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Neurophysiology of Mental Imagery and Reality Monitoring

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by

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ABSTRACT

People with vivid imaginations are less accurate at identifying whether memories originated from experience or imagination than people with less vivid imaginations. This can be modeled as a similarity between the memory traces created during vivid imagination and perception, which causes source confusion during recall. The role of visual imagery in this process has been well established, but the role of auditory imagery remains unclear. fMRI data collected from an auditory/visual imagination task was analyzed to determine the relationship between imagery ability, subjective ratings of imagery vividness, neurophysiology, and reality monitoring errors. I predicted that individuals with higher scores on measures of mental imagery would have a greater propensity for reality monitoring errors in both sensory domains. The study's goal was to increase our understanding of the brain areas involved in reality monitoring and how individual differences in imagery ability contribute to misremembering imagined events as having occurred in reality.

INDEX WORDS: Functional magnetic resonance imaging, Vivid mental imagery, Reality monitoring, Auditory imagery, Visual imagery

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DEDICATION

I would like to dedicate this thesis to Maria Rudnicka, Kazimierz Pietruszewski, Alexander Pietruszewski, and Elizabeth Rudnicka. Thank you all for your support.

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1 INTRODUCTION

1.1 Source Monitoring Framework

The inability to distinguish between a memory that occurred in external reality and a memory that is a trace of an imagined event could have devastating real-life consequences. This ability is especially critical in cases of eyewitness memory wherein people attempt to mentally recreate a witnessed event via imagination. In these circumstances an eyewitness remembering an imagined event and thinking it was experienced in external reality could result in the confabulation of remembered crime details that did not occur. The ability to make judgments about the source of a memory is referred to as source monitoring (Johnson et, al. 1993) and it allows people to distinguish between fact and fiction as well as monitor their own autobiographical experiences. The Source Monitoring Framework (SMF) suggests that there are no tags associated with memories that label their source; instead, source monitoring decisions are made by evaluating the contextual details of a memory at retrieval to determine if it is a product of perception or internal cognitive processes.

Regardless of its source, an episodic memory contains sensory details (color, sound, scent, taste), spatial information (size, location), temporal details (time of day, time of the year), semantic information (category membership, associated items), emotional information (how it made us feel, how others felt about it), and cognitive operations associated with it (thoughts present at that time) (Mitchell & Johnson, 2009). These details are all bound together to form an episode and people distinguish between episodic memories based on the differences in these details. According to the SMF, people believe that memories with a high degree of sensory detail are more likely to be real (I remember hearing the voice of my friend Sam say that), while memories with a high degree of thought processes associated with them are more likely to have been imagined (I remember the thoughts I was having when I imagined that).

1.2 **Imagery and Source Confusion**

Several studies show that differences in mental imagery abilities contribute to confusion regarding the source of memories. Dobson & Markham (1993) had students discriminate between information presented in a film and through a written description. They found that students were equally able to recognize items presented in the film regardless of their imagery ability as measured by the Vividness of Visual Imagery Questionnaire (VVIQ), but students with higher VVIQ scores were less able to discriminate between the source of items based on the written description, suggesting a role of imagery vividness in source confusion.

Horselenberg and colleagues (2000) showed that individuals with better imagery abilities had a higher propensity for imagination inflation, a memory distortion in which imagining an event increases a person’s confidence that the event occurred in reality. They had students rate the probability of 60 different childhood events and return to the lab after a four week delay to then imagine low-probability childhood events and indicate their confidence in those events being true. They found that students with better imagery ability skills saw a greater imagination inflation effect of believing that their imagined events occurred in reality than those with lower imagery abilities.

Visual imagery has traditionally been discussed as a single factor, but Blazhenkova (2016) showed that a more accurate way to understand visual imagery is to subdivide it into two unique dimensions consisting of object and spatial imagery. Visual-object imagery is the ability to visualize the shape, color, brightness, and texture of imagined objects. Visual-spatial imagery is the ability to visualize the movements of objects and their parts, spatial transformations of objects, and spatial relationships between objects.

Blazhenkova (2017) showed that individuals with high object imagery scores are more likely to engage in boundary extension, a phenomenon in which people recall more details in a scene than were originally observed. In this study participants encoded cropped images of faces and performed a forced-choice face recognition task in which they could choose from faces with varying degrees of boundary extension and boundary reduction. They found that participants with greater object imagery scores selected faces with a greater degree of boundary extension whereas those with lower object imagery scores selected faces with a greater degree of boundary reduction. These findings suggest that a relationship exists between greater imagery abilities and a propensity to confabulate imagined events with perceived events.

Although there has been little work examining the neural correlates of object and spatial imagery ability, the behavioral evidence presented by Blazhenkova (2017) suggests that object imagery could show a greater relationship with mistaking imagination for reality than spatial imagery. Furthermore, the division of the visual system into ventral (what) and dorsal (where) processing streams, and the activation of sensory areas during imagery suggests that object and spatial imagery activations could map onto ventral and dorsal streams.

1.3 Reality Monitoring Errors

Within the source monitoring framework, the confabulation of believing that imagined events were perceived in external reality is referred to as a reality monitoring error (Johnson & Raye, 1981). The framework suggests that people with vivid mental imagery create representations of imagined events that are high in sensory detail without creating a strong trace for the imagination process which leads to an external attribution of the event. Reality monitoring errors are oftentimes subtle and embarrassing such as incorporating fiction as fact, Johnson et al. (1993) describe a “60 Minutes” program in which then-president Ronald Reagan recounted a story of heroism to Navy personnel that was in fact a scene from a fictional film. These errors can also have a serious impact on courtroom decision making. According to data collected by The Innocence Project (a group of researchers, lawyers, and policy experts working to overturn wrongful convictions), mistaken eyewitness identifications account for almost 70% of the 375 wrongful convictions that have been overturned based on DNA evidence. The impact imagery has on memory has the potential to lead to mistaken identifications and people with vivid mental imagery could be especially vulnerable to such mistakes.

Mental imagery can play a critical role in the formation of memories that never occurred, leading people to believe in fictious crimes and even believing themselves to be the perpetrators of such crimes. Shaw & Porter (2015) demonstrated that convincing episodic memories can be artificially generated using suggestive memory retrieval techniques commonly used in police interviews. In this study, the researchers interviewed participants about emotional events that happened during their adolescence, and false events that were either criminal or non-criminal in nature. Over the course of three interviews, each with a week in between, the events were presented to the participants, and they were asked to visualize them and generate as many details as they could. The researchers found that 70% of participants in the criminal condition reported having memories of being involved in criminal events that resulted in police contact without being aware that these memories were completely fabricated through their imagination. Participants’ memories ranged from theft to assault and 86% percent of the participants who reported having these memories indicated a visual component to the memory, while 39% also reported an auditory component.

In a commentary on this study, Wade et al. (2018) raised an important point about the difference between false beliefs and false memories. They distinguish the two by saying that people with false beliefs accept that a false event occurred, whereas people with false memories provide further evidence that they remember an event like the emotions they felt during the event. Using multiple recoding strategies, the group showed that the number of participants reporting false memories was closer to 30%, whereas the remaining 40% reported false beliefs. Although a substantial proportion of their results showed false beliefs, rather than false memories, the work still showed that memories could be fabricated through imagination, leading people to visualize and recall details that were completely imagined.

In a similar study, Hyman & Pentland (1996) showed that imagination could be used to illicit fabricated childhood memories. In this experiment participants' parents answered a questionnaire about their children's childhood events such as hospital visits, getting lost, family vacations, meetings with prominent figures, and so on. Participants then participated in a set of three memory interviews each separated by a week. During the interviews, participants were asked about their true memories and one fabricated event. Researchers found that participants would fabricate complete events after engaging in mental imagery, suggesting that revisiting a memory through imagination increases the potential for source confusion.

1.4 **Neurophysiology of Mental Imagery**

Neuroscientific investigations into the brain areas involved in mental imagery have demonstrated the existence of a network of brain areas active during imagery across sensory modalities. A meta-analysis of 65 fMRI based mental imagery studies has identified a "general imagery network" consisting primarily of bilateral dorsal parietal and left inferior frontal regions (McNorgan, 2012). The author suggests mental imagery recruits the primary sensory cortex to a modest degree when creating representations based on perception, but that processing relies on upstream convergence zones which integrate perception into abstract representations. This perspective is supported by a recent literature review which cited several studies demonstrating that these convergence zones play a role in abstract supramodal representations and that they are consistent with locations of pathological change in semantic dementia (Binder and Desai, 2011). McNorgan (2012) provides further evidence by citing a study which compared visual memory and visual mental imagery, showing that both are mediated by fronto-parietal control regions and occipital-temporal sensory regions (Slotnik et al. 2011).

In addition to the areas involved in modality-general imagery, McNorgan (2012) also showed that regions active during imagery of specific sensory modalities overlap with, but are not limited to, areas involved in the processing of the sensory modality in question as well as areas involved in motor execution. According to McNorgan (2012), auditory imagery recruits secondary auditory cortex (planum temporale), an area involved in auditory and language processing, whereas visual imagery has been shown to activate the primary visual cortex and visual association areas, areas involved in visual processing. Subdomains of visual imagery including form imagery, color imagery, and motion imagery, each show activity in different parts of the brain including but not limited to the precuneus, lingual gyrus, and middle frontal gyrus.

