THE STRATEGY EFFECT

The effect of the encoding strategy on the representation of memory content between the cerebral hemisphere:

A replication study (part II)

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Abstract

Title: The effect of the encoding strategy on the representation of memory content between the cerebral hemisphere: A replication study (part II)

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Despite the well-established knowledge about functional specialization between the brain's hemispheres, the consequences for specific cognitive processes remain unclear. Regarding memory, it has been proposed that the enhancement of memory retrieval through visual imagery may be attributed to the additional engagement of right hemispheric visuospatial processing mechanisms, in addition to the left hemispheric language mechanisms. Thus, directly linking Paivio's dual-coding theory of associative learning to hemispheric specialization. This claim was supported by the findings of an early behavioral study by Seamon and Gazzaniga (1973), which demonstrated that the instruction to engage in visual imagery (as opposed to verbal rehearsal) during encoding of words would lead to a left visual field (or right hemisphere) response time advantage in later recognition of a drawing representing the word. However, the study included only six participants, and previous replication studies have yielded inconsistent results. The aim of the present study was to conceptually replicate the findings of Seamon and Gazzaniga with sufficient test power and by considering possible moderator variables. The experiment consisted of trials presenting the participant with two written concrete nouns (e.g., jar, pigeon), either with the instruction to silently repeat (verbal rehearsal) the two words or to form a mental image of the two named objects interacting with each other (mental imagery). After a delay, a drawing was tachistoscopically presented to either the left or the right hemifield with the instruction to indicate, by pressing the correct button, whether the drawing represented one of the words previously presented. The present study found the predicted significant interaction of Condition and Hemifield. Post-hoc testing confirmed a significant left visual field advantage for the mental imagery, but a right visual field advantage for the verbal rehearsal was not found. Thus, the present study replicates the original findings, although with a small effect size. Moreover, the study may be taken to suggest that the beneficial effect of visual imagery on memory performance is indeed dependent on an additional engagement of the right hemisphere during encoding. In this, it provides an example of how hemispheric specialization supports cognitive functions such as memory encoding.

Table of Contents

The effect of the encoding strategy on the representation of memory content between the cerebral hemisphere: A replication study (part II)

Hemispheric Lateralization

The human cerebrum is characterized by its asymmetry, consisting of separate hemispheres with different specialized functions (Gutwinski et al., 2011). Evolutionary theories propose that the typical pattern of lateralization exists due to the cognitive advantage it provides (Quin-Conroy et al., 2024). This proposed pattern of laterality may provide an explanation for the dominance of the left hemisphere for language processing complementing the right hemisphere's specialization in visuospatial processing (Gazzaniga, 2005; Quin-Conroy et al., 2024). Language lateralization is considered the most extensively researched and prominent example of functional lateralization in humans (Quin-Conroy et al., 2024), and approximately 90% of healthy individuals exhibit left hemisphere dominance for language (Tzourio-Mazoyer et al., 2017). Nevertheless, it should be noted that the left lateralization of language is not necessarily universal (Quin-Conroy et al., 2024). One important aspect associated with language dominance is handedness, with left-handedness being related to a higher probability of right hemisphere language dominance (Knecht et al., 2000). Knecht and their team (2000) discovered a reliable and nearly linear relationship between the level of handedness and the orientation of language dominance. Furthermore, in the majority of individuals, the visuospatial functions are predominantly right hemisphere localized (Quin-Conroy et al., 2024). Visuospatial processes refer to the ability to comprehend and recognize visual and spatial information, and play a part in the formation and manipulation of mental images (Ehrlichman & Barrett, 1983; Quin-Conroy et al., 2024). However, handedness has not been found to be related to a higher probability of visuospatial processing being left hemisphere lateralized (Marzi et al., 1988).

The present study aimed to replicate the findings of Seamon and Gazzaniga (1973) of the Strategy Effect. This effect highlights the importance of utilizing encoding strategies aligning with the specialized functions of each hemisphere for effective memory performance (Seamon & Gazzaniga, 1973). Additionally, the original study built upon Paivio's (1969) theory of Dual Coding, which aimed to enhance the comprehension of memory encoding by taking brain lateralization into consideration. Indicating that cognition is composed of two distinct systems (nonverbal and verbal), and that memory can be enhanced by simultaneously utilizing both systems. Therefore, the utilization of both visuospatial processing and language processing during encoding promotes the creation of two distinct memory codes (engaging the left and right hemispheres simultaneously), enhancing the ability to store and retrieve information (Paivio & Csapo, 1973). Through a series of discoveries, the comprehension of the specialized functions of the hemispheres has gradually developed over time. Furthermore, the present study seeks to provide more insight into the relationship between functional laterality and cognitive processes, specifically by including memory performance.

The Evolution of Studies on Hemispheric Lateralization

Broca (1861) was a pioneering scientist who significantly enhanced the comprehension of localization of function in the brain, mainly in the domain of speech production. One of his articles famously ended with the statement: “We speak with the left hemisphere” (Broca, 1861). The insights gained, as a result of Broca’s research, marked the onset of cerebral asymmetry research. Later, Wernicke (1874) discovered that expressive and receptive language were differently localized within the left hemisphere, and that they should be distinguished (Güntürkün, 2020). He clarified this issue by differentiating between what is now called Broca’s area and Wernicke’s area in the brain (Wernicke, 1874). Broca (1861) and Wernicke’s (1874) findings indicated that asymmetries of brain and function exist in humans (Güntürkün, 2020). Moreover, Hughlings-Jackson (1874) proposed a complementary role for the right hemisphere. Indicating a right hemispheric specialization for visuospatial functions (Hughlings-Jackson, 1974; Harris, 1999). These statements, together, paved the way for the idea that the left and right hemispheres of the brain possess different roles in cognitive processes (Harris, 1999).

The split-brain studies conducted by Sperry (1961) are widely recognized as one of the most renowned methods to investigate functional asymmetry between the hemispheres (Gazzaniga, 2005). Sperry (1961) was one of the researchers that utilized this technique at an early stage. Through these experiments, he discovered that the hemispheres ceased to interact and communicate with each other following a split-brain procedure, which further sparked his curiosity about the distinct functioning of the hemispheres (Sperry, 1961). A researcher who worked closely with Sperry on the split-brain studies was Gazzaniga (Sperry, 1961; Sperry, 1964; Gazzaniga, 2005). Later, he continued to develop and advance the research of hemispheric asymmetry, to reveal the complexities of callosal disconnection (Gazzaniga, 2005).

The split-brain studies are named after the surgical procedure the participants underwent prior to participating (corpus callosotomy). Corpus callosotomy involves a longitudinal incision down the middle of the brain to separate the hemispheres. The corpus callosum, which is the main connecting link between the hemispheres, is the principal structure that is severed during the procedure (Gazzaniga, 2005). According to Sperry (1961), the significant location and size of this structure indicated its crucial involvement in the brain's correct functioning (Sperry, 1964). Therefore, he wanted to further investigate the consequences of disconnection between the hemispheres after a split-brain procedure.

In order to examine the consequences of disconnection, Sperry and Gazzaniga carefully designed tests to specifically control which hemisphere information was relayed to, by monitoring the information presented in each of the visual hemifields (Gazzaniga, 2005; Sperry, 1964; Lienhard, 2017). One of the tests involved presenting a word exclusively to either the left visual field (LVF/right hemisphere), or the right visual field (RVF/left hemisphere) of the participant. This was achieved by having the participant look at a white screen, directing their attention to a black dot in the middle. A word would then appear on either the right or the left side of the dot (a specific visual hemifield). Notably, the participants were only able to recall the word presented to their RVF (processed by the left hemisphere). The explanation for these findings is that the left hemisphere of the brain processed the word, allowing the participants to verbally articulate what they saw. Conversely, when a word was presented to the LVF, and therefore processed by the right hemisphere, it resulted in an inability to articulate the perceived word. Sperry and Gazzaniga’s findings align with previous research, emphasizing a left hemispheric specialization for language (Sperry, 1982; Lienhard, 2017). Further, additional tests on split-brain patients were conducted. Another test involved presenting participants with two different objects in each of the visual fields, simultaneously. The results revealed that participants were able to effectively use language to describe the objects viewed in their RVF, yet they struggled to articulate what they had seen in the LVF. However, when asked to draw the objects they had perceived, participants could only reproduce those seen in their LVF, and not in their RVF. Consistent with the results of the test mentioned earlier, results yielded evidence for left hemispheric specialization for articulating and recognizing language, while the right hemisphere showed no evidence of this ability (Lienhard, 2017). Sperry and Gazzaniga's split-brain experiments were crucial in expanding the understanding of hemispheric specialization of function. Furthermore, they paved the way for future research on hemispheric lateralization (Roser et al., 2011).

Methods: Functional Lateralization

Following the split-brain studies, various methods have been utilized to research the difference in functioning between the hemispheres through the years. One method is the mental rotation task, which aims to further understand the visuospatial advantage of the right hemisphere (Roser et al., 2011). The mental rotation task requires participants to construct a mental image of a presented stimulus, mentally manipulate (turn, twist, rotate) the image, and match the image to a presented standard (Bricolo et al., 2000; Ditunno & Mann, 1990; Tomasino et al., 2003).

Corballis and Sergent (1988) conducted an experiment with several tasks, involving imagery and mental rotation on a split-brain patient. The participant was presented with a series of images or letters that flashed tachistoscopically to either the right or the left visual hemifield. The stimuli were either rotated or in their original orientation when presented and the participants' task was to identify the orientation of the stimuli (Corballis & Sergent, 1988). Corballis and Sergent (1988) found a strong LVF advantage in accuracy and response times on the task involving mental rotation on letters and stick figures, and concluded that this provided strong evidence for an advantage in mental rotation in the right hemisphere. Similarly, Ditunno and Mann (1990) conducted a mental rotation experiment that also found a LVF advantage in response times and accuracy. Based on the results, they concluded that a significant right hemisphere advantage for visuospatial processing was obtained (Ditunno & Mann, 1990). However, Corballis and Sergent (1989) conducted another mental rotation study, this time with written language as the stimulus. They found evidence for an RVF advantage in the mental rotation tasks, but explained this with the knowledge of the left hemispheric advantage for written language (Corballis & Sergent, 1989). Bricolo and their team (2000) conducted a mental rotation study on the spatial processing abilities of a patient with a right perisylvian lesion. The patient had no difficulty performing the object recognition task, but was impaired in the visuospatial task, due to the inability to mentally manipulate the objects. The results suggest that the deficit was selective to the rotational operation (Bricolo et al., 2000).

The research utilizing the mental rotation method has encompassed not only external objects, but also other processes. Tomasino and colleagues (2003) conducted a study using mental rotation of external objects in addition to mental rotation of body parts, to investigate whether they could be doubly dissociated. The participants (N=20; N=9 with unilateral lesions: 5 in the left hemisphere, 4 in the right hemisphere) performed one task involving the mental rotation of hands, and two tasks involving mental rotation of external objects. The results indicated that the participants with a lesion in the right hemisphere were impaired in the rotation of external objects, but showed intact performance on the rotation of hands. However, participants with lesions in the left hemisphere exhibited the opposite pattern. Similarly to the studies mentioned earlier, Tomasino and their team's (2003) results support earlier findings on the right hemispheres specialization for the mental rotation of external objects. However, their results suggest that the ability to mentally rotate body parts was functionally separate from the ability to rotate external objects (Tomasino et al., 2003).

