0.174	-0.034	-0.262
Zoom				
3D and presence	0.2			
Video quality	0.416	0.643^{*}		
Attractiveness	0.473	0.525	0.491	
Familiarity	0.320	0.449	0.067	0.505

$^{*}P<0.05$, $^{**}P<0.01$

remaining 10.5% knew Takeharu Seno. Therefore, it can be seen that the participants' familiarity with Takeharu Seno basically did not affect their judgments on the course content and attractiveness.

As shown in Table 1, the participants' experience of course novelty be related to the generated sense of 3D and presence. Then analyzed the Pearson correlations between the five aspects in each group. In the VAR and AAR groups, participants' perception of novelty and fun of the course is high correlated with 3D presence and video quality, which is significantly higher than the correlation between the two in the face-to-face and Zoom groups. To some extent, this indicates that with the change of VAR and AAR teaching technology, the more presence the participants felt in the course, the more interesting and novel the course will be, and the higher the quality of communication will feel. In addition, we found that the participants who were more familiar to VAR and AAR technology, then the course novelty, fun, and impressiveness was lower. This seems to fit our common sense, if we are more familiar with things, the more we will lose interest, and thus less experience makes the curriculum more novel and interesting.

3.4 Discussion

3.4.1 Summary of the Experimental Findings.

The main purpose of this study is to investigate the differences in teaching content effectiveness and subjective presence and attractiveness under the four different teaching methods. The results showed that there was no significant difference in teaching content effect under the different teaching methods, but there were significant differences in teaching novelty, satisfaction, presence, and teacher's attractiveness under these four different teaching methods. Especially, in the VAR and AAR group, participants felt the course was more novel and interesting, they also perceived the teacher was more 3D and attractive.

This study chose a simple psychology course as the teaching content and found it to be more interesting for the participants after interviews at the end of the experiment. Choosing a simple psychology course helps us to eliminate the difference in teaching effects caused by the difficulty of the content. If the difficult content were selected, participants would pay more attention to the content and ignore the changes in teaching methods. In addition, some studies found that if the course content is difficult, students are more inclined to choose the Face-to-face teaching method (Soffer & Nachmias, 2018). Therefore, this is one of the reasons we chose to use a simple psychology course as the teaching material in our research.

3.4.2 No Significant Difference in Teaching Content Effect of Four Groups.

This study found that there were no significant differences in the teaching content effects under the four teaching methods. That is to say, the correct recall rate of teaching content and teacher characteristics (hairstyle direction and T-shirt, tie colors) were the same among different groups. Previous many studies had also applied AR technologies to the teaching process, however, there is no direct participation of teachers. And found that with these AR technologies, the learning content effect of students is not only had not affected but also the learning effect has been improved (Cai et al, 2014; Chytas et al., 2020). These previous results are partially consistent with the results of this study, which also found that there was no difference in participants' recall of the teaching content when using the new VAR and AAR technology. That is to say, these two new technologies like previous AR technologies, do not interfere with students' learning performance. However, there was no improvement in the teaching content performance of the new VAR and AAR groups compared to the face-to-face and Zoom online groups.

The reasons for this result may be due to the short-term and long-term memory. In this study, the course only needs about five minutes, at the end of the lesson, participants need to answer questions after simple communication with the teacher. And the participants' short-term memory is not effectively engaged in relay into long-term memory, so it is possible that there is no difference between the four groups related to teaching content memory.

Secondly, another reason may be that the teaching content we use is relatively simple. The more difficult the course, the more participants are likely to focus on the content of the course rather than the way it is taught. Therefore, participants in this study may pay more attention to these two new AAR and VAR technologies than to information such as course content. In the past, most courses using AR technology in teaching are difficult, involving high space and operation, so AR technology has helped the teaching effect of these courses. For example, in medical anatomy or chemical structure course used AR technologies can improve students' learning performance (Cai et al, 2014; Leitritz et al.,2014).

There was also no difference in teaching content between the online and face-to-face groups, which is also inconsistent with the results of previous studies. Such as Soffer et al (2018) found that the teaching effects of online courses such as Zoom have no significant difference from those of face-to-face courses, and students can absorb knowledge equally or more effectively. In the introductory sociology course, there is a difference in learning effect between the two groups, but there is no difference in learning satisfaction (Driscoll, Jicha, Hunt, Tichavsky, & Thompson, 2012). The reason for the difference in the results of this study may be related to the existence of the selection effect. The reason for the difference may also lie in the fact that in our study, the investigation of teaching effect included participants' memory of teachers' characteristics (hair tie and t-shirt), so there may be no difference.

3.4.3 More Presence and Attractiveness in Teaching of VAR and AAR Groups.

The average evaluation of the subjects who experienced 3D, presence, course satisfaction and novelty, quality communication, surprise, and teacher's impression and attractiveness of VAR and AAR groups exceeded 3.5 points in the evaluation items related to the lesson and teacher. This tended to be better than the conventional face-to-face and the Zoom online. As a result of further correlation analysis, all the items related to the quality of communication, which are the subjects of this project, such as the enjoyment and satisfaction of the lessons, have a strong correlation with the high degree of "3D feeling" and "immersive feeling". From this, it was found that the new communication experience using VAR and AAR technology affects the positive motivation of the participants' side and the positive impression of the teacher. This is consistent with previous research results, once again proving that the new AR technology will improve student satisfaction and participation (Di Serio et al., 2013; Huang, Liaw, & Lai, 2016; Mesia et al., 2016). In other words, the VAR and AAR technology developed can also improve students' interest in learning and increase course satisfaction.

In this study, the results also confirmed that two new AR technologies can not only improve participants' satisfaction but also increase participants' interaction. This is also consistent with previous research. For example, Wang (2017) found that compared to the online group, the AR student group has more interaction in learning and a strong interest in software programming. These AR technologies enable participants to have a three-dimensional and comprehensive high-quality communication with the teachers from a distance, so the teaching satisfaction and teacher attraction are much higher than that of the face-to-face and Zoom group. The teachers in the Zoom group are more planar, while the face-to-face teachers are realistic but students felt a lack of interest. Through the communication and interview with participants, we further found that participants in the new technology will be more interested in learning.

Although both AAR and VAR sets of new 3D technologies can increase participants' satisfaction with the course, and the AAR avatar is depicted based on the 3D real Takeharu Seno's face like VAR condition, there are some specific differences. For example, the course novelty scores of the VAR group were significantly higher than those of the face-to-face and Zoom groups, but there was no significant difference between the AAR group and the face-to-face, Zoom group. This may be related to the familiarity of the participants with the AR technology, which was significantly higher in the AAR group than in the Face to face and Zoom groups, but not significantly different from the VAR group. Taken together, Chapter 3 proved to a certain extent that the new AR virtual teaching scene had a greater effect on human subjective teaching effects. When this virtual teaching scene is experienced for a longer period of time and higher immersion, and the stimulation virtual world becomes real, then the virtual experience is no longer virtual, and the virtual and real-world boundary become blurred. The virtual scene is successfully transformed into the real world.