Among the studies included in this meta-analysis was Daselaar et al. (2010), which used fMRI to compare regions of the brain involved in auditory imagery, visual imagery, and how activity varied based on the subjective vividness ratings associated with these imagery modalities. This study was conducted on sixteen healthy participants. Researchers had participants perceive auditory and visual stimuli in the form of words that they read (visual) and listened to (auditory). During the task, participants would either perceive or imagine the stimuli in an auditory or visual domain. They would then rate their subjective quality of the imagined stimulus and perceptual detail of the perceived stimulus. The researchers identified that the posterior cingulate cortex, left and right ventral parietal cortices, and medial prefrontal cortex were all active during mental imagery regardless of the sensory domain. They also identified bilateral activity in the visual association areas (lateral occipital complex) and right superior parietal cortex as being greater in the visual imagination condition compared to auditory imagination condition, as well as a nonsignificant trend of activity in the auditory association area (posterior superior temporal gyrus) as well as bilateral striatum as being greater during auditory imagination as compared to visual imagination. When examining how activity in the visual association cortices and auditory association cortices varied between levels of imagery vividness, the researchers found a significant main effect of imagery vividness and modality in the visual domain and a trending interaction in the auditory domain. These findings indicate that visual association areas are recruited during visual imagery in individuals with the ability to produce imagined events with vivid visual details. However, in auditory imagery, the findings are less clear and require further investigation.

In another study examining the neurophysiology of vivid mental imagery, Fulford and colleagues (2018) compared individuals high in visual imagery vividness to individuals low in visual imagery vividness to identify differences in brain activity. In their study the researchers measured participants' imagery vividness using the VVIQ to form low and high vividness groups, and then they had participants look at and imagine various famous and non-famous buildings and faces. The study consisted of a perception block, an imagery block, a perception control block, and an imagery control block. Each block was repeated four times before moving to the next block. During the perception block, participants were cued with the word "perception" for 1 second and then looked at a famous place or face for seven seconds. During the imagery block, participants were cued with the word "Imagery" for one second followed by the name of a famous place or face for 800 milliseconds, and then they imagined the cued stimulus for 5.2 seconds. During the perception control block, participants looked at a scrambled image of a famous place or face, and during the imagination control block participants imagined a stream of nonsense text. Immediately after completing the scan, participants were removed from the scanner, presented with the same set of images on a laptop, and asked to rate the intensity of their visually imagined event on a five point scale. The researchers then compared findings between the low and high vividness groups. The results showed that when engaging in mental imagery, the low vividness group showed increased activity in a widely distributed set of brain regions, whereas the high vividness group showed increased activity in the medial frontal lobe and the insula. The methodology used in Fulford et al. (2018) largely informed the methodology used to collect the data in the current study with a few key differences. Fulford et al. (2018) used a block design for their task whereas the data for this study was collected using an event related design, as this allows for greater randomization of trials and reduces the impact of participant expectations on results. Another key difference between the methodology used in Fulford et al. (2018) and the methodology used to collect the current data-set is the stimuli used in each task. Fulford et al. (2018) used famous places and faces as the stimuli in their task. The stimuli used in this data-set was a set of action sequences, featuring actors introduced during a practice task, organized into three-part slides. The task in this dataset controls for any effects of participants being familiar or unfamiliar with the stimuli by introducing the actors before scanning began. Another change made to the Fulford et al. (2018) methodology was that the task used in this data set included a vividness rating immediately following an encoding trial in the scanner instead of waiting to record vividness ratings after the scanning session was completed. Obtaining vividness ratings immediately following imagination is an improvement over the earlier methodology as it allows for a trial-by-trial assessment of vividness which provides a more in-the-moment measure of imagery vividness than ratings obtained following a time delay.

1.5 Neurophysiology of Reality Monitoring Errors

In addition to understanding the biological roots of mental imagery, researchers have also worked to identify the specific brain regions involved in the experience of reality monitoring errors. Kurkela & Dennis (2016) reviewed 33 studies in a meta-analysis of fMRI based studies of false memory, of which eight studies examined activity during encoding. fMRI studies of reality monitoring during encoding are most relevant because it is during encoding that features, which are later retrieved and assessed for source details, are bound together into an episode that is to be remembered (Simons et, al., 2017). Kurkela & Dennis (2016) identified that regardless of the experimental paradigm, encoding of imagined stimuli later recalled as having been experienced induced activity in the ACC and the left MTG. They point out that of the studies examining activity during encoding, only Gonsalves et al. (2004) offered an explanation for the observed ACC activity. In their study Gonsalves and colleagues had participants read aloud object names and generate a corresponding visual image to identify if mental imagery can lead to false memories. They attributed the observed ACC activity to vivid visual imagery which caused participants to mistake imagined stimuli for experienced stimuli. Kurkela & Dennis go on to explain that the observed MTG activity may occur due to the semantic processing involved in the encoding of their stimuli.

Sugimori and colleagues (2014) investigated which brain areas were active during the encoding of imagined events later recalled as experienced in the auditory domain. They had participants listen to words read in another person’s voice and imagine hearing words being read by that same voice. Later during a memory test, they had participants judge words as being either “heard”, “imagined”, or “new”. Sugimori and colleagues reported bilateral activation in the superior temporal gyrus (STG), a region of the brain involved in auditory processing, only for words which were imagined and subsequently recalled as having been heard. This observation was made in individuals with higher scores on the auditory-hallucination experience scale (LSHS-R) (a subset of the Hallucinatory Predisposition Scale used in Launay & Slade (1981)). While the LSHS-R does not measure imagery per se, Halpern (2015) explains that auditory imagery has been implicated in the experience of hallucinations.

Sugimori and colleagues showed that individuals more prone to hallucinations show bilateral STG activity when imagining an auditory stimulus that is later recalled as having been heard, and Halpern (2015) explains that the experience of auditory hallucinations is related to auditory imagery. In the current study, my first aim was to determine if individuals high in auditory imagery ability would be more prone to making reality monitoring errors. To address the first aim, I ran a *t*-test to determine if people with higher scores on the vividness dimension of the Bucknell Auditory Imagery Scale (BAIS-V) were more likely to misremember auditorily imagined stimuli as having been experienced. My second aim was to determine how subjective trial-by-trial vividness ratings relate to reality monitoring errors in the auditory domain. To address the second aim, I examined subjective trial-by-trial vividness ratings to determine if auditorily imagined trials rated as being more vivid were more likely to be recalled as having been experienced than those rated as being less vivid. My third aim was to determine if the brains of individuals high in auditory imagery ability would show bilateral STG activity for words which were imagined and subsequently recalled as having been heard. To address the third aim, I analyzed fMRI data collected during an auditory encoding task to determine if STG activity underlies the encoding of auditorily imagined events later recalled as having been experienced in individuals with greater auditory imagery ability.

In addition to the novel analysis of auditory imagery and reality monitoring errors, my first aim also sought to replicate findings showing that vivid visual imagery can contribute to reality monitoring errors in the visual domain. To address the first aim, I ran a *t*-test to determine if people with higher VVIQ scores were more likely to misremember visually imagined stimuli as having been experienced. As part of the first aim, *t*-tests were also run to determine how sub-types of visual imagery abilities in the relational (spatial) and/or object detail domains, as measured by the OSIQ, relate to misremembering imagined stimuli as having been experienced. My second aim was to determine if any differences exist between average subjective vividness ratings for visually imagined trials recalled as having been imagined and visually imagined trials recalled as having been experienced. To address the second aim, I examined subjective trial by trial vividness ratings to determine if visually imagined trials rated as being more vivid were more likely to be recalled as having been experienced than those rated as being less vivid. My third aim was to determine if the encoding of visually imagined stimuli later recalled as having been seen recruits activity in the ACC and the MTG in individuals with greater visual imagery abilities. To address the third aim, I analyzed fMRI data collected during a visual encoding task to determine if ACC and MTG activity underlie the encoding of visually imagined events later recalled as having been experienced in individuals with greater visual imagery ability.

1.6 Overview of Study

This study is an analysis of an fMRI dataset which includes scans from 28 healthy participants collected from a visual encoding task and an auditory encoding task that were administered in 2019 (for further task details see sections 2.1.4 – 2.1.6). Recently, Kleider-Offutt et al. (2019) showed that imagination regardless of sensory modality resulted in increased activity in the precentral gyrus and supplementary motor areas. They also showed that visual imagination resulted in increased activity in the fusiform gyrus, bilateral primary and secondary visual areas, as well as the inferior and middle temporal lobes. Their analysis of auditory imagination resulted in increased activity in left inferior frontal regions, however, this finding was observed at $p<0.0001$ uncorrected as no results passed FWE correction. After identifying the neural correlates for auditory and visual imagery, the paper went on to discuss differences in activity in the visual domain during encoding for high and low imagery groups. Their findings were similar to the findings in Fulford et al. (2018), showing a widely dispersed set of regions being more active in the low imagery group > high imagery contrast with no significant findings in the high imagery > low imagery contrast. The study did not report any differences in activity between vividness groups in the auditory domain.