Furthermore, the development of advanced brain imaging techniques has revealed a more complex and dynamic understanding of how the corpus callosum functions, as well as how it contributes to a better understanding of hemispheric lateralization (Gazzaniga, 2005). One of the imaging techniques is functional magnetic resonance imaging (fMRI). Kokkinos and Seimenis (2024) conducted an experiment investigating whether verbal memory fMRI tasks were effective in determining the lateralization of verbal memory processing. They also investigated whether verbal memory lateralization should be mapped independently from language lateralization (Kokkinos & Seimenis, 2024). Participants (all having temporal lobe epilepsy) underwent verbal memory, language, and visuospatial fMRI tasks. The results indicated an association between language and verbal memory lateralization. Kokkinos and Seimenis (2024) concluded that the evidence supported that verbal memory tasks could be localized in conjunction with language, as well as utilized in a presurgical evaluation of language lateralization. Additionally, a study by Okahara and colleagues (2024) also investigated language lateralization, and the focus of the study was the assessment of language lateralization and speech comprehension. Moreover, they wanted to evaluate the efficacy of passive narrative-listening tasks using fMRI as an alternative to already existing methods. Current methods include language production and language comprehension tasks. However, these are active paradigms that are less suitable for younger children and developmentally disabled participants; requiring participants to respond to speech sounds or understand verbal instructions. Okahara and colleagues (2024), therefore, conducted an experiment (N=21, N=6 with intellectual disabilities) comprising of a task with two conditions: the first condition (forward narrative & no voice) alternated between an 80-second narrating audio clip and control segments with no auditory stimuli, and the second condition (forward narrative & time-reversed) alternated between an 80-second narrating audio clip and control segments where the preceding narrative audio clip was played in reverse. Similarly to Kokkinos and Seimenis (2024), the evidence from the passive narrative-listening showed that the paradigm could provide safe and easy presurgical language localization, particularly for individuals who may not readily engage in active paradigms (Okahara et al., 2024).

Schmidbauer and colleagues (2022) also conducted an fMRI experiment, but with the aim of assessing visuospatial memory functions and memory-related networks. The task was based on a visuospatial memory paradigm and performed in a block design: alternating between activation phases and resting phases. Participants (all with temporal lobe epilepsy) were instructed to mentally navigate in a familiar environment and to remember as many details as possible during the activation phase. However, during the resting phase, participants were asked to stop the mental navigation, and to only continue from the point they stopped when the next activation phase began. Schmidbauer and their team (2022) found evidence for their paradigm being able to localize visuospatial memory functions.

Furthermore, another fMRI study, conducted by Floegal and Kell (2017) investigated the hemispheric asymmetries in brain activation between temporal and spatial processing demands in visuomotor processing. During the experiment, participants operated two vertically movable cursors in the middle of a screen (one with each hand) by applying grip force. The same screen also presented two inward-moving lines (one from left to right, the other from right to left), and the task involved moving the cursor so it would follow the trajectory of the inward-moving lines; applying pressure when ascending and removing pressure when descending. The experiment had three experimental conditions that changed the trajectory of the inward-moving lines. Floegal and Kell (2017) found evidence for a right hemispheric dominance in perceptual analyses supporting the planning of spatial movement features, whereas the left hemisphere showed dominance in movement timing indicated by visual cues.

Even though new neuroimaging paradigms have proven useful in assessing hemispheric lateralization, the split-brain method is still utilized in combination with newer technology. D'Alberto with their team (2017) investigated the difference in inhibitory capabilities between the hemispheres, utilizing fMRI combined with a split-brain patient. The results of three different inhibitory control tasks showed evidence for a superior inhibitory ability in the right hemisphere compared to the left hemisphere on all three tasks. Both hemispheres were capable of response inhibition, however, with the right hemisphere demonstrating a higher success rate (D'Alberto et al., 2017).

Cutting-edge technologies like Virtual Reality (VR) are being utilized in experimental research related to lateralization studies. This has, and continues to, develop new possibilities for various applications in research (Sokolowska, 2021). This is because it provides an excellent tool for investigating cognitive processes, behavior, and mental states in intricate, but controlled, scenarios (Klotzsche et al., 2023). One researcher who has utilized VR as a method is Sokolowska (2021). Their experiment was conducted with the aim of using VR techniques to investigate the distribution of motor functions between the left and right sides of the body. The participants were healthy right-handed adults. Sokolowska's (2021) findings indicate that the VR assessment effectively detected and evaluated functional differences between the left and right sides of the body. Moreover, they concluded that VR not only was useful for identifying the lateralization of function, but also for assessing the performance of healthy individuals (Sokolowska, 2021).

The literature's findings on hemispheric asymmetry provide a valuable understanding of the intricate functioning of the human cerebrum. However, this study seeks to further the understanding of the impact of functional lateralization on cognitive processes – by building upon already existing research.

Theoretical Groundwork

Theories on dual coding commenced in the 1960s (Paivio, 2014), and among these theories was Paivio's Dual Coding Theory (1969). Dual Coding Theory posits that cognition is composed of two distinct systems: a nonverbal system, which processes information unrelated to language (e.g., objects and events), and a verbal system, which processes language-related information (Paivio & Clark, 2006). Furthermore, it indicates a memory enhancement through the use of visual imagery in conjunction with verbal repetition. This is due to visual imagery generating an additional memory code, thereby increasing the capacity for storing and retrieving information (Paivio & Csapo, 1973). Paivio's theory (1969) developed from studies on the impact of mental images on learning associations (Paivio, 1991). However, it later explored the importance of nonverbal imagery and language in understanding associations, memory, and the role of mental images as intermediaries (Paivio, 1969). Paivio (1969) employed objective methods to assess imagery, which was then linked to memory performance and additional tasks. The methods consisted of evaluating the capacity of language structures and words to elicit mental images, using techniques to either promote or hinder the utilization of imagery, and measuring individual differences in imagery proficiency (Paivio, 1991). According to Clark and Paivio (1991), the generation of mental images resulted in superior memory performance compared to repeated encoding conditions (repetition of the target words). Paivio (1969) concluded with the existence of different modes of thought, and that verbal and visual information codes could be conceptualized like this. Later, in 1973, Seamon and Gazzaniga postulated the Dual Coding Theory in their research on the effect of encoding strategy on hemispheric specialization.

Replication Study

Seamon and Gazzaniga (1973) aimed to further investigate whether different encoding strategies (verbal or visual) would lead to distinct brain activity patterns between the left and right hemispheres. Specifically, seeking to determine if the left hemisphere would process verbal information faster than the right hemisphere, while the right hemisphere would process visual information faster than the left hemisphere in a recognition task (Seamon & Gazzaniga, 1973).

Seamon & Gazzaniga (1973) conducted an experiment utilizing a short-term recognition memory task, involving right-handed and English-speaking participants (N=6). The participants attended two separate sessions (one week apart). At the beginning of each session, the participants were given specific instructions on what coding strategy they would be utilizing throughout that session. The two coding strategies were relational imagery and verbal rehearsal. Participants were randomly assigned to two groups: one group started with relational imagery and the other group with verbal rehearsal. All participants were exposed to both coding strategies. The task involved two English nouns that were presented horizontally on a screen for 7.5 seconds, followed by a blank period for 2.5 seconds. The participants then got an auditory warning signal, followed by a recognition memory probe, presented to one of the visual hemifields for 100 milliseconds. Participants were instructed to answer “YES” or “NO” by pressing the respective button, to indicate whether the displayed image matched a word from the study set. They were instructed to respond as quickly and accurately as possible (Seamon & Gazzaniga, 1973).

During the verbal rehearsal strategy, participants were instructed to repeat the two study words silently and continuously to themselves throughout their presentation and the blank period before the auditory warning signal. However, during the relational imagery strategy, participants were asked to create a mental image of each of the two words in the study, and then combine them into a single, interconnected scene. They were instructed to hold the mental image in their mind by concentrating on it up until the auditory warning signal. When the probes were presented, in both conditions, the participants were instructed to indicate if the picture probe represented one of the two words in the study set (Seamon & Gazzaniga, 1973).

Seamon and Gazzaniga (1973) found a clear effect on response times between the two coding strategies (Plot of interaction effect in Appendix A). For the right hemisphere, response times were faster than the left hemisphere, when participants were using the relational imagery coding strategy. However, response times for the left hemisphere were faster than the right hemisphere, when using the verbal rehearsal coding strategy. Finally, their results showed faster response times overall during the relational imagery encoding condition (Table 1).

According to the results of the analysis of variance (ANOVA) conducted by Seamon and Gazzaniga (1973), the interaction between Condition and Hemisphere accounted for 67% (partial η^2) of the variance observed in the data.

Table 1:

Seamon & Gazzaniga's (1973) findings.

Condition	N	Hemisphere	
		Left	*Right*
Mental imagery	6	.*55* (.078)	.*53* (.080)
Verbal rehearsal	6	.*60* (.059)	.*63* (.059)

Note: Means and Standard Deviations of Reaction Times (in seconds) for each Condition and Hemisphere. From 6 participants (N). Results are presented as mean (*SD*).

The significant results of the interaction of coding strategy and hemisphere supported Seamon and Gazzaniga's (1973) hypothesis; that each hemisphere would exhibit faster response times and more accurate recall when words were encoded utilizing methods aligned with their respective functions. They further concluded that the interaction of coding strategy and hemisphere suggests that participants treated the information in a visually coded way for the relational image coding strategy, and in a verbally coded way for the verbal rehearsal coding strategy (Seamon & Gazzaniga, 1973).

Seamon and Gazzaniga (1973) discussed different models when discussing their findings. The first model they discussed was a model explaining the interhemispheric transfer delay when probes were presented in the inappropriate hemisphere. Therefore, producing prolonged response times due to the interhemispheric transfer time required. This type of model is called a callosal-relay model (Zaidel et al., 1990). However, this model was dependent on the assumption that visually and verbally encoded information was exclusively processed in either the left or the right hemispheres during the task. The second model discussed involved the possibility that each hemisphere could be able to process both information codes, and that the hemispheres may simply process certain types of information codes more quickly. Moreover, the differences found in the response times would then be a reflection of the difference in efficacy between the hemispheres, for both verbal and visual information. This type of model is called a direct-access model (Zaidel et al., 1990). According to this model, the left hemisphere processes verbal information faster than the right, while the right hemisphere processes visual information faster than the left. The last model demonstrated how variations in the response times may be a result of the coding strategy employed. The verbal rehearsal instruction provided only a verbal code, whereas relational imagery instruction provided both a verbal and visual code. Due to the fact that the initial presentation of stimuli in the relational imagery condition consisted of words. Therefore, the difference in response times observed in subjects during the verbal rehearsal condition may potentially indicate interhemispheric transfer, as visual probes presented to the right hemisphere needed to be transferred to the left hemisphere before a response could be provided. However, during the relational imagery condition, both hemispheres would be actively engaged and the specific hemisphere that was presented with the image would not have any impact on the response times (Seamon & Gazzaniga, 1973). This model also coincides with the Dual Coding Theory by Paivio (1969), which posits that information could be stored in two distinct formats simultaneously: verbal and visual.

Seamon and Gazzaniga (1973) found a functional relation between laterality effects and coding strategies. Consistent with earlier research on functional lateralization, their findings indicated a superiority for verbally coded information in the left hemisphere while the right hemisphere exhibited a superiority for visually coded information (Ehrlichman & Barrett, 1983; Gazzaniga, 2005; Gutwinski et al., 2011; Knecht et al., 2000; Lienhard, 2017; Quin-Conroy et al., 2024; Sperry, 1961; Tzourio-Mazoyer et al., 2017).