Chapter 4 General Discussion and Conclusion and Future Projections

Summary

This chapter discussed the impact of the self-motion illusion experience induced by 2D motion stimulation on attention and the teaching effect of AR technology in the 3D virtual world. These two studies aim to address the question of how virtual and reality are connected and interact to affect human cognition and learning, highlighting that virtual experiences are not entirely virtual. Then summarized the two key findings of this thesis: shift of exogenous spatial attention caused by the reliable vection direction and the capacity of two novel AR technologies to enhance presence and improve teaching effects. In conclusion, these results demonstrated that vection and the virtual world can successfully transform the virtual into the real world and greater effect on human cognition and teaching, and learning. Given the limitations of this thesis, six potential research directions for the future are proposed, including the exploration of new augmented reality technologies, the study of vection in various virtual scenarios, and other related virtual areas and real effects, vection as a good perspective to understand human and the world.

4.1 General Discussion

Summary. From these two studies, it becomes evident that different presentation methods (2D and 3D stimuli) to connect the virtual and real world, as well as different psychological processes (attention and teaching), along with increased immersion time, demonstrate that virtual experiences are not pure virtual and have greater effects to a certain extent. In Chapter 2, appropriate parameters such as the duration of motion stimuli were selected to induce a stable vection experience. It was found that the direction of vection (left/right and up/down) can influence spatial attention. This result indicates that subjective illusion experiences had a greater effect and transform the virtual into the real. Building on this finding, Chapter 3 aimed to further validate the successfully transforming the virtual to the real world and greater effect on human cognition and teaching. It selected common teaching scenarios from everyday life and presented them through augmented reality technology, surpassing the limitations of computer screens and TV screens. The outcomes revealed that the sense of presence was higher under these two new augmented reality technologies, resulting in increased attractiveness and improved subjective teaching effects. Once again, this chapter reinforces the notion that the lines between virtual and real are blurred and interchangeable. Furthermore, these findings can serve as experimental evidence and provide technical data support for exploring the impact of different visual stimuli or virtual scenes on cognitive and teaching, and learning processes in future research.

Stable vection shifted on spatial attention. Grating motion stimuli, consisting of alternating light and dark bars moving in a particular direction, have been used in numerous studies to investigate the relationship between visual stimuli and vection (Fujii, Seno & Allison, 2018; Seno, Ito, & Sunga, 2011; Keshavarz et al., 2017; Seno et al., 2013). In Chapter 2, this study used such grating motion stimuli presented on the

TV screen. The results show that the effect of inducing vection experience is stable by setting appropriate grating motion presentation time and so on. In addition to these factors, previous studies have also found that the direction of movement of stimuli and different types of display can also affect the intensity of vection. For example, the researcher used the random-dot optical flow in a circular field-induced vection and manipulated different directions, and found that vection intensity was stronger in cardinal directions than in the oblique directions (Fujii, & Seno., 2020). As for stimuli present display types, researchers found that the dome projection and the combination of three screens these two types of vection intensity stronger than in the single computer screen and flat projection screen conditions (Keshavarz et al., 2017). Through these latest studies, can combine these factors in future research to examine the weight of these factors in the process of inducing self-motion illusion, to provide experimental evidence and support for selecting appropriate parameters to induce stable vection experience in the future.

In Chapter 2, it is found that the intensity of vection will affect the guidance of the vection direction to spatial attention, for example in Experiment 3. In addition, participants had more spatial positioning tasks in Chapter 3, so this study canceled the collection of two vection intensity indicators, latency time and duration time so that participants can better complete the experimental tasks. According to the experimental parameters and settings, this study excluded the possible interfering factors of eye movement and motion aftereffects and explained the results by combining the two-stage processing theory of attention and vection. In addition, the future can use hyper-scanning devices to investigate the neural basis of the relationship between attention and vection based on sufficiently stable behavioral evidence. For example, some previous studies found that during vestibular processing, the medial superior temporal ventral area may be proximal to the visual posterior Sylvian area (Chen, DeAngelis, & Angelaki., 2011). Furthermore, through Event-related potentials (ERPs) and behavioral experiments, Stróżak et al. (2016) found that vection appears to slow reaction times and disrupt electrophysiological responses to targets during an oddball task and so on.

AR technologies improved on subjective teaching effects. In Chapter 3, this study chose common teaching scenes as experimental stimuli. To connect and transform the virtual and real world more effectively, incorporated new augmented reality technologies developed by this thesis. Since it is a newly developed technology, this study chose the practical field teaching activities usually used in augmented reality as the basic experiment to test the new technology and immersed more time. Therefore, the experiment in Chapter 3 did not use the spatial attention localization task, but in future research, it is possible to combine the spatial task with augmented reality in combination with stable technical test data. Thus, this study used an introductory psychology course to compare the effects of the two AR technologies as well as online and offline courses. It was found that compared with offline and online courses, courses combined with AR new technology have a higher sense of presence and better teaching effects. Through this test, this study can see that augmented reality is almost as good as offline face-to-face teaching, and even better than face-to-face teaching in some ways. These results are consistent with many previous results, showing that the newly developed augmented reality technology works stably (Wang., 2017).

Interchangeability of Virtual and Real. Through these two studies, this study has proved to a certain extent the interchangeability of virtual and real. Specifically, in Chapter 2, this study used 2D grating motion stimuli to induce the illusion of stable self-motion. It turns out that this vection experience can serve as an effective cue for spatial attention. That is to say, the participants perceived the vection direction, and it provided help for them to complete related cognitive tasks. Vection would be more like conscious self-movements than illusions. From this perspective, vection illusion experiences are real rather than virtual experiences and transform the virtual into the real. This is consistent with the results of previous studies, such as the researchers using upward and downward grating motion stimuli to induce vection experience, it was found that participants recalled positive events more frequently when they perceived upward vection. That is to say, the direction of vection can affect memory. When immersed in a vection experience for a longer period of time, this virtual experience can be successfully converted into the real world beyond the original physical stimulation to have an impact on memory. Furthermore, no modulation of emotional valence was observed with small moving gratings or static gratings that produced little or no vection. Thus, consistent with this study, only stable upward vection experiences had a strong positive effect on mood (Seno et al., 2013). The researchers then performed a memory recognition task using positive, negative, and neutral affective images with high and low arousal levels, and found that they were presented with novel images during vertical vection-inducing or neutral visual stimuli. The results show that downward vection favors the recognition of negative images and inhibits the recognition of positive images (Väljamäe and Seno, 2016). These results again illustrate the stable vection experience evoked by grating motion stimuli, bringing participants from the real world to the virtual world. As the participant's immersion time becomes longer, the virtual world will switch to the real world, at this time, the reality of the physical movement stimulus becomes weaker, and the vection has a greater impact on cognition than the physical movement stimulus.