While this previous study identified the correlates of mental imagery in auditory and visual domains and differences in activity during imagery between high and low vividness groups, researchers did not examine the behavioral questions addressed in the present study. Analyses of behavioral data could reveal valuable insights into differences between imagery ability groups in terms of their reality monitoring abilities and the neurophysiology supporting these abilities.

Through this novel behavioral analysis, I aimed to determine if people with greater mental imagery abilities and people with higher subjective vividness ratings would be more likely to misremember imagined events as having occurred in reality than people with lesser mental imagery abilities and people with lower subjective vividness ratings. The first step in this analysis was to group participants into high and low groups based on their performance on various measures of mental imagery. Performance on the VVIQ, OSIQ, and BAIS-V were all used as grouping variables in this analysis. The VVIQ and OSIQ groups were used for the visual imagery analysis whereas the BAIS-V was used for the auditory analysis. The average trial by trial vividness ratings taken during the auditory and visual encoding phases was also used as a grouping variable in both analyses. Each of these measures assess a unique subcomponent of imagery ability, so an individual with a high score on the OSIQ-O did not necessarily have a high score on the OSIQ-S. Therefore, separate *t*-tests were run for each measure. For more details about the measures see section 2.1.3.

The goal of the neurophysiological analysis was to identify which brain regions were active during encoding that later led to false alarms during recall in both auditory and visual sensory domains, and how this activity differed between high and low imagery groups. To answer these questions, imagine trials collected during encoding were sorted based on behavioral outcomes. Across both modalities, contrasts were created for imagined trials subsequently recalled as having been experienced and imagined trials correctly recalled as having been imagined. After contrasts were created, the data was further sorted into high and low imagery groups as measured by the VVIQ, OSIQ, and BAIS-V, and *t*-tests were carried out to determine if different brain regions are recruited during the encoding of false alarms for imagined events in individuals with different imagery abilities.

1.7 **Specific Aims**

<u>Aim 1:</u> ***Individuals with greater mental imagery abilities will be more likely to confuse imagined events for having occurred in reality.***

Hypothesis 1a: Higher scores on the BAIS-V will be associated with a greater number of false alarms for auditorily imagined events because individuals with greater auditory imagery ability will find it difficult to distinguish between events they experienced and events they imagined.

Hypothesis 1b: Higher scores on the VVIQ, OSIQ-O, and OSIQ-S will be associated with a greater number of false alarms for visually imagined events because individuals with greater visual imagery ability will find it difficult to distinguish between events they experienced and events they imagined.

***Aim 2:* Average subjective trial by trial vividness ratings will be greater for imagined trials recalled as having been experienced than for imagined trials recalled as having been imagined.**

Hypothesis 2a: Average trial-by-trial vividness ratings for auditorily imagined stimuli recalled as having been heard will be greater than average trial-by-trial vividness ratings for auditorily imagined stimuli recalled as having been imagined.

Hypothesis 2b: Average trial-by-trial vividness ratings for visually imagined stimuli recalled as having been seen will be greater than average trial-by-trial vividness ratings for visually imagined stimuli recalled as having been imagined.

Hypothesis 2c: Regardless of sensory domain, imagined trials rated as being more vivid will be more likely to be recalled as having been experienced than trials rated as being less vivid.

***Aim 3:* fMRI analyses of behavioral findings will identify a set of brain regions associated with the experience of false alarms for imagined events within participants in the visual domain and in the auditory domain.**

Hypothesis 3a: When compared to fMRI analyses of auditorily imagined trials recalled as having been imagined, encoding of auditorily imagined trials subsequently recalled as experienced will show increased activity in the left MTG and bilateral STG in individuals who score higher on measures of auditory imagery ability. I expect to observe these results because the MTG is thought to be associated with semantic processing during the encoding of imagined events subsequently recalled as having been experienced, and bilateral STG activity has been observed during the encoding of auditorily imagined events that were later recalled as having been experienced.

Hypothesis 3b: When compared to fMRI analyses of visually imagined trials recalled as having been imagined, encoding of visually imagined trials recalled as having been experienced will show increased activity in the ACC and MTG in individuals who score higher on measures of visual imagery ability because the ACC and MTG have been shown to be active during the encoding of visually imagined events that were later recalled as having been experienced in individuals high in visual imagery ability.

2 METHODS

2.1 IRB Approval

This study analyzed fMRI and behavioral data collected in 2019. Scans were completed using a 3T scanner at the GSU/GT Center for Advanced Brain Imaging. Procedures were approved by the Georgia State University and Georgia Tech institutional review boards.

2.2 Participants

Twenty-eight participants were recruited from the Georgia State University undergraduate subject pool and scanned during an auditory imagination encoding task and a visual imagination encoding task. They were screened for medications, psychosis, substance abuse, metal rods or pins embedded in the body, homemade tattoos that may include metals and English illiteracy as exclusionary criteria in the study. All participants underwent a series of assessments to determine their imagery capabilities as measured by the Object-Spatial Imagery Questionnaire and the Bucknell Auditory Imagery Scale. Participants self-identified their age (range = 19-39, M = 24.6), gender (14 women, 12 men), and race/ethnicity (11 Black, 5 White, 4 Hispanic/Latino, 3 Asian, 1 Bi/Multi-racial, 1 Native Hawaiian, 1 did not respond). Three participants were removed from any analyses because of issues during the fMRI scan, described in further detail below, and three participants were removed because they did not fully complete the assessments. The final sample consisted of twenty-two participants. This sample size is based on prior research using fMRI to study mental imagery (Sugimori et al. 2014, Gonsalves et al. 2004). This data was used in Kleider et al. (2019) and the same data will be used in this novel analysis.

2.3 Measures

Three scales were used to measure auditory and visual imagery abilities for each participant. Visual imagery abilities were measured using the VVIQ and the OSIQ, whereas auditory imagery abilities were measured using the BAIS-V.

2.3.1 VVIQ

The Vividness of Visual Imagery Questionnaire (VVIQ) (Marks, 1973) is a validated 16 item assessment used to quantify vividness of visual imagery. In this measure participants are asked to imagine various images, such as the face of someone they know, and indicate the vividness on a seven point scale. It is scored by summing all the values for a total visual imagery rating. The mean VVIQ score in this sample was 61.91 with a range of 37 and a standard deviation of 10.48. For a more detailed distribution of VVIQ scores see Figure 1.

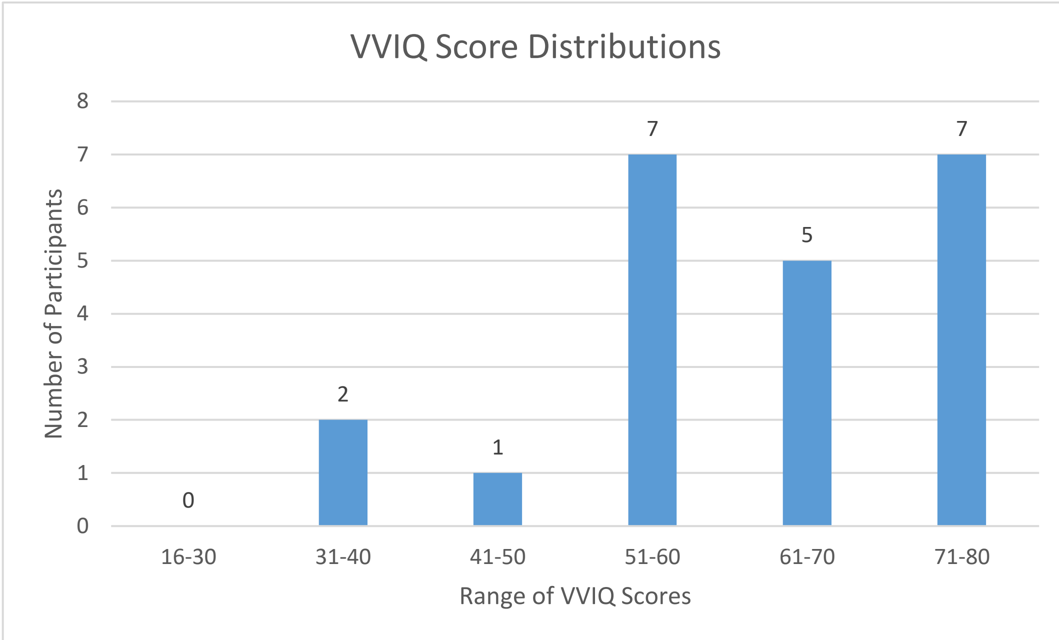

***Figure 1** Distribution of VVIQ scores collected from the proposed sample population.*

2.3.2 OSIQ

The Object-Spatial Imagery Questionnaire (OSIQ) (Blajenkova et al., 2006) consists of 30 items measuring individual differences in object and spatial imagery ability. The items consist of imagery use in the real world (e.g., “I am good at Tetris”). Participants are then asked to rate these items on a five-point scale from one (strongly disagree) to five (strongly agree). Half of these questions relate to spatial imagery ability (OSIQ-S), whereas the other half relate to object imagery ability (OSIQ-O). Scores are calculated for the two scales separately. The mean OSIQ-S score in this sample was 2.42 with a range of 2.4 and a standard deviation of 0.60. The mean OSIQ-O score in this sample was 3.45 with a range of 1.73 and a standard deviation of 0.48. For a more detailed distribution of OSIQ scores see Figures 2 and 3. Since the two subscales of the OSIQ measure unique aspects of visual imagery and there is little evidence to suggest that either component is more pertinent to reality monitoring than the other, both will be considered for analysis.