Nevertheless, the study conducted by Seamon and Gazzaniga (1973) had certain limitations. Firstly, it had a small sample size of only six participants (N=6), which would limit the study's statistical power and increase the likelihood of a false positive result (Lakens, 2022). Secondly, the number of trials per condition was relatively small: consisting of two sessions, each presenting one condition, and 36 trials in each session. However, the first 12 trials in each session were considered practice and were not included in the final analysis. Therefore, only 24 trials per session in both conditions were included in the final analysis. Lastly, the study's findings may have been constrained by the technological limitations of the early 1970s (Seamon & Gazzania, 1973). However, Seamon and Gazzaniga’s (1973) study on the Strategy Effect has interesting initial findings and a good theoretical framework. Consequently, due to the limitations, a replication is needed to further investigate the implementation of different encoding strategies on each of the cerebral hemispheres.

Only a limited number of replication attempts has been conducted, with just two studies found to have been able to replicate the findings of Seamon and Gazzaniga (1973). One of these replications was conducted by Metzger and Antes (1976). In experiment II of their paper, they tried to replicate the findings of Seamon and Gazzaniga (1973). Similarly, they found evidence for a left hemisphere advantage in response times for verbal rehearsal encoding, while the right hemisphere exhibited faster response times during the relational imagery encoding. However, they did not find evidence that imagery led to faster response times overall (Metzger & Antes, 1976). In addition, the study was limited by their small sample size (N=10), and a low number of trials (2 conditions, with a total of 32 trials each). Consequently, the sample size was insufficient to provide strong statistical power or generalizability (Lakens, 2022).

Bersted (1983) claims, in a footnote, to have replicated Seamon and Gazzaniga's (1973) study. However, the results of this apparent replication are not included in the article, and the original article is not accessible.

Two replications were conducted by Antone (2022): one online (Experiment I) and one in a controlled setting (Experiment II). In Experiment I of their paper, a replication was conducted through an online study (N=52). Similarly to the original study, an interaction effect between encoding strategy and response time was found (plot of interaction in Appendix B). Their findings yielded no significant main effect for either condition or hemifield, which also mirrored the findings of Seamon and Gazzaniga (1973). However, a difference between the studies was that the interaction effect from the original study by Seamon and Gazzaniga (1973) found a difference between conditions within both hemifields, while Experiment I from Antone (2022) only found an effect on both hemifields during the mental imagery condition. Additionally, an effect on both conditions was only present in the LVF. A potential limitation of the study was its online form, which would potentially affect the quality of the data. Antone (2022) conducted another replication in Experiment II in their paper, but this time in a controlled environment (N=55). Additionally, the number of trials was increased. A significant interaction effect between condition and hemifield was not found in Experiment II (plot of interaction in Appendix C), suggesting that the findings of Seamon and Gazzaniga’s (1973) original study were not successfully replicated. Nor could Experiment II replicate the findings of Experiment I (Antone, 2022).

Thus, it is clear that a replication is needed to rectify whether the original study is replicable or not. This is a consequence of the results of the existing replications being inconsistent, and the aim of the present study is, therefore, to offer more clarification. The main objective of the present study is to replicate the findings obtained in previous research, considering the influence of moderator variables.

Objectives

The objective of the present study is to conceptually replicate the findings of Seamon and Gazzaniga's (1973) with sufficient test power, and by considering possible moderator variables, in a controlled laboratory setting. The moderator variables include (a) Order of Condition: wherein commencing with mental imagery in the first condition may hinder participants from engaging in verbal rehearsal in the second condition (carry-over effect); (b) Trait of visual imagery abilities: wherein only participants with high abilities of visual imagery might benefit from the mental imagery condition. The study also wants to control possible confounding effects that previous studies have not accounted for. These include (a) assure left language representation, as for right hemispheric language dominant individuals the model would predict the reversed pattern, which might reduce the effect size on group level (using DL); (b) use native speakers of Norwegian only, as the high number of non-native speakers in Antone II might have affected the results of the replication. Finally, in order to integrate the evidence for the Strategy effect across the available studies, a meta-analytic statistical analysis was conducted by focusing on the right hemispheric contribution to the imagery effect. This was done in the experiment outlined below.

Methods

Participants

A total sample size of thirty-eight (N=38) participants completed the study. All were aged between 18-40 (M = 23.8, SD = 3.1), and had Norwegian as their native language. The number of participants was determined by *a priori* sample size calculation, designed to achieve a test power of .80 (alpha threshold at 5%; assuming a mean correlation between measures of .64). It utilizes the effect size reported by Seamon and Gazzaniga (1973) as an estimate for the population effect size (i.e., explaining the variance) of the effect of interest, which is the interaction between encoding Condition and Hemifield. The current study did not achieve the minimum sample size determined (N=38). Due to technical issues, the data of 2 participants was lost (not saved). After excluding 5 participants (outlined below), the final total of participants was thirty-one (N=31, 24 female, 28 right-handed).

All participants gave informed consent by signing a document before the experiment started. The study obtained approval from the internal review board of the Department of Psychology at the University of Oslo (Reference number: 16954956).

Exclusion Criteria

Participants were excluded if they fell outside the following criteria: (a) participants whose native language was not Norwegian, (b) participants outside the age limit (below age 18, or over 40), (c) low likelihood of being left hemi dominant for language, and (d) participants whose overall reaction time deviated by 3 or more standard deviations (*SDs*) from the sample mean were excluded to eliminate outliers.

A total of five participants (N=5) was excluded from the current study: 2 for the low likelihood of being left hemi dominant for language (based on the dichotic listening laterality), 2 for non-native speakers of Norwegian, and 1 with an overall reaction time that deviated by 3 or more *SDs* from the group mean. Making the final total sample size thirty-one (N=31).

Data Collection Procedure

Recruitment and data collection began in September 2023 - mainly through social media posts, as well as announcements to students through different university courses. Participants had to register themselves as interested through a protected online data collection system provided by the University of Oslo (nettskjema@usit.uio.no). Timeslots for participation were decided via email. Consent from the participants was obtained upon arrival. Among the four experimental paradigms participants were required to finish, three of them consisted of English instructions and questions: Dichotic listening (DL), Vividness in Visual Imagery Questionnaire (VVIQ), and

Edinburgh Handedness Index (EHI). The third task, the Strategy Effect test, provided participants with English instructions and Norwegian stimulus words.

Prior to the experiment, participants were given a distinct identification number based on their order of participation. The ID number had no connection to the testing material that may reveal their identity. The tests were consistently administered in the following sequence: Optimal Dichotic Listening task, followed by the Strategy Effect paradigm, and lastly, the questionnaire (Memory Performance, VVIQ, EHI, demographic information). All of these are outlined in the following 'Test Procedure' section. After the completion of the testing, participants received a 200kr (NOK) voucher as an award, and acknowledged this by signing a receipt.

Materials

The experiment consisted of two experimental paradigms followed by a questionnaire. Participants conducted the two experiments and the questionnaire at the same desk and computer at a private office at the University of Oslo, Department of Psychology. The Optimal Dichotic Listening task (Westerhausen & Samuelsen, 2020) and the Strategy Effect test were programmed in PsychoPy2 (Peirce et al., 2019) and administered by the program Pavlovia (pavlovia.org). The DL task employed auditory stimuli, presented through headphones (Sennheiser HD280), while the Strategy Effect paradigm utilized a chin-rest. The questionnaire was administered online through a secure data collection system provided by the University of Oslo (nettskjema@usit.uio.no).

Test Procedure

The participants were directed to a testing area where they were provided with a desk, equipped with a monitor, a keyboard, a set of headphones, and a chin rest. The arrangement of this guaranteed that all participants were positioned with their backs towards the room during testing, and with the screen in front of them. This was oriented to minimize any potential distractions. A description of both the test paradigms and the questionnaire will now be presented. The entire procedure, encompassing the information and subsequent instructions for the paradigms, lasted approximately 60 minutes.

The Strategy Effect Paradigm

The paradigm included images obtained from a standardized picture library (Bates et al., 2003; Snodgrass & Vanderwart, 1980), accompanied by a list of nouns representing tangible objects, all of neutral nature (e.g., jar or pigeon).

The Strategy Effect paradigm consisted of two identical blocks, in which participants were given distinct instructions to memorize pairs of probe words. The instructions for each block consisted of one encoding strategy: either verbal rehearsal, which involved silently repeating words to oneself (engaging the left hemisphere), or mental imagery, which involved constructing a mental image of the two presented words interacting (engaging the right hemisphere). The testing platform Pavlovia determined the order of the two blocks for all participants. The order was randomized and balanced; half of the participants starting with the verbal rehearsal block followed by the mental imagery block, the other half starting with the mental imagery block followed by the verbal rehearsal block. For example, if the words given were 'JAR' and 'PIGEON', the participant would need to silently repeat these two words to themselves during the verbal rehearsal condition, and mentally picture a pigeon perched on top of a jar during the mental imagery condition.