To further clarify this issue, this thesis developed new augmented reality technologies and expanded the scene to a more realistic educational scene. It was found that under the virtual teaching methods, participants were more satisfied with the overall teaching and had a better sense of presence. This shows that learning in virtual environments is real and even efficient. Previous research has found this effect and influence not only in teaching settings but also in other settings such as e-retailers are always trying to optimize their online presence to be more competitive. Researchers have proposed a model to explain the reuse of AR-based app shopping programs. The results of the study show that these shopping programs can enhance participants' sense of immersion and realism, which will affect human shopping experience and behavior (Daassi, & Debbabi, 2021). In addition, augmented and virtual reality immersive technologies have also been widely used in the field of tourism. A recent review paper retrieved data from 65 independent studies from 56 papers. It turns out that a sense of presence is considered to be a core feature of augmented and virtual reality in tourism. Moreover, it is further found that the sense of presence directly or indirectly has different effects on the tourism experience through the intermediary factors of value perception and psychological response. These studies show that with the continuous development and updating of augmented and virtual reality technologies, participants' sense of immersion in the virtual world is getting higher. In other words, augmented reality technology combining real-world stimuli can affect and transform the virtual world into the real world. Thus, vection and AR virtual scenes bring participants into the virtual world, and then successfully bring participants from virtual reality into the real world with longer immersion, this real world has a greater impact on human cognition and teaching and learning, as well as other behaviors.

In addition to vection and augmented reality, two methods for efficiently linking and translating the virtual and the real, other methods are also being developed. For example, researchers have used data models to remove cues of facial attractiveness, trying to find other factors that affect the trustworthiness of faces. It was found that visual cues of trust and attraction may be independent. This result shows that the virtual data model will also affect our judgment (Oh et al., 2023). The other researchers used the virtual spatial cognition assessment test and found that the stronger the presence, the better their spatial cognition performance. This shows that more realistic stimuli make participants feel more real than virtual (Maneuvrier et al., 2020). Through these studies, it can be found that there are other potentially effective ways to connect the virtual and real worlds, which makes the boundary between virtual and reality more blurred, and then bring participants into the virtual world through these methods. As the immersion time increases, the participants seem to switch to the new real world. At this time, the real world seems to have a greater impact on human cognition and behavior, which shows that the interaction between the virtual world and the real world is more complex, and it affects human cognition and behavior uniformly. This topic is an area worthy of further exploration in the future. Through continuous and in-depth research, human beings will have new doubts about what is the real world. Both virtual and reality have an impact on human cognitive behavior, but how to interact or who has the greater influence is still unclear, so what the next real world will look like is worth looking forward to.

4.2 General Conclusion

This thesis mainly carried out two behavioral experimental studies. Before conducting the experiment, a literature review was conducted on the basic concepts and relationships between vection and attention, and virtual and reality in the Chapter 1, and it was found that previous studies rarely explored the effect of vection and AR technology on the interchange of virtual and real worlds. Previous research has found that the self-motion illusion is more real and useful than the motion stimuli, with the ability to switch between virtual and real world. In order to further clarify whether the virtual world can be interchanged with the real world to affect human behavior. Then using 3D virtual reality technology to connect and transform the virtual and real worlds will be a more convincing method. Therefore, this thesis conducted two studies to explore how interact virtuality and reality affect human cognition and behavior.

In Chapter 2, this thesis selected appropriate values to induce a stable vection experience. Then this chapter used modified versions of Posner's classic spatial attention cueing paradigm to examine whether vection-direction could serve as an exogenous cue to spatial attention. Consistent with this proposal, results found that 'vection-valid' cues reduced reaction times compared to 'vection-invalid cues. However, this vection-based cueing effect was only observed when the vection inducing grating motions were presented for 20 s (not 5 s), and when the target was visual (not when it was audiovisual in nature). The vection cueing effects didn't alter by experiment task (spatial orientation task and the color discrimination go-no-go task). These findings indicate that vection-direction can be used to direct spatial attention, but only (it appears) when the vection is strong and reliable, and sufficient attentional resources are available. Therefore, these four experimental results provide new evidence for the influence of vection on visuospatial attention and further clarify the complex relationship between vection and cognitive factors (such as audiovisual interaction).

In Chapter 3, this study investigated the effects of four different teaching methods: VAR, AAR technology, face-to-face, and the Zoom, on participants' learning outcomes and course satisfaction. It was found that while there may be no difference in the effects of teaching content under the four teaching methods, educational satisfaction, and teacher attractiveness under the new VAR and AAR technology may be higher. Through this research, can also find that the new technologies that have been developed can enhance course satisfaction, and teacher attractiveness and improve the presence, improved subjective teaching effect, and engagement of introduction to psychology courses. Taken together, these two studies prove to a certain extent that vection and the virtual scene had a greater effect on human cognition and subjective teaching effects. When the vection experience and virtual scene are experienced for a longer period of time and higher immersion, and the stimulation virtual world becomes real, then the vection and virtual experience is no longer virtual, and the virtual and real-world boundary become blurred. In conclusion, these results demonstrate that vection and the virtual world can successfully interchange the virtual and real world and greater effect on human cognition and subjective teaching effects.

4.3 Future Projections

In summary, combining these two behavioral experimental studies, the limitations and future research topics of this thesis mainly include the following six aspects.

1) Effects of other low-level properties of the visual stimuli on vection intensity. Research in Chapter 2 used the suitable presenting time, stimuli speed, and size to induce the stable linear vection. In addition to these three factors, the researchers also examined other possible factors, such as the density of visual stimuli. Some studies have found that as the density of stimulation increases, the intensity of vection increases

(Keshavarz et al., 2019). There is also the field of view, stereoscopic depth, oscillation, visual stimuli generated by computer graphics techniques, and direction of movement of visual stimuli and these factors also adjust the intensity of vection (Bossard et al., 2016, 2020; Fujii, & Seno, 2020; Keshavarz et al., 2017; Morimoto et al., 2019; Palmisano, 2002; Sato et al., 2020; Seya, & Shinoda, 2018). Therefore, combined with the above research, future research can investigate the comparison of the effects of these factors under different types of vection (linear vection or circular vection, or curvilinear vection). Then properly examine the interaction between these factors, such as the oscillation of the stimulus and the field of view. How to adjust the intensity of vection under conditions such as when the oscillatory visual stimulus is presented in half, and when the oscillatory stimulus in the left and right visual fields moves in opposite directions.

2) Use other methods to measure vection and self-motion perception. In this thesis, we only use the indicators of direct subjective reports, so there may be individual differences in Chapter 2, which leads to greater variability in subjective vection strength. Therefore, future research can consider adding other indicators such as indirect measurement methods such as distance traveled (Fauville et al., 2021) and postural responses (Apthorp, Nagle, & Palmisano, 2014); and can also consider adding some objective indicators such as compensatory eye movement (Kooijman et al., 2022; Palmisano et al., 2015). Regarding the relationship between attention and vection, this thesis only used behavioral experiments. However, as this chapter's general discussion part statement, using the high temporal resolution electroencephalogram (EEG) (McAssey, 2022), event-related potentials (ERPs), and high spatial resolution functional magnetic resonance imaging (fMRI) (Smith et al., 1998) method to investigate the influence of vection on spatial attention will clarify the temporal and spatial neural pathways and mechanisms of this process. For example, the ERPs results can mainly focus on the amplitude of P1, N2, and P3 (Stróżak et al., 2016, 2019), the fMRI results can mainly focus on the right temporal-parietal junction and right ventral frontal cortex involved the in stimulus-driven attention orientating (Tang, Wu and Shen, 2016).