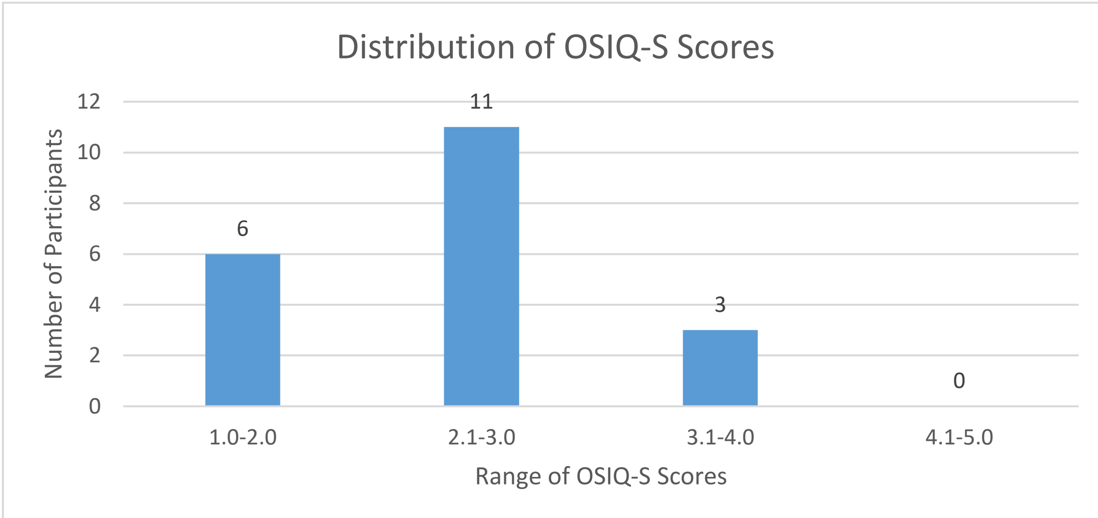

Figure 2 *Distribution of OSIQ-S scores collected from the proposed sample population.*

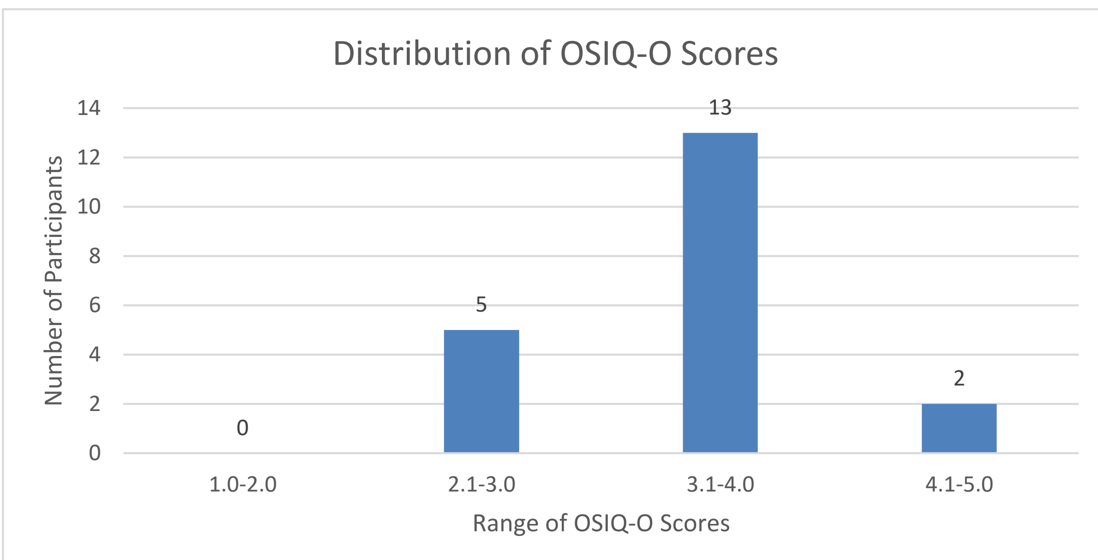

Figure 3 *Distribution of OSIQ-O scores collected from the proposed sample population.*

2.3.3 BAIS

The Bucknell Auditory Imagery Scale (BAIS) (Halpern, 2015) is a validated scale used to measure auditory imagery ability. The scale consists of several tasks in which participants are asked to imagine auditory stimuli, indicate their similarity to real world stimuli, and indicate the vividness of their imagination. The BAIS includes the subcomponents BAIS-V and BAIS-C which represent the vividness and control subscales. The BAIS-V score represents the clarity of imagined stimuli and the BAIS-C score represents how easy it was for the participant to imagine the stimulus. The mean BAIS-V score in this sample was 61.3 with a range of 62 and a standard deviation of 15.89. The BAIS-C subcomponent will not be considered in this analysis because the experimental question is focused on vividness of mental imagery, not the ability to control mental representations. For a more detailed distribution of BAIS-V scores see Figure 4.

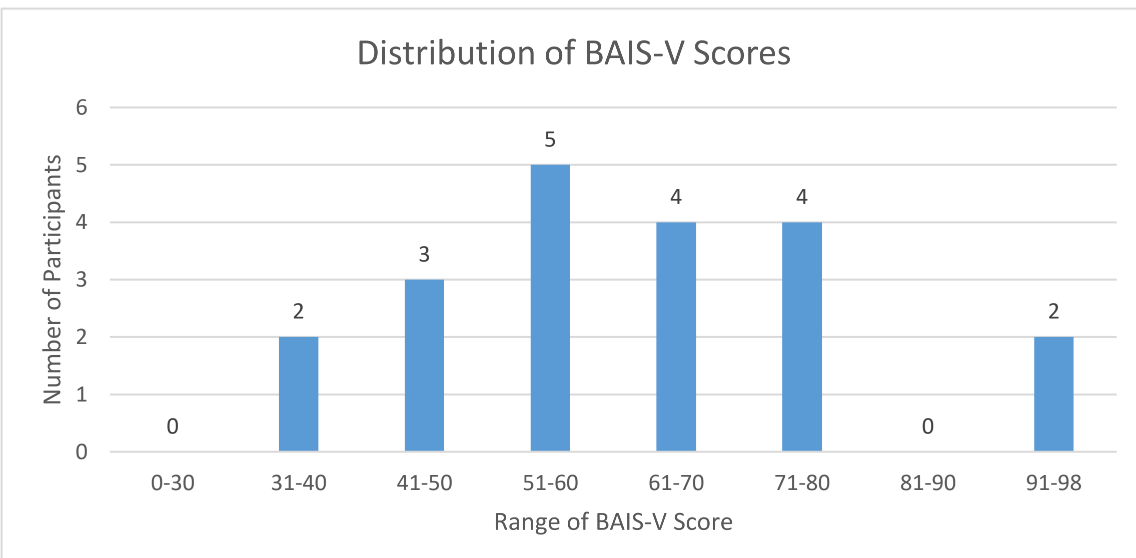

Figure 4 *Distribution of BAIS-V scores collected from the proposed sample population.*

2.4 Imagery Training and Practice Task

After consent was obtained - but before scanning began - all participants underwent mental imagery training and practice versions of both the auditory and visual encoding tasks. The mental imagery training was included to ensure that participants understood the level of detail required for their imagined events. The practice task was included so participants would know what to expect during the experimental trials.

First participants were trained on how vivid their visual mental imagery should be, and then they began the visual practice task. During the visual mental imagery training, participants imagined a painter holding a paint brush. They were asked to report imagined details which included descriptions of how the brush felt, whether the brush was warm or cold, whether the painter was inside or outside, and what the air around the painter smelled like. Participants were also asked to imagine that the painter took out a rag and wiped paint off of the brush’s handle. Then they were asked to imagine how the rag feels in the painter’s hand, identify the color of the rag, and determine if the rag was soft or rough. During the visual mental imagery practice task, participants saw a slide show of pictures with a mechanic and a hairdresser performing different actions and rated the clarity of these actions on a four-point scale. They also saw sentences with the word “IMAGINE” written in front of them, were asked to imagine the events described in these sentences and were asked to indicate the vividness of their imagination on a four-point scale. The visual practice task also included an example of the control condition in which sentences were read and not imagined. These trials were marked with the word “READ” before them and participants indicated the length of these sentences on a four-point scale.

After completing the visual imagination training and practice task, participants were trained on how vivid their auditory imagery should be, and then they completed the auditory practice task. During the auditory imagination training, participants were introduced to the pre-recorded voices of Joe and Jill who each read a sentence while the participant kept their eyes open. Participants were then asked to imagine a sentence being read by Jill and then another sentence being read by Joe. Participants had ten seconds to imagine the sentence being read, and then they were asked to indicate the sex of the voice they imagined, whether the voice was loud or soft, what the pitch of the voice was, and if the voice was pleasant or not. During the auditory imagery practice task, participants listened to Joe and Jill read a short passage and were instructed to focus on the sound of their voices so they could imagine the voices speaking later. Then participants saw sentences marked with “IMAGINE JILL” or “IMAGINE JOE” on the screen, imagined those sentences being read in the voice of Joe or Jill, and indicated the vividness of their imagination on a four-point scale. The auditory practice task also included an example of the control condition in which participants looked at nonsensical gibberish. These trials were marked with the word “LOOK AT” before them and participants rated how engaging the sentences were on a four-point scale. After both the imagination training sessions and practice tasks were completed, participants were brought to the scanner room where the experiment took place.