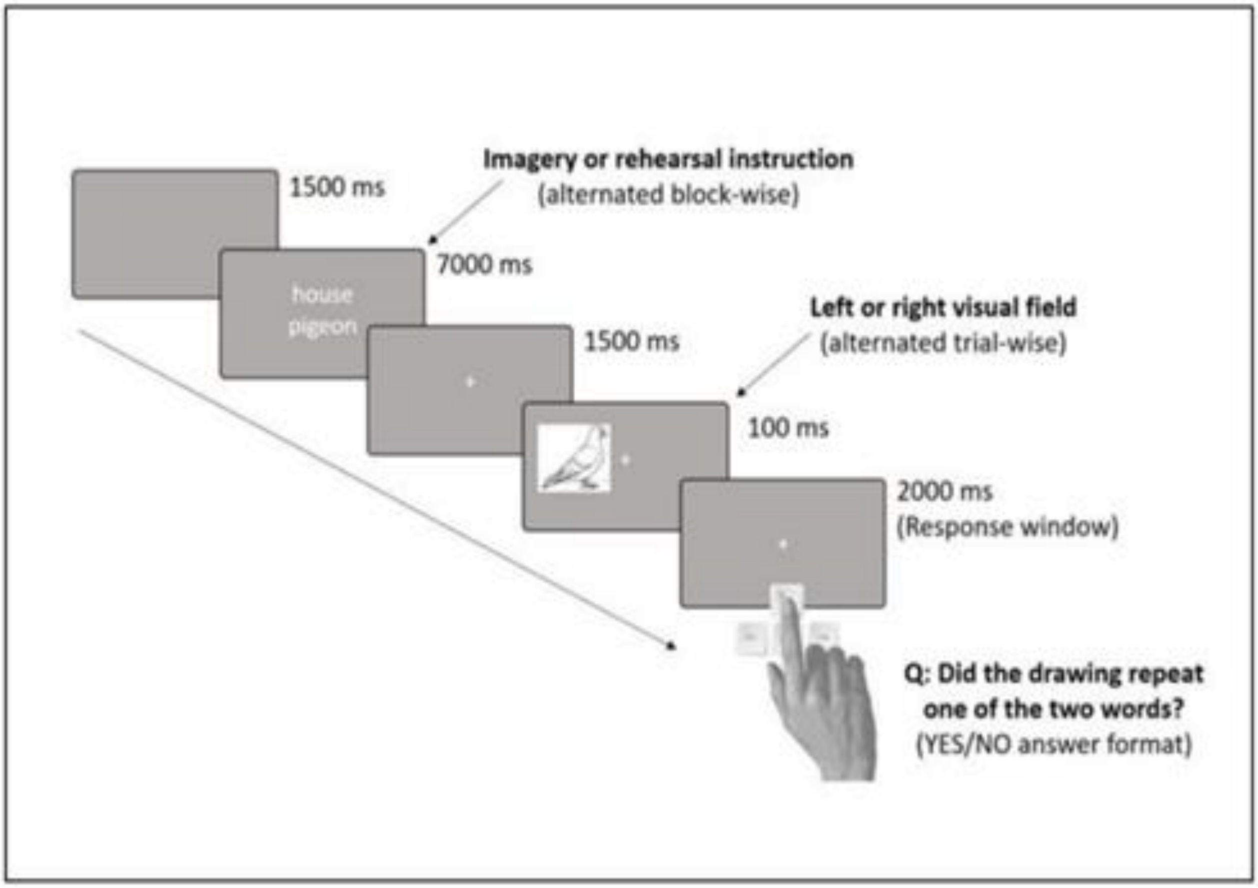
Each block consisted of 40 trials. The structure of each trial is illustrated in Figure 1. The experiment began with a 1500 millisecond interval of a blank screen, after which two stimulus words were shown in the center of the screen, positioned horizontally (one on top of the other). The participant was allotted a time frame of 7000 milliseconds to process and store the stimulus words in accordance with the provided encoding instruction. Subsequently, a blank screen featuring a fixation cross was displayed for a duration of 1500 milliseconds. The participant were instructed to direct their attention towards the fixation cross while maintaining the current stimulus words or mental image in their memory. Afterward, an outline illustration obtained from a standardized collection of images (Bates et al., 2003; Snodgrass & Vanderwart, 1980) was briefly presented on the screen for a duration of 100 milliseconds. The illustration was positioned either to the left or right of the fixation cross, thereby exclusively stimulating one visual hemifield. The presentation's short duration was crucial in order to prevent participants from shifting their attention away from the fixation cross towards the stimuli. The participant was given a time interval of 2000 milliseconds to provide a response. Participants were required to indicate whether the illustration presented matched either of the two stimulus words they were presented in that trial. A response was provided by pressing the 'yes' key (up arrow) or the 'no' key (down arrow) on the keyboard. If the image portrayed a jar or a pigeon, the appropriate response for the words 'JAR' and 'PIGEON' would be 'yes'. Nevertheless, if the image portrayed anything other than a jar or a pigeon, the appropriate response would be 'no'.

The test was designed to ensure that the illustration shown briefly to the participant in each trial was presented to both visual hemifields, positioned away from the center of the fixation cross (20 times on each side). The program was designed to ensure that each block included 30 trials necessitating a correct response of 'yes' and 10 trials necessitating a correct response of 'no'. Participants were given clear instructions to respond quickly and accurately to all trials in both blocks. Within each block, the participant was required to recollect the two words that were recently presented in each trial, without the need to retain information about the previous word-pairs presented.

The complete examination, encompassing both instructions and breaks between blocks, had a duration of about 25 minutes.

Figure 1:

Example trial structure of the Strategy Effect paradigm.



Note: The figure shows the sequence of one example trial (following the arrow from the top left corner to the bottom right corner). Starting with a blank period (1500ms), followed by stimulus words (7000ms), then a fixation cross (1500ms), then the presentation of the recognition probe (100ms), and lastly a response window (2000ms). Figure taken from Antone (2022).

Hemispheric Language Dominance Assessment by The Optimal Dichotic Listening

In addition to the primary paradigm, the Optimal Dichotic Listening task (Westerhausen & Samuelsen, 2020) was incorporated to assess the hemispheric dominance for language. During the paradigm, the participants were provided with headphones and subjected to six separate syllables ("ba", "ka", "fa", "pa", "ga", and "da") that were simultaneously played to each ear. The complete assessment comprised an initial segment with 10 practice trials, followed by 3 test blocks, each comprising 46 trials. That is, each block consisted of 40 pairs of distinct syllables that were simultaneously presented to each ear (dichotic), while 6 trials entailed presenting the same syllable to both ears (diotic). A combined total of 138 pairs, including 120 dichotic pairs and 18 diotic pairs, were presented across the three blocks. The trials were presented in a pseudo-random order that remained consistent for all participants. Each trial in this test lasted for 4000 milliseconds, with a preliminary phase of 1000 milliseconds, a stimulus presentation of 500 milliseconds, and a reaction period of 2500 milliseconds. Throughout each trial, participants were instructed to discern the particular syllable they heard by pressing one of six labeled buttons corresponding to the syllable they heard. Each button on the keyboard corresponding to a syllable was the first letter of the syllable. Throughout each trial, a fixation cross was displayed at the center of the screen. This cross was replaced by the question "What did you hear?" which appeared in the middle of the screen throughout the response interval. Subsequently, a circular symbol was presented at the center of the screen to indicate the participant's choice of answer. Afterward, the screen reverted back to showing the fixation cross as the next trial began. The complete examination, encompassing both the instructions and breaks between sections, had a duration of around 12 minutes.

The Optimal Dichotic Listening task was utilized to determine the dominant hemisphere for language processing in the participants. The reason for this was that the paradigm has demonstrated its reliability in assessing language dominance (Westerhausen & Samuelsen, 2020). In order to examine the Strategy Effect, it was necessary to involve participants who demonstrated left hemisphere dominance for language processing. Two participants were excluded as their laterality index (LI, defined as the percentage difference between right and left-ear recall) was below 0. Of note, 2 participants with an LI = 0 were included in the sample, as this value is with a high likelihood associated with left hemisphere dominance for language (see Sørensen & Westerhausen, 2020). For matters of completeness, the mean LI of the total sample (before exclusion) was 10.0 (*SD* = 22.1, range from -98.2 to 46.9).

Questionnaire: Memory Performance, Vividness of Visual Imagery, Hand Preference

Memory was assessed by administering a bespoke recognition-memory test for words presented in the Strategy Effect paradigm. A list of 48 words was presented to the participants. This list comprised a selection of words previously presented as encoding words during the

Strategy Effect paradigm, while the remaining words were ones that participants had not encountered during the testing. Participants were instructed to indicate their response by choosing either the 'yes' or 'no' box, indicating whether they had observed the word in the previous test or not.

The VVIQ by Marks (1973) was utilized to assess the participants' ability to create mental imagery. This was a self-report test used to assess an individual's subjective perception of the clarity and vividness of their visual mental images. The questionnaire comprised a sequence of items that prompted participants to imagine different scenarios and indicate the vividness of their mental imagery on a scale from 1 to 5. The scale went from “no image at all” to “perfectly clear”. An example of a prompt may be “Visualize a rising sun”, and the following inquiries would be: (a) The sun is rising above the horizon into a hazy sky, (b) The sky clears and surrounds the sun with blueness, (c) Clouds. A storm blows up, with flashes of lightning, (d) A rainbow appears (Marks, 1973). The VVIQ questionnaire was utilized due to being the most extensively used method to assess the vividness of mental imagery, because of its established validity as a psychometric tool (Campos, 2011).

EHI was used to assess hand preference by asking participants to indicate their dominant hand for performing different manual tasks: such as writing, throwing, or striking a match (Oldfield, 1971). The EHI questionnaire response format was modified from the original. The current system employed a 5-point scale that allowed participants to provide their response ranging from "always right" to "always left", with a neutral midpoint labeled as "both equally". The laterality quotient was determined based on the participant's responses, reflecting the level of preference for handedness. Right-handedness was indicated by positive numbers, left-handedness was indicated by negative values, and values closer to zero suggested mixed-handedness (Oldfield, 1971). This was employed due to the increased possibility between left-handedness and right hemispheric dominance in language processing (Knecht et al., 2000).

The questionnaire concluded by including fundamental demographic inquiries on age, gender, and native language.

Data Extraction for Meta-Analytic Integration

The strategy effect is usually confirmed by a significant interaction of Hemifield by Condition. However, interaction effect sizes cannot be easily integrated across studies as the effect sizes like eta squared, considered alone, do not allow any conclusion about the exact pattern of the interaction (Harrer et al., 2024). Thus, to allow for a meaningful meta-analysis, the Hemifield by Condition interaction may be quantified in multiple pairwise comparisons. Here the two comparisons were selected that inform about the expected right-hemisphere advantage for imagery-based encoded material: (a) the effect of rehearsal vs. imagery on the response to LVF probing (comparison of response time within the LVF), and (b) the hemifield advantage for mental imagery encoding (the response time difference between LVF and RVF). For this purpose, the respective mean values, standard deviations, and bivariate correlations (calculated based on the raw data) were extracted from all available experiments (Seamon & Gazzaniga, 1973; Exp. 2 from Metzger & Antes,1976; Exp. 1 and 2 from Antone, 2022; and the present empirical study). The effect size was expressed as Cohen's d for within designs (*dz*). Of note, Metzger and Antes (1976) only provided the mean response times for their study, and the average standard error and correlations from the other studies was used to estimate the effect size. Finally, the study mentioned in Bersted (1983) could not be obtained and was not included.

Statistical Analysis

The dependent variable was the (median) response time, and the effect of interest was the interaction of Condition and Hemifield. A two-factorial ANOVA was conducted, following the analysis from the original publication, with the within factors Condition (mental imagery/verbal rehearsal) and Hemifield (right visual field/left visual field).

Furthermore, three exploratory analyses were performed in addition to the aforementioned analysis. Firstly, the ANOVA discussed previously was expanded to include Condition Order as a fixed factor. Here a three-way interaction was the effect of interest, as it would qualify the interpretation of the Condition by Hemifield interaction. Additionally, an ANOVA including VVIQ (based on median split) as a third (between) factor was conducted. Here, the three-way interaction would suggest the Strategy effect is modulated by individual differences in imagery abilities. Finally, to confirm that experimental instruction worked, an

ANOVA was conducted to test the effect of the encoding instruction on the subsequent memory performance. A main effect of the encoding condition, with better performance after mental imagery as compared with rehearsal encoding was predicted, in accordance with the dual-coding theory (Paivio, 1969). Here the memory sensitivity (i.e. d-prime; considering hit and false positive rates in one variable) was used as the dependent variable. For more details see Stanislaw and Todorov (1999).

Where necessary, post-hoc explorations of the interactions were performed using pairwise t-tests, and the effect size was calculated as partial eta squared (η^2). An alpha threshold of 5% was assumed. All analyses were conducted using R (R Core Team, 2023; version 4.3.2) and RStudio (Posit Team, 2024), and the figures were created using the ggplot2 package (Wickham, 2016). A script including the steps for exclusion and analysis was saved for future use (see Appendix E).

Lastly, two meta-analyses were conducted: (a) a comparison between the rehearsal condition and the imagery condition in the LVF, and (b) a comparison between LVF and RVF after the mental imagery condition. In both cases, the pooled effect size (expressed as Cohen's *dz*) was estimated using a random-effects model. The between-study variance ($\tau 2$) was determined with the DerSimonian-Laird method and using the Hartung-Knapp adjustment to account for the small number of studies. The calculations were conducted in R using the "meta" package (version 7.0; Schwarzer, 2020). Given the small number of studies, an evaluation of potential report bias was omitted.