Vection and self-motion perception are closely related. Whether for humans or animals, detecting motion information and self-motion perception are very important in our lives, such as in any driving experience. Therefore, through the perspective of self-motion perception, we can combine more stimuli and experimental approaches to examine vection and motion perception. Such as we can examine the psychological behavior and neural mechanism of self-motion perception by combining different subjects, methods, scenarios, and perspectives. Especially we can combine behavioral and neurophysiological measurements and take a deeper step to understand in combination with the pilot's spatial orientation and other practical applications and different angles (previous studies mainly focused on passive optical flow-induced self-motion, but can also from the perspective of active control of motion perception) vection and self-motion perception. For example, a recent review summarized and put the role of active control in self-motion perception, with insights into things like spatial disorientation and motion sickness in aviation (Rineau et al., 2023). In addition, recent research using genetic manipulations and neural measurements to study drosophila fly's rotation motion and optical flow detection behavior found how the brain improved heading stability (Tanaka et al., 2023). To sum up, the combination of self-motion perception can provide more angles, methods, and application scenarios for the study of vection and motion perception.

3) Endogenous and exogenous attention and vection. Typically, the relationship between endogenous attention and exogenous attention is more complicated. Previous studies have found that observers do not ignore exogenous cues, but may ignore endogenous cues. The predictiveness of cues had little effect on exogenous attention orientation. The researchers propose that these two types of attention may be separate systems with different neural bases (Chica, Bartolomeo, & Lupiáñez, 2013). In addition, multisensory interaction plays an important role in endogenous and exogenous attention (Tang, Wu, Shen, 2016). Therefore, future research can examine the impact of endogenous attention on vection by changing the ratio of grating motion directions, and presenting auditory modality information while grating motion cues are presented. Together, the relationship between vection and endogenous and exogenous attention can be further clarified, as well as the role of multisensory interaction in it, providing experimental evidence for related fields of attention and motion perception.

4) Vection and presence and motion sickness in virtual reality and augmented reality. With the development of virtual reality technology, more and more studies have examined the role of vection in virtual reality. Self-motion perception itself is a process involving the processing of multisensory cues, such as vision and the vestibular (Zhou, & Gu, 2023). Vection is generally believed to improve simulator fidelity and enhance virtual reality applications and so on. Especially when examining low-level grating motion stimuli, dots, or other induced vection stimuli. At present, there are mainly three aspects of research. First, virtual reality can enhance the vection experience. The connection between the vection experience enhanced by multisensory information input and the real world is examined in virtual reality. Second, there is a positive correlation between vection and sense of presence in virtual reality. Third, there is a complex relationship between vection and motion sickness in virtual reality. Reducing motion sickness in the metaverse world is a research trend.

Firstly, the effectiveness of virtual reality in enhancing vection induced by visual or auditory or tactile stimuli and so on. For example, vection experiences are usually evoked by visual stimuli, but recent studies have found that other modalities or multisensory cues can have an impact on vection intensity. Specifically, in virtual reality, the researchers compared the vection intensity of single sensory stimulation and multisensory interactive stimulation by manipulating visual, auditory, and tactile cue stimulation in rotating stimuli that induce circular vection. The results revealed that vection strength and duration had increased in the condition of simultaneous presentation of multisensory cues (Murovec et al., 2021). Subsequent studies have also confirmed this effect. In a larger field of view, auditory and tactile stimuli are presented simultaneously, which increased the vection strength, both in older adults and younger adults (Murovec et al., 2022). In addition, some researchers have recently changed the way participants observe stimuli, for example, in addition to standing or sitting, they also added floating on the water surface, that is, increased tactile information. The results found that participants in the water experienced a significant increase in vection intensity (Fauville et al., 2021). Because of the important role of walking or locomotion in the optic flow process and perception (Horrocks, Mareschal, & Saleem, 2023) and also that walking naturally in a virtual environment is often difficult, the researchers also developed the foot tactile system and found that visual, auditory, and oscillatory tactile cues were presented simultaneously enhanced vection intensity (Kruijff et al., 2016). In addition to visual, auditory, and tactile information in virtual reality, a study found a positive correlation between perceived scent intensity and vection intensity (Aruga, Bannai, & Seno, 2019). Therefore, future research can combine more information from multisensory modalities to examine the vection intensity in virtual reality.

Secondly, since an important indicator of virtual reality is the sense of presence, researchers usually study the role of vection in virtual reality together with the sense of presence. It was found that there is a positive correlation between the intensity of vection and the sense of presence. Specially, forward self-motion in depth was simulated in virtual reality by Oculus Rift head-mounted display. While viewing these stimuli, participants performed different sequential yaw head movements and found consistent trends in vection and sense of presence. Thus, this positive relationship also holds for a wide range of head-to-display lags. Similar results also appeared in spatial presence. The researchers also used a head-mounted display virtual environment to observe different optical flow stimuli and found that anisometropia suppression reduced both vection intensity and spatial presence (Luu et al., 2021). In addition, this positive relationship is also not affected by visual-induced motion sickness in the form of cybersickness (Kooijman et al., 2022). However, a study has also found that the intensity of vection varies with the way participants stand and float in the water in the virtual reality experience, but there is no significant difference in the sense of presence. This shows that the relationship between presence and self-motion perception is complex and may be related according to the way the participants feel (Fauville et al., 2021).

Finally, previous studies found when the spatial frequency value is too high, most participants interviewed after behavior experiments were known to be prone to motion sickness. Motion sickness (response to motion stimuli) or cybersickness (exposure to virtual reality) are also side effects of virtual reality. Previous studies have examined motion sickness through questionnaires (Keshavarz et al., 2023), such as a recent study using six short visually induced motion sickness susceptibility questionnaires and found a high correlation between motion sickness and susceptibility to motion sickness by car, migraine, and urban vertigo (Lukacova, Keshavarz, & Golding, 2023). Previous studies have found that the relationship between vection and motion sickness is complex, such as Keshavarz et al. (2015) reviewed the vection and visually induced motion sickness, found that there is vection experience without motion sickness, and it is very likely to experience vection experience at the same time when have the motion sickness. It was also found that vection may not be the direct cause of motion sickness in recent experiments (Kuiper, Bos, & Diels, 2019). The relationship between the vection and motion sickness/cybersickness may be related to the vection strength, stimuli type, and type of sensory conflicts. This was proved in other subsequent experimental studies, using the head-mounted display-based virtual reality found that cybersickness was positive with vection intensity (Anthony Teixeira, Miellet, & Palmisano, 2021); cybersickness is mainly related to vection and postural stability in the Fraser Wilcox illusions of virtual reality (Pöhlmann et al., 2020); researchers used head-mounted displays and found that cybersickness occurs when the head movement of the body does not match the perceived head movement, but the relationship between vection and motion sickness is not very strong (Palmisano, Mursic, & Kim, 2017). Additionally, a recent study showed that with rotational motion at increased rotational speeds and low linear velocities, greater vection was associated with higher levels of motion sickness. They also found that motion sickness can be suppressed by suppressing rotational speed (Matsumoto, & Zhang, 2022). Previous studies also used the vection evoked by visual stimuli presented in virtual reality to provide a reference for auditory vection and found that auditory stimuli also induced the corresponding self-motion illusion experience. And as the intensity of auditory vection increases, the severity of motion sickness also increases (Mursic, & Palmisano, 2020). Additionally, some previous studies have examined the relationship between the presence, and cybersickness simultaneously. Recently, another review paper on the relationship between cybersickness and presence found a negative correlation relationship between the two factors, meaning that as the sense of presence increased, the intensity of cybersickness decreased (Weech, Kenny, & Barnett-Cowan, 2019). The relationship between vection, presence, and motion sickness or cybersickness is more complicated, and the relationship may be different in different stimulus types and different situations, and further exploration is needed in the future.