2.5 Experimental Design

2.5.1 Stimuli

The stimuli in the visual task consisted of three slide sequences displaying photographs of actors performing various tasks, sentences indicating for the participant to visually imagine one of the actors performing a task, and sentences telling the participant to read something that cannot be imagined. Our first actor was a female who played the role of a hair-stylist. Our second actor was a male who played the role of a mechanic. Each scan included 18 sets of photograph sequences, 18 sentences to be imagined, and 18 non-imagined sentences.

The stimuli in the auditory encoding task consisted of sentences being read by the voices of Joe and Jill, sentences indicating for the participant to imagine the voice of Joe or Jill, and sentences telling the participant to read nonsensical words. Each scan included 32 sets of sentences being read, 32 sentences to be imagined, and 16 sentences comprised of nonsensical words.

2.6 Encoding Tasks

The auditory-visual encoding task consisted of two distinct runs in the scanner. During the visual run participants saw visual stimuli for the experience condition. During the auditory run participants heard auditory stimuli for the experience condition. In both runs participants experienced a stimulus, imagined a similar stimulus, experienced a control condition, and rated the vividness of their imagination.

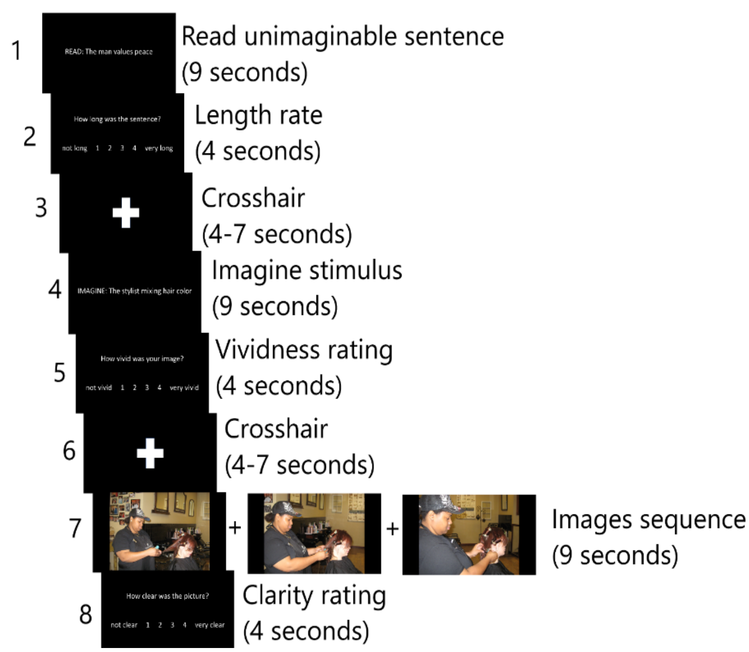

Figure 5 Visual Encoding Slideshow. Example of the visual slideshow and timing of stimuli presentation, crosshairs, and button responses as seen in the scanner.

Stimuli in the visual task appeared in a three-slide format in which the pictures were intended to have continuity like seeing a hair stylist inserting hair curls (see Figure 5 for example). Participants viewed visual stimuli for nine seconds before rating the clarity of the images they saw on a four-point scale using a button box (1 =

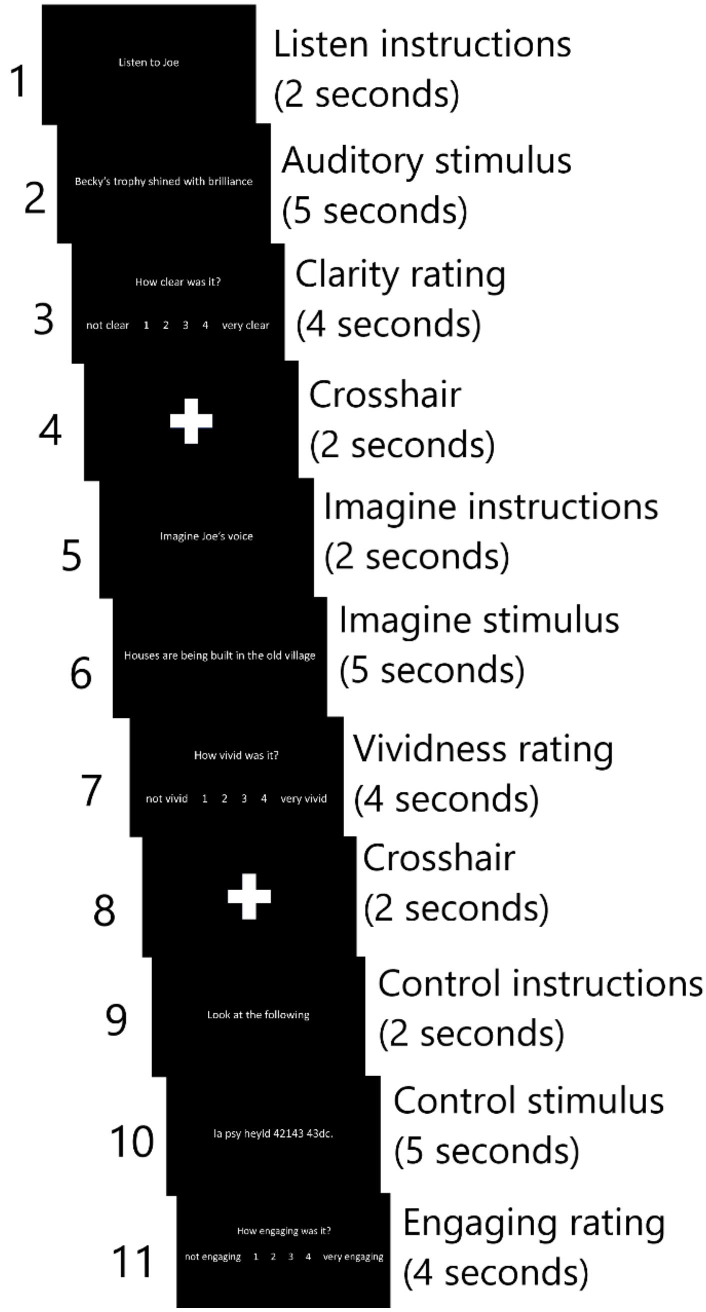

Figure 6 Auditory Encoding Slideshow. Example of the auditory slideshow and timing of stimuli presentation, crosshairs, and button responses as seen in the scanner.

not clear, 4 = very clear). Each run included nine instances of visual stimuli. Participants were then asked to imagine a similar scene like a hair-stylist washing a client's hair and rate the vividness of their imagined event using a four-point scale (1 = not vivid, 4 = very vivid). Each run included nine instances of stimuli to imagine. The control condition in the visual task was for participants to read sentences that cannot be imagined and to rate the length of these sentences (1 = not long, 4 = very long).

In each section of the task, a crosshair is displayed before every visual, imagine, and control stimulus for four to seven seconds. Each run included nine instances of control stimuli. For an example of the visual encoding task see Figure 5.

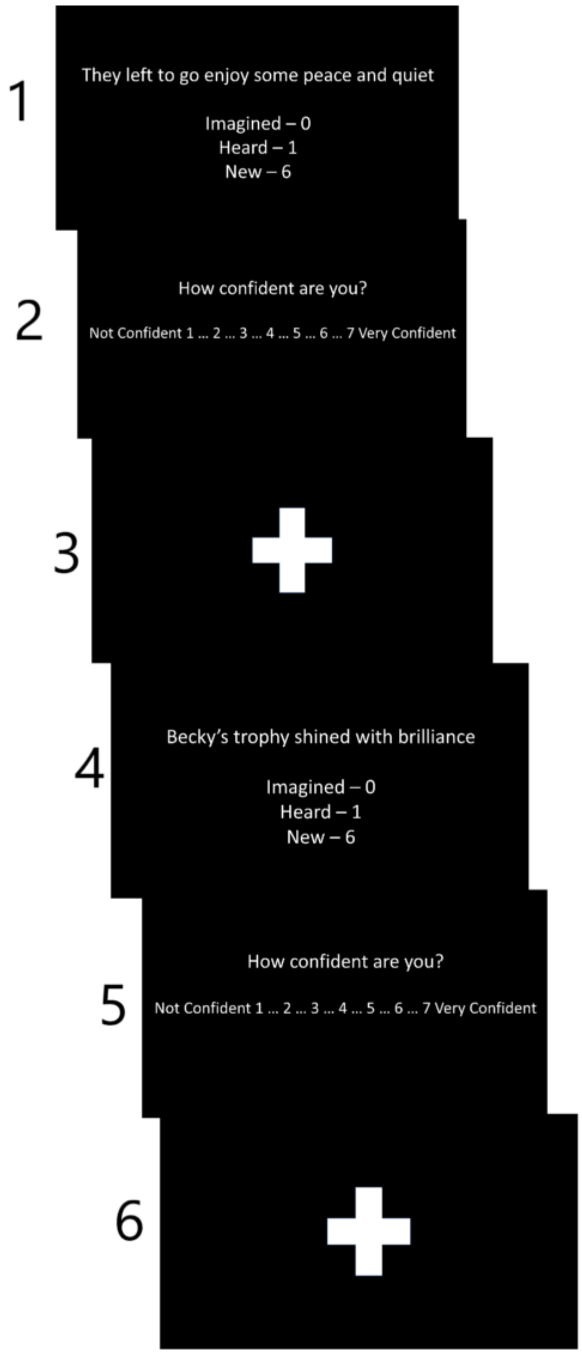

Figure 7 Auditory Test. Example of the auditory stimuli test, crosshairs, and button responses as seen in the scanner.