Results

The subsequent analysis was performed to determine if the current study reproduced the results of the original study conducted by Seamon and Gazzaniga (1973). Additional analyses were performed to further explore the data, as well as examine moderator variables and memory performance. Lastly, a meta-analysis, including the original findings, was conducted to examine the overall findings from the replications.

Analysis 1: Interaction between Condition and Hemifield

A statistically significant interaction effect between Condition and Hemifield was found in the Strategy Effect paradigm ($F(1,30) = 5.40$, $\eta^2 = .153$, $p = .027$). However, the main effects of Condition and Hemifield were not statistically significant ($F(1,30) = 0.71$, $\eta^2 = .023$, $p = .407$; $F(1,30) = 1.00$, $\eta^2 = .032$, $p = .325$). The means and standard deviations for each Condition and Hemifield are presented in Table 2, and a plot of the data can be found in Figure 2.

Table 2:

Means (of the medians) and Standard Deviations of Reaction Times (in seconds) for each Condition and Hemifield.

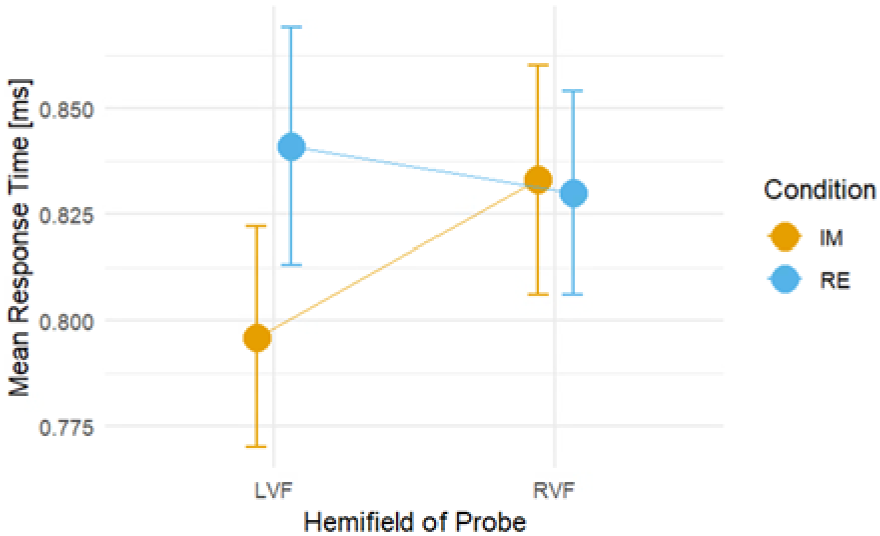
Condition	N	Hemisphere	
		Left (RVF)	*Right (LVF)*
Mental imagery	31	*.83* (.15)	*.80* (.15)
Verbal rehearsal	31	*.83* (.15)	*.84* (.13)

Note: The table shows the mean response times from the Strategy Effect paradigm. From 31 participants (N). Results are presented as mean (SD).

Post-hoc testing of the interaction of Hemifield within Condition found a significant difference between the hemifields in the imagery condition ($p = .01$). No significant difference was found between the hemifields in the rehearsal condition ($p = .576$). Furthermore, the testing of interaction of condition within hemifield found no significant difference between conditions in the LVF ($p = .094$), nor between conditions in the RVF ($p = .993$).

Figure 2:

Interaction effect between Condition and Hemifield.



Note: The figure shows the interaction effect between Condition and Hemifield. No significant difference in response times between Conditions in RVF or LVF. A significant difference between response times in LVF and RVF in the imagery Condition, no difference in the rehearsal Condition.

Analysis 2: Interaction of Condition, Hemifield, and Condition Order

An exploratory ANOVA was conducted adding Condition Order as a fixed factor. The crucial three-way interaction of Condition, Hemifield, and Condition Order was not significant ($F(1,29) = 0.597$, $\eta^2 = .020$, $p = 0.446$). Also, the interaction of Condition and Hemifield remained significant and was of comparable size as in Analysis 1 ($F(1,29) = 5.207$, $\eta^2 = .15$, $p = 0.003$). Hence, no further post-hoc explorations were considered relevant.

Analysis 3: VVIQ

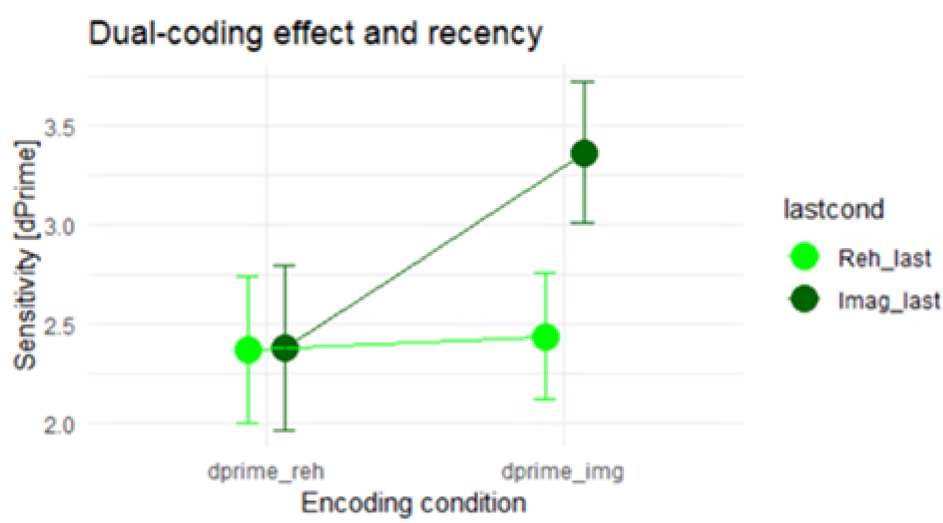
Additionally, an exploratory ANOVA was conducted with VVIQ as a fixed factor. No significant interaction effect was found between VVIQ, Condition and Hemifield ($F(1,29) = 0.045$, $\eta^2 = .002$, $p = .833$).

Analysis 4: Dual Coding effects

Lastly, an ANOVA was conducted to investigate dual coding and recency effects on Memory Performance. The conducted ANOVA found a significant main effect of Encoding Condition on memory performance ($F(1,29) = 9.911$, $\eta^2 = .255$, $p = .004$), indicating a higher sensitivity for item encoded under imagery instruction. Additionally, the interaction Encoding Condition and Condition Order was significant ($F(1,29) = 7.508$, $\eta^2 = .206$, $p = .010$). As can be seen in Figure 3, the interaction effects suggest that main effect of Encoding condition was mainly driven by participants who had the imagery condition as a second condition ($t(14) = 3.69$, $p = .002$, $d = 0.95$).

Figure 3:

Sensitivity (dPrime) for each Condition Order between both Conditions on Memory Performance.



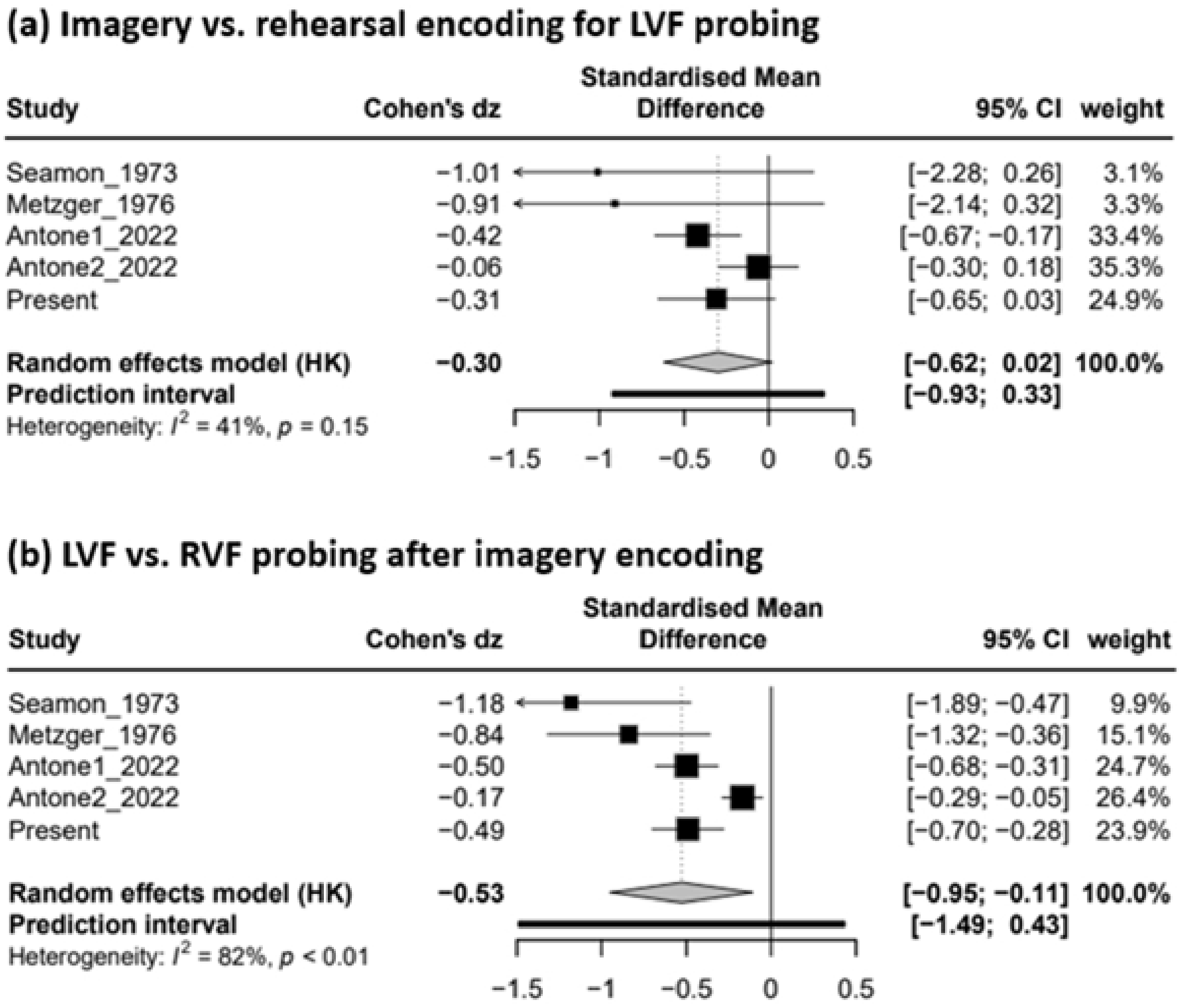
Note: (dprime_reh = verbal rehearsal, dprime_img = mental imagery, Reh_last = verbal rehearsal last, Imag_last = mental imagery last). The figure shows that there was no difference in Memory Performance between the Conditions in the first block. However, there was a difference between the Conditions in the last block. Showing that imagery Condition enhanced the Memory Performance when it was the last Condition, however, no such recency effect was found for the rehearsal Condition.

Meta-analysis

For the comparison between the encoding conditions in the LVF, the pooled effect size across the $k = 5$ studies ($N = 156$ data points per condition) was $dz = 0.30$ (CI95%: -0.62; 0.02). However, this was not significant ($t(4) = -2.60$, $p = .06$). Although the mean response time was faster for the imagery condition than for the rehearsal condition, the difference failed to reach the significance threshold. The pooled effect size ($k = 5$ studies, $N = 156$) for hemifield difference after imagery encoding was $dz = 0.53$ (CI95%: -0.95; -0.11). This was statistically significant ($t(4) = -3.51$, $p = .025$), indicating an LVF advantage. A forest plot of both analyses is presented in Figure 4.