To sum up, most of the previous studies on vection in virtual reality are low-level visual motion or depth simulation and other stimuli, and rarely use real vection-related stimuli in reality, such as the train illusion related and so on. A recent study compared train illusion-analogy stimuli and optical flow motion stimuli in virtual reality and found that optical flow motion induces a stronger vection experience (Kooijman et al., 2023). According to the train illusion example used in this experiment, there is stimulus visibility that seems relatively low, this may cause the realism of the stimulus to be compromised and so on. Similarly, in studies of presence and motion sickness, there are only a few published links to real stimuli, such as a study has found that direct airflow and indirect airflow can't affect motion sickness in simulated driving, but indirect airflow may be more comfortable (Igoshina et al., 2022). In addition, in the past, most of the vection research used virtual reality technology instead of augmented reality technology. AR can superimpose digital information on the real world and is widely used in education and navigation and so on. The effect of train illusion stimulation is not very ideal in virtual reality in the vection study, so what will be the result of combining augmented reality and real train illusion stimulation?

Based on Chapter 3's results, the future can similarly record a moving video of a train in reality and present it through Volumetric video AR technology and present it through Avatar-based AR technology. Then choose the grating stimulus used in Chapter 2 as the control condition so that we can compare the effects of train illusion analogy of these two new AR technologies and grating motion stimuli in these two technologies to induce vection. In addition, a recent study using virtual reality technology and the effects of cognitive factors (e.g., the vividness of imagination) on vection intensity found that imagery has no effect on the experience of visually induced vection (Kooijman et al., 2022). Thus, similarly, on this basis, the attention cognitive task and other cognitive processes can also add it, and the experimental conditions can refer to the parameters in Chapter 2. Then in augmented reality technology, white boxes, and red stimuli can be replaced with more realistic advertising stimuli pictures. By combining augmented reality technology with vection and attention, we can systematically investigate the cognitive relationship between motion perception and attention under more realistic conditions.

Therefore, in the future, this virtual reality technology can be combined to create a completely virtual game scene, and augmented reality technology can be used to create a virtual driving scene superimposed on the real world and so on. To examine the intensity of the participants' vection experience in different scenes and different technologies. Also, can consider the role of stimuli present way and attention in this process (Yue et al., 2017). On the one hand, trying to further clarify the relationship between vection, presence, and motion sickness, and to provide new experimental evidence for enhancing the sense of presence and reducing the experience of motion sickness in the metaverse world. On the other hand, we can also examine whether the cognitive and learning performance of participants in different virtual scenarios is better than that in real scenarios so that we can further examine the issue of whether virtual is not virtual, and provide certain data for future metaverse and other worlds support.

5) Virtual reality is a not second-class reality. The findings of this thesis open up avenues for future research to further connect and transform between the virtual and real worlds. When stimuli are presented with longer durations and higher immersion, the virtual world ceases to feel purely virtual and becomes more real to many individuals. For instance, patients who are unable to experience normal walking may perceive themselves as walking in a virtual sensory experience with extended immersion. At this point, the vection experienced in the virtual world is their perceived reality. Moreover, for patients with certain mental illnesses, the virtual world can offer a safe and relatively realistic environment for psychotherapy. Virtual reality therapy, which employs computer-generated simulations to create controlled and immersive experiences, has been applied successfully in treating various mental health conditions, including phobias, post-traumatic stress disorder (PTSD), anxiety disorders, and addiction. VR therapy's interactive and immersive nature enables clients to confront and process their fears, traumas, and anxieties in a secure and controlled setting, facilitating therapeutic progress (Emmelkamp & Meyerbröker, 2021).

Combining VR therapy with traditional psychotherapeutic techniques, such as sand play therapy, cognitive-behavioral therapy (CBT), psychodynamic therapy, or mindfulness-based approaches, can further enhance immersion and the therapeutic process. These integrative approaches leverage the benefits of innovative technologies (VR) and creative expression (sand play) along with evidence-based therapeutic modalities to cater to individual client needs and preferences. For instance, a sandbox game system based on virtual reality technology has been proposed as an alternative to traditional sandbox games, addressing issues like space requirements, accessibility, and treatment record-keeping. Users can naturally and smoothly interact with various sandbox models in multiple themed sandboxes using motion capture gloves, while switching to a first-person perspective to experience the virtual world they've created. The results of experiments with this system demonstrated participant satisfaction and improved mood (Wang et al., 2023). Another promising example is virtual reality exposure-based cognitive-behavioral therapy (VRE-CBT), which has shown therapeutic efficacy in (subclinical) anxiety disorders and may be a viable alternative to in vivo exposure in conventional CBT. Meta-analysis results indicate that VRE-CBT is as effective as CBT not only for treating normal anxiety disorders but also more severe cases. Therefore, VRE-CBT holds promise as an alternative treatment for patients with severe anxiety disorders (Van Loenen et al., 2022). Overall, the interplay between the virtual and real worlds extends beyond cognitive processes and teaching and learning. These technological advancements have far-reaching implications for mental health treatment, offering innovative and effective therapeutic tools that enhance immersion and therapeutic outcomes. As the boundaries between the virtual and real worlds continue to blur, further research in this area is crucial to fully understand the impact on human cognition, behavior, and well-being. These exciting developments will undoubtedly prompt more exploration and understanding of what constitutes the real world and how virtual and reality influence human experiences and perceptions.

Moreover, for individuals who fear certain entertainment attractions, such as roller coasters, the development of a more realistic stimulus presentation system can greatly benefit them. With such advancements, they can experience thrilling rides without the actual physical risks, allowing them to have a genuine and immersive experience. While it may seem like a distant possibility at present, one can envision a future where people can use virtual devices to travel to places like Hawaii while being in Japan. Additionally, the future can consider other illusions and also combine with vection to create a clearer and more unique and immersive world and make human beings have a more wonderful and interesting experience. Such as the Plüflich effect (depth illusion) (Pulfrich 1922), which can create and matches the era of large-screen images. Concurrently with 3D imaging technology, the resolution of images continues to improve. 8K is composed of 7680 horizontal pixels and 4320 vertical pixels, in Japan, 4K8K satellite broadcasting began in December 2018. In the private sector, 8K Cultural Heritage Viewing Solution/8K Interactive Museum is operated by Sharp Corporation. With the unprecedented advancements in image quality and resolution, is there any possible way to translate this overwhelming power of expression directly into 3D? It was might found a possibility in the Pulfrich effect. No matter how advanced video technology becomes in the future (16K, 128K, and so on), there will always be a method that is not limited by devices.