Stimuli for the auditory task were sentences read by voices that were introduced during the practice session. Participants listened to a sentence being read for five seconds, then rated the clarity of what they heard on a four-point scale using a button-box (1 = not clear, 4 = very clear). Each run included 16 instances of auditory stimuli. Then participants were asked to imagine a new sentence being read by either Joe or Jill and to rate the vividness of their imagined event (1 = not vivid, 4 = very vivid). Each run included 16 instances of stimuli to be imagined. The control condition in the auditory task was for participants to look at sentences of nonsense syllables and to rate how engaging they found the sentences on a four-point scale (1 = not engaging, 4 = very engaging). In each section of the task, a crosshair is displayed before every auditory, imagine, and control stimulus for two seconds. Each run included eight instances of control stimuli. For an example of the auditory encoding task see Figure 6.

2.6.1 Memory test – outside of the scanner

After the encoding portion of the task was completed, participants returned to the lab after 72 hours to complete the VVIQ and memory tests which they completed on a computer. For the VVIQ, participants were instructed to read a sentence about an object or scene, to imagine what is described, and then to rate how vivid their mental picture was on a five-point scale.

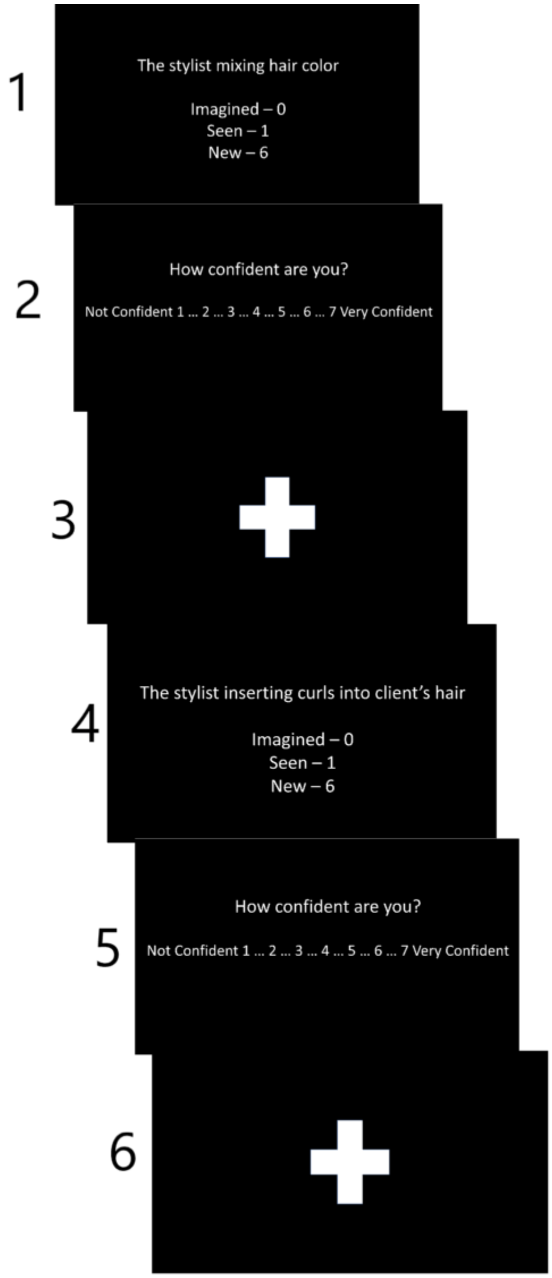

Figure 8 Visual Test. Example of the visual stimuli test, crosshairs, and button responses as seen in the scanner.

After the VVIQ was completed, participants began the memory tests. There were separate memory tests for the visual and auditory encoding tasks. First participants completed the auditory memory test. During the auditory memory test participants read sentences as they appeared on the computer screen. After reading a sentence, participants would indicate via key press if the sentence was heard, imagined, or completely novel. After each response, participants were also asked to indicate how confident they felt in their answer on a seven-point scale (1 being not confident, 7 being very confident). For an example of the auditory test see Figure 7.

After completing the auditory memory test, participants completed the visual memory test. During the visual memory test, participants read sentences as they appeared on the computer screen. Participants would then press a key to indicate if the sentence described a scene that they had seen, a scene they had imagined, or if the sentence described a completely novel scene. After each response, participants were also asked to indicate how confident they felt in their answer on a seven-point scale (1 being not confident, 7 being very confident). For an example of the visual test see Figure 8.

2.7 Neuroimaging

Scanning was conducted using a Siemens Magnetom Prisma 3T scanner. A T1-weighted MPRAGE sequence (TR = 2530.0 ms, TE = 3.55 ms, flip angle = 7^{o}, field of view = 256 mm, voxel size = 1.0 x 1.0 x 1.0 mm voxels, 176 slices) structural scan was collected. Functional images were collected with a single-shot echoplanar gradient-echo pulse sequence (TR = 1200.0 ms, TE = 30.0 ms, flip angle = 65^{o}, field of view = 220 mm, voxel size = 2.5 x 2.5 x 2.5 mm voxels, 48 slices). The visual encoding data was collected first. Visual encoding data was collected in two runs with each run being seven minutes in length. The auditory data was collected second. Auditory encoding data was collected in two runs with each run being 10 minutes in length.

	Auditory Part 1	**Auditory Part 2**	**Visual Part 1**	**Visual Part 2**
Overall Head Motion	0.16	0.16	0.17	0.16

Table 1 *Overall group head motions in mm for participants included in fMRI analysis.*

2.8 Preprocessing

All neuroimaging data was preprocessed using fMRIprep (Esteban et al., 2019). The T1w image was corrected for intensity nonuniformity with N4BiasFieldCorrection and skull stripped to the OASIS template with a *Nipype* implementation of the antsBrainExtraction.sh workflow (Marcus et al., 2007; Gorgolewski et al., 2011). FAST, an FSL-based segmentation tool, was used to implement brain tissue segmentation of cerebrospinal fluid (CSF), white matter (WM), and gray matter (GM) on the brain-extracted T1-weighted image (T1w) (Zhang et al., 2001). Recon-all, a FreeSurfer based tool for anatomical reconstruction, was used to reconstruct brain surfaces from the subject's T1w reference (Dale et al., 1999). Spatial normalization to the ICBM 152 Nonlinear Asymmetrical template was performed using non-linear regression with antsRegistration (Avants et al., 2008).

For preprocessing of functional data, a reference volume and its skull-stripped version was generated using custom fMRIprep (Esteban et al., 2019) methodology. A field map was estimated based on two echo-planar imaging references with opposing phase-encoding directions using 3dQwarp, an AFNI based tool for distortion estimation and unwarping (Cox et al., 1997). A corrected echo-planar imaging reference was calculated for more accurate co-registration with the anatomical reference based on the estimated susceptibility distortion. The BOLD reference was then co-registered to the T1w reference using bbregister which implements boundary-based registration. Co-registration was configured with six degrees of freedom (Greve et al., 2009). Head-motion parameters and the six corresponding rotation and translation parameters were estimated and corrected for using MCFLIRT (Jenkinson et al., 2002). This was done before any spatiotemporal filtering. The BOLD time-series were resampled onto their original native space by applying a single transform to correct for head-motion and susceptibility distortions. The BOLD time-series were also resampled into the MNI152Lin2009cAsym standard space. Spatial smoothing was done with an isotropic gaussian kernel of 6mm FWHM (full-width half-maximum). Percent signal change was not computed. Principal components for the two

CompCor variants (temporal and anatomical) were estimated after high-pass filtering the preprocessed BOLD time-series. TCompCor (temporal) components were calculated from the top 5% variable voxels within a mask covering the subcortical regions. ACompCor (anatomical) components were calculated within the intersection of the aforementioned mask and the union of CSF and WM masks calculated in T1w space after their projection to the native space of each functional run. Frames that exceeded a threshold of 0.5 mm FD or 1.5 standardized DVARS were annotated as motion outliers. Two participants were marked as having scans with excessive motion: one participant with multiple images who was not considered in the neurophysiological analyses, and another participant who had three images with excessive motion, all of which were collected from the second part of the visual task. Since there were so few images with motion artifacts, the second participant will still be included in the fMRI analyses. GLMs for auditory and visual encoding included conditions for every task condition including imagination, experience, control, and button-response. Vividness rating scores were included as parameters in the imagine condition for each task. SPM's canonical HRF was used and framewise displacement was included as a regressor.