Figure 4:

Forest plots for the two meta-analyses (a and b).



Note: The figure shows the comparison between the mental imagery Condition and verbal rehearsal Condition in the LVF. No significant difference was found between the Conditions. Meta-analysis b shows the comparison between the LVF and RVF after the mental imaging Condition. The difference was significant, with faster response times for the LVF. Cohen's *dz* and the standardized mean difference for each study is provided.

Discussion

Replication of Seamon & Gazzaniga

The aim of the present study was to conceptually replicate the findings of Seamon and Gazzaniga (1973) while considering possible moderator variables. The replication of the main effect was successful, with a significant interaction effect on the speed of response times between which encoding strategy was employed, and which hemifield, and therefore hemisphere, was engaged. Similar to the original study, no main effects of condition or hemifield were found, further reinforcing the notion of a successful replication. These results also replicate the findings from Experiment I of Antone (2022), which managed to replicate the main interaction effect of the original study. Seamon and Gazzaniga's (1973) interaction effect between condition and hemisphere accounted for 67% of the variance observed in the data, while the present study's findings only accounted for 15% of the variance (η^2 = .153). However, the original study had a smaller number of participants, which may have influenced their achievement of a larger effect size (e.g., by outliers). The effect size from the current study was also smaller than Antone's (2022) effect size from their successful replication in Experiment I (η^2 = .208).

Looking closer at the pairwise comparisons of the initial interaction effect, it becomes evident that the patterns of the present study exhibit dissimilarities from the original findings. However, similar to the original study, a significant difference between the hemifields in the mental imagery condition was found; with faster response times in the LVF (right hemisphere), than in the RVF (left hemisphere; Table 2). This may be attributed to the visuospatial specialization of the right hemisphere (Seamon & Gazzaniga, 1973). However, the present study found no significant difference between the hemifields in the verbal rehearsal condition, which contradicts the findings by Seamon and Gazzaniga (1973). The original study observed significantly faster response times in the RVF (left hemisphere) compared to the LVF (right hemisphere) in the verbal rehearsal condition (Table 1) as well. This difference was attributed to the left hemispheric specialization for language. Faster response times in the RVF than in the LVF were also observed in the present study (Table 2). Nevertheless, it is important to note that this difference was not significant. The results from the pairwise comparisons from the current study replicate those of Experiment I conducted by Antone (2022). Similar to their study, the current study seems to be driven by imagery. The presence of an effect on both hemifields was observed exclusively during the mental imagery condition, while the presence of an effect on both conditions was observed exclusively in the LVF, projecting to the right visuospatial hemisphere. Thus, the difference between the hemifields seems to be driven by mental imagery, while the difference between the effects of condition seems to be influenced by the right visuospatial hemisphere (specifically, through the LVF).

Nevertheless, the current study successfully replicated the main finding observed by Seamon and Gazzaniga (1973), highlighting a significant interaction effect between encoding strategy and which hemifield was engaged on the participants response times. Each hemisphere demonstrated faster response times when words were encoded using methods aligned with their respective functions (right hemisphere for language, left hemisphere for visuospatial tasks). However, only the imagery condition exhibited a significant difference in response time between Hemifields. These results underscore the pivotal role of mental imagery in driving hemispheric effects. As well as emphasizing the influence of the right visuospatial hemisphere in the processing of visual information. Thus, the current study appears to have successfully replicated the findings of the original study, however with different effect sizes and data patterns.

The results from the meta-analysis also indicate an advantage in the LVF for recognition of familiar objects that were encoded using visual imagery. The advantage was consistent in both the present investigation and the meta-analysis. This advantage, which is marked by a moderate effect size, possibly indicates the participation of the right hemisphere in the processing of mental images. Furthermore, when comparing mental imagery encoding to verbal rehearsal encoding, a tendency for faster identification in the LVF when engaging in mental imagery was found. The effect size was small, but somewhat consistent across all studies. These findings, although observed in various studies, could be strengthened in future research by using bigger sample sizes to enhance the reliability and significance.

Hemispheric Specialization of Function

The results of the current study imply that the interaction effect occurred as a result of the specialized functions of the hemispheres influencing the speed of responses from the participants. Nevertheless, the main difference between the hemifields was attributed to the utilization of mental imagery. Although the left hemisphere is considered the dominant language processor, research has shown that the right hemisphere also possesses substantial language processing capabilities. The right hemisphere exhibits proficiency in identifying concrete words, although demonstrates a lesser ability in processing abstract words and extracting syntax (Lindell, 2006). However, while the right hemisphere excels in visuospatial processing, the left hemisphere has been found to have a limited ability to process nonverbal information (Mengotti et al., 2020; Moeck et al., 2020; Gainotti, 2021).

In the context of the present findings, assuming both hemispheres possess the capacity to process language, albeit to a lesser extent in the right hemisphere, this may give an explanation to why no significant difference was found on the response times between the two hemifields in the verbal rehearsal condition. Despite the left hemisphere's dominance in language processing, the response times were not significantly faster compared to the right hemisphere. Nevertheless, the right hemisphere still possesses substantial language processing ability, resulting in no significant difference found in the response times between the hemispheres. Moreover, it would explain the significant difference observed in the mental imagery condition between the hemifields, as the right hemisphere exhibits a dominance in visuospatial processing capabilities, while the left hemisphere has been found to possess a minimal presence of such abilities. Thus, leading to significantly faster response times during the mental imagery condition when processed in the right hemisphere compared to the left hemisphere. Additionally, it would account for the significant difference found in response times between the encoding conditions in the LVF. Due to the right hemispheric dominance for processing visual imagery influencing response times, while the considerable poorer linguistic ability requiring more time to process, resulting in longer response times.

Antone (2022) similarly concluded imagery to be the driving force behind their findings. They discussed the right hemisphere exhibiting a greater degree of specialization in functions frequently associated with the left hemisphere and theorized that this potentially influenced the response times of participants.

In short, the capacity for processing mental imagery is significantly different between the hemispheres, than that for word processing, which may clarify the differences found in response times for the conditions between the hemifields, as well as the difference between the conditions in LVF (right hemisphere).

Dual Coding & Memory Performance

An analysis was conducted to investigate the effect of dual coding as well as the recency effect on the memory performance of the participants. A significant effect was observed between encoding condition and memory performance. No recency effect was observed for the rehearsal condition. However, a recency effect was observed in the imagery condition; with an enhancement in memory performance for participants who conducted the mental imagery condition last. These findings also demonstrate that the participants experienced no difficulties in discontinuing the use of mental imagery when they conducted the mental imagery condition first; given that there was no improvement in memory performance when comparing rehearsal as the first condition and rehearsal as the last condition. The results indicate that the memory for imagery was superior to that for words, however, this was only observed in the last condition. The phenomenon of imagery being more easily memorized is consistent with previous research on memory performance comparing imagery and language (Funnel et al., 2001). The findings of Experiment II, conducted by Antone (2022), align with the current result, indicating that imagery improves memory performance specifically when it is the last Condition.

The significant interaction effect found between encoding condition and memory performance may be attributed to dual coding, due to the generation of mental images resulting in significantly better memory performance (Paivio & Csapo, 1973). The Dual Coding Theory proposes an enhancement of memory by using visual imagery information in conjunction with verbal information (Paivio, 1969); due to visual imagery generating an additional memory code and thereby increasing the capacity for storing and retrieving information (Paivio & Csapo, 1973). The results obtained from the present study seem to be consistent with these findings. During the mental imagery condition, participants were presented with written words and utilized these to create the mental image. Therefore, participants were utilizing mental imaging codes in conjunction with verbal codes (engaging both hemispheres), which may be the reason behind the enhancement in memory performance.

Concurrent to the results of the significant interaction, the difference in response times may also be attributed to dual coding. Similarly to what Seamon and Gazzaniga (1973) discussed in their study, the verbal rehearsal condition in the present study provided only a verbal code. However, the mental imagery condition provided both a verbal and a visual code. The differences in response times in the verbal rehearsal condition could therefore be a product of interhemispheric transfer. Therefore, producing prolonged response times during the verbal rehearsal condition due to the visual nature of the probes presented, necessitating the utilization of the visuospatial processing ability of the right hemisphere. This concept aligns with Paivio's Dual Coding Theory (1969), which suggests that information can be stored concurrently in two distinct formats: verbal and visual. Moreover, that the performance would be enhanced if both of these codes were utilized together.

However, earlier research has found contradicting results on memory performance between the hemispheres. Macbeth and Chiarello (2019) found evidence of recognition being faster when the stimulus was presented in the same hemifield during both encoding and retrieval. Nevertheless, the current study found evidence of recognition being faster due to the processing applied to the stimulus (strategy of encoding), and not the location of the stimulus at encoding. According to Macbeth and Chiarello (2019), their findings indicate that both hemispheres of the brain are capable of encoding and retrieving memory representations equally well, as long as the stimuli do not contain any linguistic information. Their findings contradict the present studies, and the findings in the original study by Seamon and Gazzaniga (1973). The current study's findings suggest that memory performance is improved when dual coding is utilized, thus creating a stronger memory code. However, Macbeth and Chiarello (2019) concluded with stronger memory representation in the original hemisphere of input, compared to the indirectly activated hemisphere. This implies that nonverbal stimuli presented in the RVF, and processed by the left hemisphere, had to interpret visuospatial information. Although earlier research mentioned have demonstrated that the left hemisphere possesses little ability to process visuospatial information.

Moderator Variables

The aim of the present study involved considering possible moderator variables. The variables accounted for in the current study are sex differences, language differences, and individual differences in vividness in visual imagery. As well as the order the encoding conditions were presented for the participants (rehearsal-imagery or imagery-rehearsal).

The current study utilized DL to ensure that participants had a left hemisphere language representation. Subsequently, participants with a high likelihood of being right hemispheric dominant for language processing were excluded from the final sample size. However, it is theorized that differences between males and females in hemispheric laterality exist (Clemets et al. 2006). These differences would not be detected by the DL paradigm. In their study, Clemets and their team (2006) found evidence for differences in laterality between males and females in the processing of language compared to visuospatial information. Their findings suggest that males exhibit a higher degree of lateralization during language tasks, while having increased bilateral activity during visuospatial tasks. In contrast, females demonstrate more bilateral activity during language tasks, and a more right-lateralized activity in visuospatial tasks. However, other studies have failed to find differences in the laterality of cerebral activity on language or visuospatial tasks between males and females (Frost et al., 1999; Unterrainer et al., 2000). The current study had more female than male participants (24 female, 7 male). If sex differences in laterality for language or visuospatial processing exist the way Clemets and their team (2006) found evidence for, this could perhaps explain why there was no significant difference found between the hemifields in the rehearsal condition. Based on the findings of Clemets and colleagues (2006), females tend to engage both hemispheres when processing language and exhibit a stronger right-sided preference for visuospatial processing. As a result, the difference in response times between the hemifields in the mental imagery condition would be greater, while the response times in the verbal rehearsal condition between the hemifields would be less distinct. Nevertheless, Antone (2022) accounted for sex differences in their replication studies of the Strategy Effect and found no effect with sex as an added factor in either Experiment I or II. Therefore, gender was not accounted for in this experiment.