A method that allows creators to create what they want to create without any restrictions and apply a monocular filter only when they want to do so. This is the method of creating 3D image content using the Pulfrich effect. Efficient stereoscopic viewing requires ingenuity in the speed and direction of movement. The creators and the viewers should learn from each other as they accumulate the know-how to achieve this. Another advantage of Pulfrich is the right to choose 2D. With conventional 3D images, the viewer does not have the right to not pop out. If you take off your glasses in a movie theater, the image is blurred. Conversely, if you wear glasses, you cannot escape the filter's reduction in brightness. With Pulfrich imagery, the presented image is always perfect as 2D, and the viewer can choose to enjoy the stereoscopic effect of his or her own volition, without losing the right to enjoy it as 2D. It is also a methodology to realize an inclusive expression that can be enjoyed by people who can enjoy stereoscopic images as well as those who cannot, regardless of their individuality, such as ship's eyes or strabismus. Currently, video content can be produced based on the assumption that it will be viewed repeatedly. Therefore, by attaching and removing filters, people can enjoy different experiences over and over again. Because human can actively create their own unique video experience, humans can expect to have a one-of-a-kind experience and memory. Furthermore, it is extremely simple and inexpensive. The Pulfrich effect requires motion stimuli that move uniformly and mainly horizontally on a large screen. This stimulus, if the screen itself is large, induces an illusory sense of movement of the self-body, or vection, in many observers. Vection has been used extensively in films in the past at the beginning of the film with the intention of increasing immersion in the image (Tokunaga et al. 2016). Vection works well with Pulfrich and matches the era of large-screen images. In addition, the improved resolution of the screen increased the sense of realism, and a synergistic effect with the three-dimensional effect could be expected. Aoki et al. (2020) have summarized the history of vection as content, and it has been widely explored from the early days to the present, including movies, Cinerama, large-scale video exhibitions, 4DX, and so on. In recent years, it has also been used in picture books and content for rehabilitation. Since movement in the metaverse space is vection, the use of vection will become even more valuable in the future. For this reason, in future video work and the virtual reality world, researchers can consider the effective use of vection as well as Pulfrich. Thus, as mentioned by Chalmers (2017), at least virtual reality is not a second-class reality, in the future, virtual reality may be non-illusory, more real, and more useful or will be on a par with physical reality.

6) Reality becomes a choice. Psychology is a discipline that examines and comprehends sensory perception, cognition, thinking, emotions, and the body in a comprehensive manner. While the mind may seem to be divided into these components, it cannot be entirely reduced to them. In essence, the conclusion drawn from psychology is that the mind remains inscrutable. The reason for this lies in the fact that scientists, as psychologists, do not truly understand what each of these five elements of the mind ultimately represents. Scholars attempting to solve the “hard problem” of defining the mind, using language or propositions, have not emerged. However, an important fact should not be overlooked; humans have, in a sense, already resolved the “hard problem.” This resolution is an acrobatic solution, coexisting cheerfully with the mind. In the past, a shift in perspective occurred from geocentrism to heliocentrism. The earth is not stationary, but revolves around the sun. Vection was thought to bring about the inversion of subject and object, and furthermore, the unification of subject and object, creating a sense of “emptiness.” In Hegel’s words, the “Aufheben” (sublation) and the realization it brought about were both expressions of “vection.” In the future, further research on the concept and function of vection will help us to understand ourselves and the world better. The earliest description of vection has been reported by Wood in 1895, who reported that it “described a personal experience with an optical illusion in which every vibration of the swing.” In addition, this illusion also exists in some natural landscapes, such as looking up at a river or looking up at snow causes vection, so it was thought that such descriptions must have existed even earlier. In fact, there are many scenes of the shaking and movement of heaven and earth in creation myths. Myths arose from the way people in ancient times were perplexed by natural phenomena, the movement of celestial bodies, the changes of the seasons, and how they understood them. When he began to notice inexplicable natural phenomena around him, such as the shaking of the earth and the rising and falling of the sun and moon, he associated them with the gods. And described the formation of heaven and earth: light things gradually rise and become heaven, and heavy things fall down and become the ground, also shows that the concepts of god and the above are associated in the mind (Yuan, 2016). In other words, it can be pointed out that the relative position of space and its deviation have long been associated with the place of the mind. Since ancient times, clouds have often been depicted in mythology as sacred and mystical, and have been closely associated with the sky and with the gods. Clouds of various shapes and colors are often viewed as beings from the mystical realm and inspire human imagination and creativity. Sometimes clouds flow in the sky, but when you are traveling by plane or standing on a high mountain where you can see a distant view, you can see a series of large clouds like the sea in front of you. Such clouds that can be observed are called “sea of clouds” (Marzol et al., 2008). You should be able to feel vection when you look at the sea of clouds, just as you feel vection when you look at the sea or river from afar. During self-motion, the world usually appears stationary (Durgin et al., 2005). In other words, it is possible to understand that vection is an “empty” that transcends whether it is self-movement (free will) or movement of external stimuli (determinism) and integrates both. The shift in the position of the heavens and the earth that people felt, and the movement of the moon in ancient times are also moving away from us as words. Transcend time and space, move past time in your brain tens of thousands of times faster, and imagine and experience it like an image. The past is empty, in the brain, virtual. The only way to believe in the existence of the physical world is to focus on the here and now. Don’t close in on the past, don’t expect too much from the future, and carefully capture that blink of an eye.

Thus, as previously discussed in this thesis, understanding the evolution of the term "vection" could signify the transition in humanity's comprehension of the world. With humans increasingly spending time in virtual spaces like the metaverse, the adaptation to this virtual realm might lead to changes in the understanding and usage of "vection". Such changes could imply a fundamental shift in human world perception, shedding light on the transition into the information dimension. Does "vection" retain its meaning in the metaverse? Comparing the experience of sitting in a car's passenger seat to watching vection videos on a large-screen TV, one can notice the distinction in the sense of movement, or "vection", felt in the latter scenario. Meta-awareness is necessary to recognize vection as an illusion. As vection stimulation approaches reality, it loses its illusory quality, eventually becoming a mere perception of movement. The most potent vection is expected to create an environment where vection is imperceptible. In our daily walking, we do not feel vection. It is when vection reaches a certain level that it becomes a true representation of movement.

The term "vection" has undergone an expansion in its definitions over time. Initially, it referred to the illusion of bodily movement induced by visual stimuli. However, scholars soon proposed that it could extend beyond visual stimulation. For example, reports emerged suggesting that rotation sounds or sounds implying straight motion could also induce vection, leading to the concept of auditory vection. Furthermore, categorizing vection solely as an illusion became challenging. For instance, when a subject stands on a treadmill and observes diffusing dots, they experience a sensation of forward movement. Determining whether this sensation qualifies as an illusion or a genuine experience becomes a complex question. Individual differences also play a significant role in the perception of vection. As a result, the term "vection" began to evolve during the 2010s, gradually shedding its constraint of being strictly an illusion.

By 2022, “vection” can be considered nearly synonymous with the term “self-motion”. When experiencing vection in the metaverse, individuals recognize it as a “lie” concerning the virtual space and the movement within it. If vection experienced in the metaverse diminishes over time, it could suggest that the virtual space is becoming more realistic, potentially indicating the embodiment of avatars in that space. This ongoing transformation in the understanding of vection marks a significant aspect of our evolving relationship with virtual environments and technology.