3 ANALYSIS

3.1 Analyses

To assess if greater mental imagery ability and higher subjective vividness ratings contribute to an increase in reality monitoring errors, *t*-tests were carried out between high and low scoring groups using SPSS. The *p*-value decision criterion for significance was set to 0.05.

fMRI analyses at the subject and group level were performed using SPM12. A grey matter mask was applied to all group level analyses to ensure data was not included from white matter. Multiple comparisons were corrected for using family wise error correction and an extent threshold of ten voxels was set as that threshold was used in similar studies (Sugimori et al., 2014).

3.1.1 Aim 1

The relationship between imagery ability and false alarms for imagined events was determined by grouping participants into high and low groups for each measure (VVIQ, OSIQ-O, OSIQ-S, BAIS-V) using a median split. *T*-tests were then conducted comparing high and low scoring groups for each measure to determine if there was a significant difference in the number of false alarms for imagined events made by each group.

The median VVIQ score was 63. The median scores for the OSIQ-O and the OSIQ-S were 3.33 and 2.53. The median score for the BAIS-V was 60. Participants who scored above the median of a particular measure were grouped into the high group for that measure whereas participants who scored below the median were grouped into the low group.

3.1.2 Aim 2

Differences between average vividness ratings for imagined trials recalled as having been experienced and imagined trials recalled as having been imagined were determined by computing the mean vividness ratings for visually imagined trials recalled as having been seen, visually imagined trials recalled as having been imagined, auditorily imagined trials recalled as having been heard, and auditorily imagined trials recalled as having been imagined. *T*-tests were conducted to determine if there was a significant difference in average vividness ratings between imagined trials subsequently recalled as having been experienced, and imagined trials subsequently recalled as having been imagined, in both sensory domains.

3.1.3 Aim 3

Within each sensory modality, subject level analyses included conditions for imagined stimuli recalled as having been imagined, imagined stimuli recalled as having been experienced, imagined stimuli recalled as being new, experienced stimuli recalled as having been experienced, experienced stimuli recalled as having been imagined, experienced stimuli recalled as being new and framewise displacements for both runs of the task.

Group level analyses were conducted to determine differences in activity during encoding between high and low scoring individuals across each measure. 2x2 factorial ANOVAs were used at the group level with imagery ability (high or low) and response type (correct recognition or false alarm) as factors. Activity during the encoding of imagined trials recalled as having been experienced was compared to activity during the encoding of imagined trials recalled as having been imagined, in the high versus low imagery ability groups.

3.2 **Power Considerations**

In order to identify a sufficient number of participants for this study, a power analysis was conducted using G*Power (Faul et al., 2007). The analysis was run using a 2x2 mixed effects design. The results showed that 34 participants would be required for the study to be sufficiently powered. While our sample does not have 34 participants, it does approach the sample size for similar fMRI studies. Gonsalves et al. (2004) reported a sample of 11 participants in their visual imagery study, Sugimori et al. (2014) reported a sample of 20 participants for the auditory imagery study, and Kleider et al. (2019) reported a sample of 28 participants for their multi-modal imagery study. Therefore, while our study does not meet the sample size described by G*Power, it does have a sample similar in size to studies utilizing a similar design.

4 RESULTS

4.1 Aim 1

4.1.1 VVIQ Scores and False Alarms for Imagined Events

The high VVIQ group (M=6.18, SD=3.86) and the low VVIQ group (M=5.60, SD=4.11) exhibited no statistically significant difference in the number of false alarms made for imagined events $t(19)=-.334$, p=.742. The range of false alarms for the high and low VVIQ groups was 12 and 12.

No statistically significant difference were observed between high (M=7.55, SD=1.74) and low (M=9.10, SD=5.11) VVIQ groups in the number of correct responses for imagined events $t(17)=.861$, p=.401. The range of correct recognitions for the high and low VVIQ groups was 5 and 16.

4.1.2 OSIQ-O Scores and False Alarms for Imagined Events

The high OSIQ-O group (M=7.00, SD=3.67) and the low OSIQ-O group (M=4.44, SD=4.03) exhibited no statistically significant difference in the number of false alarms made for imagined events $t(16)=-1.41$, p=.179. The range of false alarms for the high and low OSIQ-O groups was 12 and 12.

No statistically significant difference were observed between high (M=6.50, SD=3.63) and low (M=9.44, SD=3.84) OSIQ-O groups in the number of correct responses for imagined events $t(15)=1.619$ p=.126. The range of correct recognitions for the high and low OSIQ-O groups was 12 and 13.

4.1.3 OSIQ-S Scores and False Alarms for Imagined Events

The high OSIQ-S group (M=5.55, SD=4.18) and the low OSIQ-S group (M=5.88, SD=3.98) exhibited no statistically significant difference in the number of false alarms made for imagined events *t*(16)=.173, p=.865. The range of false alarms for the high and low OSIQ-S groups was 13 and 11.

No statistically significant difference were observed between high (M=9.33, SD=3.91 and low (M=6.63, SD=3.66) OSIQ-S groups in the number of correct responses for imagined events *t*(15)=-1.469 p=.162. The range of correct recognitions for the high and low OSIQ-S groups was 13 and 11.

4.1.4 BAIS-V Scores and False Alarms for Imagined Events

The high BAIS-V group (M=5.55, SD=3.77) and the low BAIS-V group (M=6.00, SD=3.38) exhibited no statistically significant difference in the number of false alarms made for imagined events *t*(15)=.254, p=.803. The range of false alarms for the high and low BAIS-V groups was 13 and 9.

No statistically significant difference were observed between high (M=5.28, SD=3.40 and low (M=4.43, SD=2.57) BAIS-V groups in the number of correct responses for imagined events *t*(12)=-.532 p=.605. The range of correct recognitions for the high and low BAIS-V groups was 11 and 7.

4.2 Aim 2

4.2.1 Auditory Vividness Ratings for False Alarms and Correct Recognition

A paired-samples *t*-test was conducted to evaluate the impact of response type (false alarm or correct recognition) on vividness rating in the auditory domain. There was no significant difference in the vividness rating for false alarms (M=3.05, SD=.39) and correct recognitions (M=3.04, SD=.55), *t*(15)=-.068, p=.947.

4.2.2 Visual Vividness Ratings for False Alarms and Correct Recognition

A paired-samples *t*-test was conducted to evaluate the impact of response type (false alarm or correct recognition) on vividness rating in the visual domain. There was a significant difference in the vividness rating for false alarms (M=3.34, SD=.42) and correct recognitions (M=2.99, SD=.61) $t(18)=-2.768$, p=.013. Participants reported significantly higher subjective vividness ratings for imagined trials later recalled as having been experienced than for imagined trials later recalled as having been imagined.

4.3 Aim 3

4.3.1 Neuroimaging Results

At the group level, fMRI data was analyzed using 2x2 factorial ANOVAs. No activations for false alarms vs correct recognitions in the high or low imagery groups in either sensory domain reached the threshold for cluster-wise significance or passed FWE correction. Reaction time data was not collected during memory tests. Nonsignificant results were identified using the next highest possible thresholds for exploratory purposes. The thresholds for non-significant results identified the highest peaks of non-significant activations. Follow up analyses examined the main effect of false alarms in the visual and auditory domains regardless of imagery groups. Main effects did not reach the threshold for cluster-wise significance or pass FWE correction. Analyses of main effects were thresholded at 0.001 uncorrected in the visual domain and 0.01 uncorrected in the auditory domain.

4.3.2 Group X Response Type Interaction Effects

4.3.2.1 VVIQ Results

VVIQ results were thresholded at 0.01 uncorrected for the high imagery group and 0.005 uncorrected for the low imagery group. The high VVIQ group exhibited non-significant activations in the right putamen, the left middle frontal lobe, and the left and middle cerebellum for false alarms vs correct recognitions. The low VVIQ group exhibited non-significant activations in the right supplementary motor area and the right inferior parietal gyrus for the same contrast.

Brodmann Area	Anatomical Area	MNI Coordinates	Cluster Extent (in voxels)	Peak
High VVIQ				
48	R. Putamen	-31 0 -6	11	4.31
37	L Cerebellum	24 -50 -18	11	3.73
6	L Mid. Frontal Gyrus	24 3 62	12	3.63
Low VVIQ				
6	R Supp. Motor Area	-11 -4 62	10	4.91
40	R Inf. Parietal	-38 -37 52	10	3.91

Table 2 *Nonsignificant activations identified for false alarms > correct recognitions in high and low VVIQ groups.*

4.3.2.2 OSIQ-O Results

OSIQ-O results were thresholded at 0.01 uncorrected for the high imagery group and 0.005 uncorrected for the low imagery group. The high OSIQ-O group exhibited non-significant activations in bilateral precentral gyrus, bilateral middle frontal gyrus, left cerebellum, right supplementary motor area, right putamen, and right superior frontal gyrus. The low OSIQ-O group exhibited non-significant activations in the left precentral gyrus.