Differences in the cerebral lateralization of multiple languages are still a topic of interest in the research of laterality (D'Anselmo et al., 2013), and the findings are contradictory. Hull and Vaid's (2007) findings indicate that functional lateralization of language was influenced by the age of onset of bilingualism. They found a bilateral hemispheric involvement for both languages in participants who acquired both languages before the age of 6. However, left hemisphere dominance for both languages were found for participants who acquired their second language after the age of 6 (Hull & Vaid, 2007). Nevertheless, D'Anselmo and colleagues (2013) found evidence for a left hemispheric specialization in language in both first and second language. Despite the conflicting results of previous research on the differences in laterality between first and second languages, the present study accounted for this by only recruiting participants with

Norwegian as their native language. Similarly, the study conducted by Seamon and Gazzaniga (1973) only included native English-speaking participants. While the instructions for two of the paradigms were written in English in the current study, oral instructions were given in Norwegian to control for potential language barriers or misunderstandings.

Mental imagery has been linked to the cognitive process of visual working memory, with the ability to visualize ranging from aphantasia (completely absent) to hyperphantasia (photo-like) (Keogh et al., 2011). Therefore, the current study investigated whether participants' ability to visualize mental imagery would affect the data from the Strategy Effect paradigm by utilizing the VVIQ. No significant effect of the ability to visualize was found in the current study; meaning that the ability to visualize did not modulate the participants' response times. According to Keogh and their team (2021) aphantastic individuals can also be highly imaginative, as well as complete tasks previously thought to rely on visual imagery. This demonstrates that there are many ways of representing absent objects, and mental visualization is only one of them (Keogh et al., 2021).

The subsequent analysis is unrelated to the replication study of Seamon and Gazzaniga's (1973) findings. Nevertheless, an exploratory analysis was conducted using condition order as a fixed factor. There was no significant interaction observed between condition, hemifield, and order of condition. Consequently, the order of condition had no impact or carry-over effects. Thus, it can be concluded that the main interaction between condition and hemifield was not significantly influenced by the condition order: indicating that it did not modulate the response times. Antone (2022) similarly observed no evidence of a three-way interaction effect in their successful replication in Experiment I. The results of order of encoding condition not influencing response times further confirm that the paradigm was successful.

The potential moderator variables considered included differences in sex, language, and the vividness of visual mental imagery. The response times of the participants were not influenced by their ability to create mental images, language, or the order the conditions were presented in. The influence of sex on response times was not included in this study due to previous replications not finding evidence of an effect.

Limitations

The current study had some limitations. Firstly, the final total sample size was lower than the number of participants calculated by *a priori* power analysis (N=38). Thirty-eight participants were recruited, but due to the exclusion of five participants, and data loss of two participants, the final total was thirty-one participants (N=31). However, a significant interaction effect was found, suggesting that the observed effect is robust and not merely a false positive. Nevertheless, the lower-than-expected sample size could potentially influence the reliability and generalizability of the pairwise comparisons, warranting cautious interpretation of these findings (Lakens, 2014).

Finally, another limitation might be gender effects, due to the current study having more female participants than male, which was not accounted for in the current study. However, earlier replications have, as mentioned earlier, not found any effects of gender on the main interaction effect.

Conclusion

The objective of the present study was to conceptually replicate the findings of Seamon and Gazzaniga's (1973) study of the Strategy Effect, while considering possible moderator variables. The original study investigated if encoding strategies would influence laterality effects, and effects consistent with the ones found in the original study were found in the present study. Moreover, the results from the present study demonstrated that mental imagery played a significant role in the performance differences between the two hemispheres, and this effect was consistent across all analyses. Therefore, the results imply that the interaction effect occurred as a result of the specialized functions of the hemispheres influencing the speed of responses from the participants. These results suggest a successful replication of the original study by Seamon and Gazzaniga (1973), however with some dissimilarities in effect size and patterns. The present study additionally examined potential moderator variables; however, no effect was observed on the response times as a consequence of these variables. Furthermore, the meta-analysis provided similar results, indicating that the mental imagery encoding condition was the driving force behind faster response times. Moreover, the present study sought to provide more insight into the relationship between functional laterality and memory performance. An enhancement of memory performance was found when mental imagery was the last encoding condition, compared to verbal rehearsal. The improved memory performance can be attributed to dual coding: with the generation of images resulting in significantly better memory performance (Paivio & Csapo, 1973). While the original study by Seamon and Gazzaniga (1973) likely overestimated the size of the strategy effect, the present empirical and meta-analysis data can be taken to suggest that the effect of imagery encoding is supported, in particular by, right hemispheric functions. Thus, it appears the well-established dual-coding effect originally described by Paivio (1969) relies on utilizing right-hemispheric, in addition to, pure left-hemispheric stimulus processing during encoding. In this, the strategy effect is an interesting example of how hemispheric specialization supports cognitive performance.

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Appendix

Appendix A:

Main interaction effect from the original study by Seamon and Gazzaniga (1973)

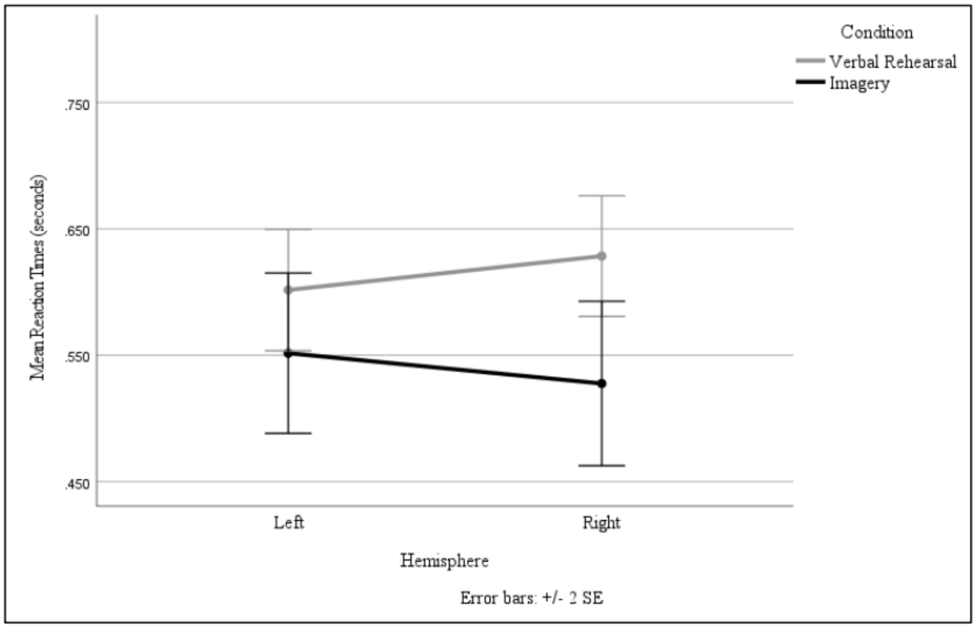
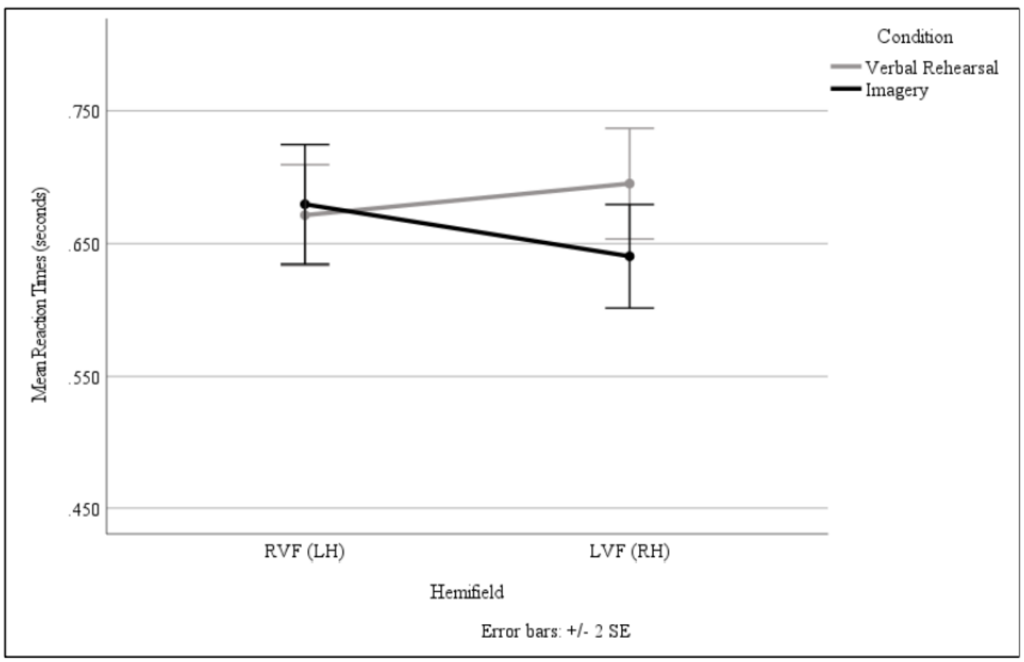


Figure taken from Antone and Westerhausen (2022).

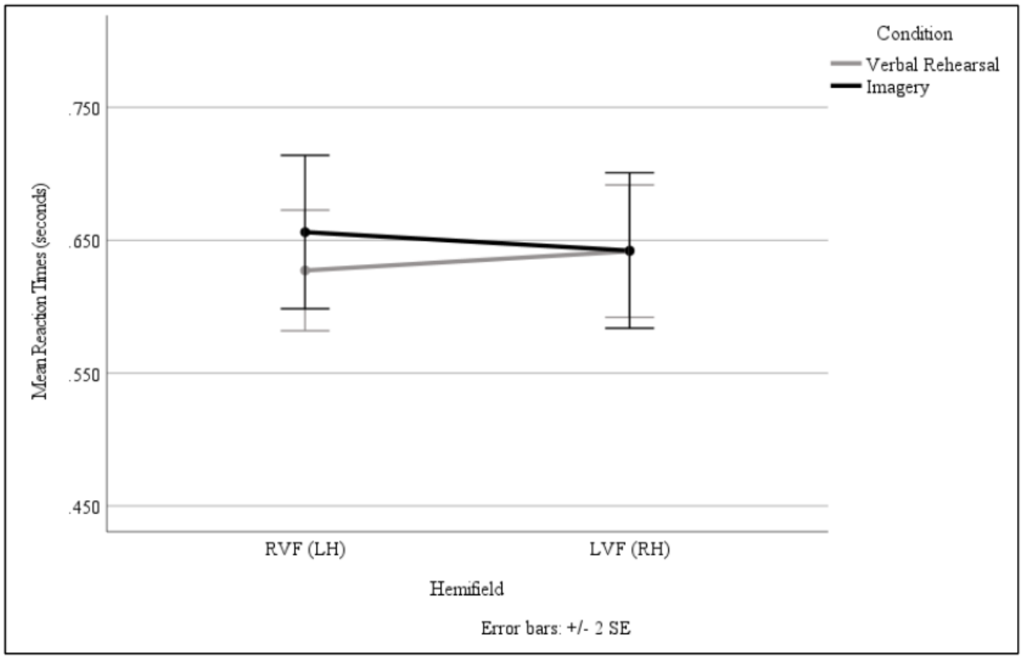
Appendix B:

Main interaction from Experiment I from Antone (2022).



Appendix C:

Main interaction from Experiment II from Antone (2022).