If it is possible to record the process of human beings changing and updating their understanding of the word vection, human beings can also record the changes in their understanding of the relationship between the self-subjective world and the objective world. The subjective world and the objective world were considered to be opposites by human beings before, but one concept that has been consistently considered in the East since ancient times is subject-object unity. Nomura (2007) makes a comparison, saying, ‘In the West, traditionally, the separation of subject and object, in which the self is separated from the world that confronts it, has been accepted, while in the East, the aim has been to unite the self and the world’. This difference has created a big difference in culture and has had a great impact on the field of psychology. It seems that this is also the reason why psychology has been built up based on natural scientific models. However, as far as looking at the changes in the definition of vection’s words, it is not possible to capture the human experience completely in the state of subject-object separation. That is why researchers would like to challenge a new psychological way of thinking by capturing this change in words now. This way of thinking itself is by no means new. This indicates an attempt to overcome Descartes' mind-body dualism, aiming for a state of “I think, therefore I am not.” Nishida (2007) explored self-consciousness by regarding the state before the separation of subject and object as pure experience and investigated the relationship between the self and the world from that perspective. Gibson (2008) proposed the concept of affordances from the field of ecological psychology, demonstrating that intention and action are inherently inseparable. Can vection and illusions, in general, have pure experiences? For example, the Rotating Snakes illusion creates an impression of movement. When we perceive and understand this as an illusion, it requires metacognition, acknowledging that “the actual external world is stationary,” and denying the brain’s presentation of movement. Without this attitude, the illusion loses its intrigue.

If pure experience perceives visual illusions and only extracts motion, it cannot be considered an illusion. It would be perceived as ordinary visual motion perception. However, could the process of recognizing and correcting perception be included within the realm of pure experience? For vection to occur, it must be understood as an illusion. If it does not qualify as an illusion, it cannot be called vection. “But aren't you feeling it before it becomes like that? The joy of vection.” This is intuition, and it is correct. Vection can be part of pure experience. Even complex stimuli like vection, the brain already knows them beforehand. The brain has already accepted them. Acknowledging the domination of the black box and refraining from anticipating outcomes—that is, illusions exist before the recognition of being illusions. Ultimately, psychology is nothing more than the reconstruction of the black box's movements into interpretable language and chronological order, forming post hoc theories. Even under the premise of metacognition as an illusion, it would be mere wordplay before the black box. Illusions are not just illusions, and the brain is not deceived. The brain knows and accepts everything beforehand. Humans cannot deceive the sun, the sky, or the ground. The brain is a part of nature. Moreover, the possibility that our physical bodies, as entities in the physical space (referred to as the real world), could be someone’s avatar in a VR game cannot be ruled out. The player in that game might find it ridiculous to consider those avatars as real bodies. Just as humans perceive Dhalsim's elongated limbs in Street Fighter II as unreal and laughable. From the moment humans were born, humans have been wearing an HMD (head-mounted display) that humans cannot remove, and humans are existing in a world of lies presented to us. Now, by obtaining a space one level down, namely the metaverse space, it is on the verge of being validated. If this is the case, questions such as "Do humans need bodies? Do humans need things?" might transform into "Do humans need to remain in this level of reality?" Reality becomes a choice, and what we perceive as real is determined by our own beliefs. The world we experience is shaped by the reality we choose for our past, present, and future. Therefore, which world is more real at the moment, the human subjective world or the physical objective world, depends on the interaction between human cognition and the physical world.

Appendix

Chapter 3: English version of teaching content and after-course survey questionnaire.

1. Course record video (English): Hello, everyone. I am Takeharu Seno, associate professor of psychology at the Kyushu University Graduate School of Design **(in order to avoid the influence of the location on the teaching effect, face-to-face group of the teacher reported this location: Graduate School of humanities, Seinan Gakuin University, the other three groups are all the same Kyushu University).** Today, please allow me to use about five minutes to make a speech, and please enlighten me. I think mind is a very magical thing, and also consciousness is a very magical thing. In the latest psychological research, there is a tendency to negate the existence of consciousness. Now please try to raise your right hand and put it down. Even though it was my request to do it, wasn't it your own consciousness that guided it? In fact, I did the same thing, and in the process, there was an experiment that demonstrated this behavioral processing. This was discovered by Benjamin Libet, and in his experiments, participants wore electrodes that measured brain waves and raised their hands when they saw a favorite stimulus. Specifically, participants were presented with a special clock running in front of them, and they could raise their hands at their favorite time. During this process, they consciously observed the clock and then remembered it. At the same time, brain waves are also being tested. When the body moves, there is a kind of preparation potential that can promote the appearance of brain waves. When this brain wave appears, it can be accurately detected. Finally, the device can detect when the wrist is actually moving. Therefore, we can see that there are three steps in the

process. First, consciousness is generated, then the brain starts to operate based on this consciousness, and the preparation potential appears. Finally, according to this preparation potential, the wrist is lifted. This is what we generally think of as the correct processing sequence. In Benjamin Libet's experiment, consciousness was generated 0.5 seconds before the wrist was lifted, and brain waves were generated 0.2 seconds before conscious processing. Thus, the correct sequence is brain preparation, then awareness, and then hands up. Consciousness can only happen after the brain processes it. Mental is really an inscrutable thing. Although brain science research has made progress in the past 100 years, there are still many rules that have not been found. For example, when you see a red apple, only you can feel the degree of red. When you see something red, red, it's a sensory object, it's also called "Qualia". What exactly is Qualia? It's not clear yet. While the biological structure of the brain is being processed in the objective physical world, the subjective world is unknown. Other things like what I am, where consciousness comes from, and what kind of creature has consciousness, are still unknown. These unsolvable, difficult problems remain, named of "Hard problem" by David Charmers. What is "Hard problem"? In 1995, David Charmers proposed that in the absence of an answer to these questions, science has moved on. The mind is a very complicated and interesting thing, and if you find anything interesting for just the five minutes, I will be very happy. Thank you for listening.

2. Questionnaire (English) (three VAR, AAR, and Zoom group, **face-to-face group)**

Since the third group was face to face, the expressions of some questions were modified and marked in blue in the questionnaire.

Appendix

1. This experiment does not measure an individual's ability. There are no particular risks, disadvantages, pains or side effects in the experiment. You can quit at any time after agreeing. Information that is tagged with personal data and personal information, and does not use data. Your privacy is protected. If you do not agree, you will not be disadvantaged. If you understand the above and agree to become a subject, please proceed to the next page.

   Please enter your name. Please be sure not to abbreviate it with your real name.
2. Please state your age. Please be sure to enter the correct age.
3. Your sex: 1) Male; 2) Female; 3) Other.
4. Do you agree with the experiment? 1) Yes, I agree to participate this experiment.

   2) No, I do not agree and will not participate in the experiment.

Part 1: Course content confirmation test. Please select and answer the following questions. **(The correct answers to each of the following questions (5-14) have been marked in bold black.)**

5. Where did you say that the person who gave the lecture belonged to?

   1) Kyushu Sangyo University Graduate School of Design. **2) Kyushu University Graduate School of Design.** 3) Seinan Gakuin University Graduate School of Design. 4) Kyushu Sangyo University Faculty of Humanities. 5) Kyushu University Faculty of Humanities. **6) Graduate School of humanities, Seinan Gakuin University (this is the correct answer for face-to-face group).**
6. What is the name of the person who gave the lecture?