Appendix D:

Table of the initial ANOVA

ANOVA Table (type III tests)

	Effect	DFn	DFd	F	p	p<.05	pes
1	Condition	1	30	0.708	0.407		0.023
2	Hemifield	1	30	1.001	0.325		0.032
3	Condition:Hemifield	1	30	5.399	0.027	*	0.153

Appendix E:

Script of the Exclusion and Analysis of the data

```
#============================================================================#
##SCRIPT REANALYSIS OF StratEffect EXPERIMENT 3: lab testing
#============================================================================#
library(ggplot2)
library(ggpubr)
library(tidyr)
library(stringr)
```

```
library(rstatix)
#----------------------------------------------------------------------------#
#import data
setwd("//hypatia.uio.no/LH-SV-PSI/Projects/Laterality/StratEffect/Experiment3/stats/")
df.quest = read.csv("ExtractedQuestionnaireData.csv")
df.dl = read.csv("ExtractedDLData.csv")
df.strat = read.csv("ExtractedSEData.csv")

#merge files
df.in = merge(df.quest, df.dl, by = "ID")
df.in = merge(df.in, df.strat, by = "ID")

#----------------------------------------------------------------------------#
# EXCLUSION of participants based on predefined criteria
temp.dl = df.in$total_LI

# 1) Weighted Mean RT across all conditions >3 SD from Sample mean
#unweighted average
df.in$Mean_rt = (df.in$img_rt_LVF + df.in$img_rt_RVF + df.in$reh_rt_LVF + df.in$reh_rt_RVF)/4
SampleMean_rt = mean(df.in$Mean_rt, na.rm = TRUE)
SampleMean_rt_sd = sd(df.in$Mean_rt, na.rm = TRUE)
df.in$Mean_rt_z = (df.in$Mean_rt-SampleMean_rt)/SampleMean_rt_sd #z transformation
df.in = df.in[which(abs(df.in$Mean_rt_z) <3),] # absolute value of z >3 excluded
##>> removes 1

# 2) Age < 16 and older >50 excluded
df.in = df.in[which(df.in$Age_InYears > 16 & df.in$Age_InYears <= 50),]
##>> removes 0

# 3) Participants with problems during data collection
#df.in = df.in[which(df.in$ExData==0),]
##>> removes

# 4) Low likelihood of being left hemi dominant for language = LI 0 or positive
df.in = df.in[which(df.in$total_LI >= 0),]
#>> removes 2
```

```
# 5) Non-native for Norwegian (added  after registration)
df.in = df.in[which(df.in$MotherTongue == "Norwegian"),]
#>> removes 2

#----------------------------------------------------------------------------#

#need to make deskriptive statistics: age, sex distribution, handedness

#age
mean_age = mean(df.in$Age_InYears)
sd_age = sd(df.in$Age_InYears)

#sex
sex_dist = table(df.in$Sex)

#handedness
df.in$handcat = factor(df.in$ehi_lq >0)
levels(df.in$handcat) = c("Left", "Right")
hd_dist = table(df.in$handcat)

#dichotic listening LQ (=> before exclusion)
mean_dl_lq = mean(temp.dl)
sd_dl_lq = sd(temp.dl)
min_dl_lq = min(temp.dl)
max_dl_lq = max(temp.dl)
n_smaller_0 = sum(temp.dl<0)

#----------------------------------------------------------------------------#
#convert data to long format
df.in_long = gather(df.in, varname, dv, c(img_rt_LVF, img_rt_RVF, reh_rt_LVF, reh_rt_RVF),
factor_key=TRUE)
df.temp = as.data.frame(str_split_fixed(df.in_long$varname, "_", 2))
names(df.temp)=c("Condition","Hemifield")
df.in_long = cbind(df.in_long, df.temp)
df.in_long$Condition = as.factor(df.in_long$Condition)
df.in_long$Hemifield = as.factor(df.in_long$Hemifield)
df.in_long$Sex = as.factor(df.in_long$Sex)
```

```
df.in_long$firstcon = as.factor(df.in_long$firstcon)
levels(df.in_long$firstcon) = c("IM_first", "RE_first")
names(df.in_long)[2] = "Id"

#transformation to make lables/variables comparable to analysis of Seamon & Gazzaniga data
levels(df.in_long$Condition) = c("IM", "RE")
levels(df.in_long$Hemifield) = c("LVF", "RVF")

#---------------------------------------------------------------------------#
#Descriptive statistics
DescTable = df.in_long %>% group_by(Condition, Hemifield) %>%
        get_summary_stats(dv, type = "full")

#testing normality assumption
df.in_long %>% group_by(Condition, Hemifield) %>%
  shapiro_test(dv)
ggqqplot(df.in_long, "dv", ggtheme = theme_bw()) +
  facet_grid(Hemifield ~ Condition, labeller = "label_both")
#Shapiro ns

#---------------------------------------------------------------------------#
#ANOVA
res.aov = anova_test(data = df.in_long,
              wid = Id,
              dv = dv,
              within = c(Condition, Hemifield),
              effect.size = "pes",
              type =3) #as used in original publication
get_anova_table(res.aov)

#---------------------------------------------------------------------------#
#Post-hoc testing of interaction
#(1) Hemifield within Conditions
ph_c1 = df.in_long %>%
  group_by(Condition) %>%
  pairwise_t_test(
    dv ~ Hemifield, paired = TRUE,
```

```
    p.adjust.method = "none")

ph_c1_d = df.in_long %>%
  group_by(Condition) %>%
  cohens_d(formula = dv ~ Hemifield, paired = TRUE)

#(2) Conditions within Hemifield
ph_c2 = df.in_long %>%
  group_by(Hemifield) %>%
  pairwise_t_test(
    dv ~ Condition, paired = TRUE,
    p.adjust.method = "none")

ph_c2_d = df.in_long %>%
  group_by(Hemifield) %>%
  cohens_d(formula = dv ~ Condition, paired = TRUE)

#---------------------------------------------------------------------------#
#Added 230424 - For meta-analysis
#(1) Reh vs Img in LVF
TE_lvf = ph_c2_d$effsize[[1]]
corr_lvf = cor(df.in$img_rt_LVF,df.in$reh_rt_LVF)
TE_lvf_se = sqrt(((2*(1-corr_lvf))/ph_c2$n1[[1]]) + (TE_lvf^2/(2*ph_c2$n1[[1]])))
#formula see here:: https://bookdown.org/MathiasHarrer/Doing_Meta_Analysis_in_R/effects.html#s-md

#(2) LVF vs RVF in Img
TE_img = ph_c1_d$effsize[[1]]
corr_img = cor(df.in$img_rt_LVF,df.in$img_rt_RVF)
TE_img_se = sqrt(((2*(1-corr_img))/ph_c1$n1[[1]]) + (TE_img^2/(2*ph_c1$n1[[1]])))



#---------------------------------------------------------------------------#
#Plotting interaction as line plot based on means
ggplot(DescTable, aes(x=Hemifield, y=mean, colour=Condition)) +
        geom_errorbar(aes(ymin=mean-se, ymax=mean+se),
                      width=.15,
                      position=position_dodge(width=.25)) +
```

```
    geom_point(size = 5,
            position=position_dodge(width=.25)) +
    geom_line(aes(x=as.numeric(Hemifield)),
    position=position_dodge(width=.25)) +
    scale_color_manual(values=c("#E69F00", "#56B4E9"))+
    ggtitle("Experiment 3: lab") +
    xlab("Hemifield of Probe") +
    ylab("Mean Response Time [ms]") +
    theme_light()+
    theme(aspect.ratio=1,
          axis.text.x = element_text(size=12),
          axis.title.x = element_text(size=14, face="bold"),
          axis.text.y = element_text(size=12),
          axis.title.y = element_text(size=14, face="bold"),
          legend.text = element_text(size = 12),
          legend.title = element_text(size=14, face="bold"))

#=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o=o#

#Additional analyses

#==========================================================================#
#(1) Adding "Condition Order" as between subject factor
#--------------------------------------------------------------------------#

#3 factorial ANOVA
res.aov_order = anova_test(data = df.in_long,
             wid = Id,
             dv = dv,
             within = c(Condition, Hemifield),
             between = firstcon,
             effect.size = "pes",
             type =3) #as used in original publication
get_anova_table(res.aov_order)

#NOTE: the three-way interaction was NOT significant. > Order of encod cond does not matter
```

```
#---------------------------------------------------------------------------#
#(2) Adding "VVIQ" as factor
#---------------------------------------------------------------------------#
#looking at vviq first
vviq_stats = get_summary_stats(data = df.in, vviq_score, type = "full")

#histogram
ggplot(data=df.in, aes(vviq_score)) +
  theme_light()+
  theme(aspect.ratio=1) +
  geom_histogram(fill="black",
                 alpha = .2) +
  labs(x="VVIQ total score", y="Count") +
  geom_vline(xintercept = vviq_stats$median, color = "red", size=0.5)

#median split in df.in_long variable
tempvar = replicate(dim(df.in_long)[1], 1)
tempvar[df.in_long$vviq_score>vviq_stats$median]=2
df.in_long$vviq_cat =as.factor(tempvar)
levels(df.in_long$vviq_cat) = c("low score", "high score")


#3 factorial ANOVA
res.aov_vviq = anova_test(data = df.in_long,
                          wid = Id,
                          dv = dv,
                          within = c(Condition, Hemifield),
                          between =  vviq_cat,
                         effect.size = "pes",
                          type =3) #as used in original publication
get_anova_table(res.aov_vviq)

#>> vviq does not nteract with anything, or: VVIQ does not modulate response times
```

```
#---------------------------------------------------------------------------#
#(4) Testing for dual coding effect on memory performance: dv = dprime
#---------------------------------------------------------------------------#

#recoded as last condition, as the last condition was tested for recogn memory
df.in$lastcond = as.factor(df.in$firstcon)
levels(df.in$lastcond) = c("Reh_last", "Imag_last")

df.in_long2 = gather(df.in, varname, dv, c(dprime_reh, dprime_img), factor_key=TRUE)


DescTable_mem = df.in_long2 %>% group_by(lastcond, varname) %>%
  get_summary_stats(dv, type = "full")

res.anova_mem = anova_test(data = df.in_long2,
                           wid = ID,
                           dv = dv,
                           between =  lastcond,
                           within = varname,
                           effect.size = "pes",
                           type =3)

get_anova_table(res.anova_mem)

#main effect of encoding condition (varname)+ interaction; Interpretation: no
#recency effect only for imagery encoding; no stop "imagining" problem when img first


#---------------------------------------------------------------------------#
#Plotting interaction as line plot based on means
ggplot(DescTable_mem, aes(x=varname, y=mean, colour=lastcond)) +
  geom_errorbar(aes(ymin=mean-se, ymax=mean+se),
                width=.15,
                position=position_dodge(width=.25)) +
  geom_point(size = 5,
             position=position_dodge(width=.25)) +
  geom_line(aes(x=as.numeric(varname)),
```

```
    position=position_dodge(width=.25)) +
scale_color_manual(values=c("green", "darkgreen"))+
ggtitle("Dual-coding effect and recency") +
xlab("Encoding condition") +
ylab("Sensitivity [dPrime]") +
theme_light()+
theme(aspect.ratio=1,
  axis.text.x = element_text(size=12),
  axis.title.x = element_text(size=14, face="bold"),
  axis.text.y = element_text(size=12),
  axis.title.y = element_text(size=14, face="bold"),
  legend.text = element_text(size = 12),
  legend.title = element_text(size=14, face="bold"))
```