   1) Inou Takaharu 2) Inou Takafumi 3) Seno Takaharu **4) Seno Takeharu**

5) Kanou Takashi

7. What was the identity of the person who gave the lecture?

   1) Professor **2) Associate Professor** 3) Teaching assistant 4) Assistant 5) researcher 6) Student

8. Which is the correct order?

   1) Brain activity → Volition → Action 2) Action → Volition → Brain activity 3) Volition → Brain activity → Action 4) Action → Brain activity → Volition

   5) Brain activity → Action → Volition

9. What was the name of the psychologist who conducted the experiment to deny free will?

   1) Rivet Batson **2) Benjamin Libet** 3) Liberty Cart 4) Benjamin Button

10. Who is the proponent of the hard problem?

    1) Donald Ferguson 2) Daniel Emerson **3) David Chalmers** 4) Charles David

11. What do you call the texture of the senses that only you can see? **(Qualia)**

12. What was the color of the shirt the teacher wore?

    1) Azury 2) White **3) Green** 4) Black

13. What was the color of the tie that the teacher wore?

    1) grey 2) Azury 3) Yellow 4) Black **5) White**

14. What was the teacher's hairstyle?

    1) It was flowing to the right 2) It was flowing to the left **3) Other (this is correct for AAR group)**

Appendix

Part 2: We will evaluate the psychology of the lessons you have taken. Please answer as an overall impression including the class itself and how to present it. Please answer without omission. Thank you.

15. Fun of this course:

    1) I couldn't enjoy it at all 2) not enjoying it 3) moderate 4) relatively enjoyable 5) I enjoyed it very much (Among them, 2-4 were not explicitly written down, but participants were told that the higher the score, the more interesting and active the class was, the following questions were similar).

16. The course novelty:

    1) It wasn't a completely new experience 2) was not a new experience 3) moderate 4) relatively new experience 5) It was a very new experience

17. The course satisfaction:

    1) I wasn't satisfied at all 2) was not satisfy 3) moderate satisfy 4) relatively satisfy 5) I was very satisfied

18. Quality of communication:

    1) I couldn't communicate very well 2) was not communicate well 3) moderate communicate 4) relatively good communication 5) I was able to communicate very smoothly

19. The surprise of course:

    1) I wasn't surprised 2) was not surprised 3) moderate surprised 4) relatively surprised 5) I was very surprised

20. 3D feeling of the teacher **(face-to-face group: As you think he is an image)**

    1) Was flat 2) was not flat 3) moderate 3D **(image)** 4) relatively 3D **(image)** 5) It was three-dimensional

21. A sensed presence:

1) There was no high sense of presence or immersion 2) was no presence 3) moderate sense of presence 4) relatively sense of presence 5) The sense of presence and immersive was very high

22. Do you want to take it again?

1) I don't want to take this course anymore 2) want not to take this course 3) moderate 4) relatively want to take this course 5) I want to take it again very much

23. Speak voice quality:

1) The voice was hard to hear 2) voice was not easy to hear 3) moderate 4) relatively was easy to hear 5) The voice was very easy to hear

24. Speak video or **(face-to-face group: figure quality as you think he is an image):**

1) The video **(figure)** was hard to see 2) video **(figure)** was not easy to see 3) moderate 4) relatively was easy to see 5) The video **(figure)** was very easy to see

25. Impression of the teacher:

1) Was very bad impression 2) was bad impression 3) moderate 4) relatively was good impression 5) Was very good impression

26. The charm of the teacher:

1) It wasn't attractive at all 2) was not attractive 3) moderate 4) relatively was attractive 5) Was very attractive

27. I will ask you about you. Are you familiar with VAR and AAR?

1) I don't know at all 2) I don’t know 3) moderate 4) I know a little 5) I know very much

28. I will ask you about you. Are you familiar with psychology?

1) I don't know at all 2) I don’t know 3) moderate 4) I know a little 5) I know very much

29. Did you know the teacher, Takeharu Seno?

1) I know well 2) I only know the name of teacher 3) I don't know at all

30. If you have any thoughts or impressions at the end, please feel free to write them (This question is optional and is not mandatory. All the other questions are mandatory).

That's all for the questionnaire. Thank you very much.

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Publications

A. Publications

1. **Guo, X.R.*,** Morimoto, Y., Seno, T.*, Ohata, L., & Palmisano, S. (2023). Evidence of exogenous shifts in spatial attention produced by vection. Cognition (Under Review).

2. **Guo, X.R.***, Yoshinaga, T., Hilton, A., Harumoto, S., Hilton, E., Ono, S., Seno, T.*, (2022) The Sense of Presence between Volumetric-Video and Avatar-Based Augmented Reality and Physical-Zoom Teaching Activities. PRESENCE: Virtual and Augmented Reality. https://doi.org/10.1162/pres_a_00351

3. Fu, J.#, **Guo. X.R.# (co-first authors)**, Tang. X.Y.*, Wang. A.J., Zhang. M., Gao. Y.L., Seno. T., (2021). The Effects of Bilateral and Ipsilateral Auditory Stimuli on the Subcomponents of Visual Attention. i-Perception,12(6), 1-19. https://doi.org/10.1177/20416695211058222

B. Oral Presentations in Conferences

1. **Guo, X.R.*,** Morimoto, Y., Seno, T., Palmisano, S. (2022.8) Does the degree of abstraction in a video stimulus alter the experience of vection? Fechner Day 2022, International Society for Psychophysics, Lund, Sweden (In-person oral presentation).

2. **Guo, X.R.***, Yoshinaga, T., Hilton, A., Harumoto, S., Hilton, E., Ono, S., Seno, T.*, (2021.8) Psychology teaching by using Volumetric video augmented reality and Avatar based augmented reality technology is more presence and attractive than those by Face to face and Zoom. Technical Meeting on Institute of Perceptual Information, IEEE, Japan (Online oral presentation).

3. 井藤駆, 妹尾武治, **Xuanru Guo,** 村田佳代子, 森将輝, 森田磨里絵, 藤井芳孝, & 分部利紘. (2021, March). オンラインベクション実験アプリその開発と評価. In

電気学会研究会資料. PI= The papers of Technical Meeting on" Perception Information", IEE Japan, /知覚情報研究会 [編] (Vol. 2021, No. 19-25・27-30, pp. 7-12). 電気学会.

C. Poster Presentations in Conferences

1. **Guo, X.R.***, Seno, T., Palmisano, S. (2023.5) (Expect) Exogenous spatial attention shift induced by up and down vection direction. Vision Sciences Society 2023.
2. **Guo, X.R.***, Morimoto, Y., Seno, T., Ohata, L., Palmisano, S. (2022.6) Vection can serve as a cue for exogenous spatial attention. Vision Sciences Society 2022 (online poster).
3. **Guo, X.R.***, Nakamura, S., Fujii, Y., Seno, T.*, & Palmisano, S. (2021.8) Vection depends on the average luminance, luminance contrast, and the spatial frequency of the stimulus. 43rd European Conference on Visual Perception (Online poster).
4. Nishimi, A., Suzuki, W., **Guo, X.R.,** Takeichi, H., Nakamura, S., Seno, T., ... & Palmisano, S. (2022). The additive effects of the two types of oscillation on vection. Journal of Vision, 22(14), 3399-3399.

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