Brodmann Area	Anatomical Area	MNI Coordinates	Cluster Extent (in voxels)	Peak
High OSIQ-O				
4	R Precentral Gyrus	-36 -17 52	16	4.91
10	R Mid Frontal Gyrus	-31 50 4	17	4.62

19	L Cerebellum	16 -50 -13	19	3.87
6	L Precentral Gyrus	54 8 27	11	3.71
6	R Supp Motor Area	-8 3 50	20	3.48
48	R Putamen	-28 8 -8	16	3.4
45	L Mid Frontal Gyrus	42 46 24	11	3.34
6	R Sup. Frontal Gyrus	-24 -12 64	12	3.18
Low OSIQ-O				
4	L Precentral Gyrus	59 -2 32	14	4.06

Table 3 *Nonsignificant activations identified for false alarms > correct recognitions in high and low OSIQ-O groups.*

4.3.2.3 OSIQ-S Results

OSIQ-S results were thresholded at 0.005 uncorrected for the high imagery group and 0.01 uncorrected for the low imagery group. The high OSIQ-S group exhibited non-significant activations in the left supplementary motor area and the right postcentral gyrus. The low OSIQ-S group exhibited non-significant activations in the right precuneus.

Brodmann Area	Anatomical Area	MNI Coordinates	Cluster Extent (in voxels)	Peak
High OSIQ-S				
6	L Supp. Motor Area	6 -14 57	25	3.9
4	R Postcentral Gyrus	-28 -30 67	17	3.63
Low OSIQ-S				
7	R Precuneus	-6 -77 47	10	4.23

Table 4 *Nonsignificant activations identified for false alarms > correct recognitions in high and low OSIQ-S groups.*

4.3.2.4 BAIS-V Results

BAIS-V results were thresholded at 0.06 uncorrected for the high imagery group and 0.02 uncorrected for the low imagery group. The high BAIS-V group exhibited non-significant activations in the right cerebellum. The low BAIS-V group exhibited non-significant activations in the left supplementary motor area, the left middle temporal lobe, the left middle frontal lobe, the left inferior frontal lobe, the right cuneus, the left medial superior frontal lobe, and the left precuneus.

Brodmann Area	Anatomical Area	MNI Coordinates	Cluster Extent (in voxels)	Peak
High BAIS-V				
-	R Cerebellum	-16 -87 -33	46	2.8
47	R Inf. Frontal Gyrus	-38 26 -10	17	2.61
10	R Sup. Medial Frontal	-4 60 30	12	2.26
44	R Precentral	-46 3 27	10	2.26
-	Middle Cingulum	-1 -17 32	14	2.25
Low BAIS-V				
-	L Supp Motor Area	-1 20 57	12	3.41
21	L Mid Temporal	66 -42 -3	11	3.35
8	L Mid Frontal Gyrus	26 16 60	12	3.13
44	L Inf Frontal Gyrus	34 16 14	15	3.06
-	R Cuneus	-14, -70, 30	15	2.97
8	L Medial Sup. Frontal	6 38 44	10	2.8
-	L Precuneus	9 -54 32	33	2.76

Table 5 *Nonsignificant activations identified for false alarms > correct recognitions in high and low BAIS-V groups.*

4.3.3 Main Effect of False Alarms

4.3.3.1 Visual False Alarms

Main effects of false alarms in the visual domain were thresholded at 0.001 uncorrected. The results showed non-significant activations in bilateral supplementary motor area, bilateral inferior frontal gyrus, right angular gyrus, right insula, right inferior frontal gyrus, right inferior temporal gyrus, right lingual gyrus, left inferior occipital gyrus, and right inferior parietal gyrus.

Brodmann Area	Anatomical Area	MNI Coordinates	Cluster Extent (in voxels)	Peak
Main Effects of False Alarms in Visual Domain				
8	R Supp Motor Area	-4 16 52	108	7.11
45	R Inf Frontal Gyrus	-54 30 20	211	6.06
7	R Angular Gyrus	-36 -62 50	72	5.8
47	R Insula	-31 26 0	48	5.67
37	R Inf Temporal Gyrus	-46 -52 -10	16	5.5
18	R Lingual Gyrus	-18 -84 -6	21	5.09
18	L Inf Occipital Gyrus	22 -87 -6	39	5.04
47	L Inf Frontal Gyrus	32 30 -3	13	4.88
40	R Inf Parietal Gyrus	-36 -44 40	10	4.69
32	L Supp Motor Area	9 20 50	32	4.38

Table 6 *Nonsignificant activations identified for main effect of false alarms in the visual domain.*

4.3.3.2 Auditory False Alarms

Main effects of false alarms in the auditory domain were thresholded at 0.01 uncorrected. The results showed that only the right inferior occipital gyrus exhibited non-significant activations for false alarms in the auditory domain. A cluster of 12 voxels was detected at MNI coordinates [-26, -94, -8] showing a peak activation of T = 4.45.

5 DISCUSSION

The objective of this thesis was to identify how differences in imagery vividness relate to false alarms for imagined events across sensory modalities and how activity in the brain relates to false alarms for imagined events in people with high versus low imagery abilities. The source monitoring framework suggests that individuals high in imagery ability would be more likely to confuse imagined events as having occurred in reality than individuals low in imagery ability. Previous works identified several key regions as playing a role in this process including the anterior cingulate cortex and the middle temporal gyrus in vivid visual imagery, and the middle temporal gyrus and the superior temporal gyrus in vivid auditory imagery. Our findings yielded mixed support for our hypotheses regarding between group differences in number of false alarms and the regions associated with false alarms for imagined events.

We did not identify any statistically significant differences in the number of false alarms to imagined events or in the number of correct recognitions for imagined events in any group. While no group differences were observed in number of false alarms for imagined events, there was a significant difference in the subjective vividness ratings for false alarms and for correct recognitions in the visual domain. Participants rated their imagination for events later recalled as having been experienced as significantly more vivid than their imagination for events later recalled as having been imagined in the visual domain. Meanwhile, no significant effects were identified in the auditory domain, suggesting that the relationship between vividness and false alarms could be domain specific.

5.1 Behavioral Results

Regarding the relationship between BAIS-V scores and false alarms, we expected to find that the high BAIS-V group would exhibit a greater number of false alarms than the low BAIS-V group. This prediction was based on the source monitoring framework which suggests that greater imagery ability would be related to a greater number of false alarms. However, the literature surrounding source monitoring in the auditory domain did not support this perspective. In fact, we were unable to find any studies up to this point which specifically examined the relationship between BAIS-V and false alarms. Rather, Halpern (2015) found a relationship between hallucination proclivity as measured by the LSHS-R and BAIS-V scores, and Sugimori et al. (2014) found a relationship between BOLD responses in the STG for false alarms in participants with high scores on the LSHS-R. Since individuals prone to hallucinations were shown to have higher BAIS-V scores and there was a relationship between hallucination proclivity and false alarms, we expected that relationship to extend to auditory imagery ability as well. Our findings, however, indicate that auditory imagery ability is not related to false alarms in the auditory domain. Additionally, no differences were observed in auditory vividness ratings between false alarms and correct recognitions, which serves as a more direct measure of in-the-moment imagery vividness than the BAIS-V, suggesting no relationship between vividness of auditory imagery and false alarms for imagined auditory events in our sample.

Regarding the relationship between measures of visual imagery (OSIQ-O, OSIQ-S, and VVIQ) and false alarms to imagined events, we expected to find that high scoring participants would exhibit a greater number of false alarms than low scoring participants across all three measures. This prediction was informed by both the source monitoring framework and previous work demonstrating that individuals with greater visual imagery ability were more prone to memory distortions in the form of source confusion, imagination inflation, and boundary extension (Dobson & Markham, 1993; Horselenburg et al., 2000; Blazhenkova, 2017). However, we were unable to replicate these effects in our sample. Our sample did not show a bimodal distribution in any of our measures which could explain the observed result. Alternatively, this could be interpreted as a lack of a relationship between visual imagery ability and false alarms to imagined events, however, we did observe an effect of subjective vividness ratings being significantly greater for false alarms to imagined events than for correct recognition of imagined events. This observation suggests that trial-by-trial vividness ratings taken moments after engaging in imagery are a better predictor of whether or not an imagined event will be mistaken for experience than a person's overall imagery ability. Furthermore, although non-significant, a greater difference in means was observed between high and low groups for object imagery than for spatial imagery. This is likely because the stimuli used in the task focused on the actors and what they were doing rather than spatial relationships between different objects or actors. Therefore, when people engaged in imagery, they were likely focusing on creating vivid representations of imagined actors instead of accurate representations of where objects were located in imagined space. This focus on creating vivid representations of imagined actors and objects led to greater interference from object imagery in the high object imagery group than interference from spatial imagery in either the high or low groups.

The most likely explanation for our null results is that our sample size was simply too small to observe an effect. It is also possible that the limited distribution of scores across our sample made it difficult to identify group differences. Having an increased sample size with a greater degree of difference in scores between high and low groups would allow for a more robust analysis. By performing a median split, participants who had scores that were relatively average but trending high or low were included in either group. This meant that we could not fully assess differences between high and low vividness groups, as participants with average scores were included in both groups. An alternative approach would be to split the sample into three groups and remove participants with average scores from the analysis; however, our limited sample size prevented us from doing so. We did, however, identify moderate correlations between all measures of imagery and subjective vividness ratings. The VVIQ had a correlation of $r = 0.41$, the OSIQ-O had a correlation of $r = 0.38$, the OSIQ-S had a correlation of $r = 0.53$, and the BAIS-V had a correlation of $r = 0.46$. The correlations between scores on imagery assessments and subjective ratings of vividness suggest that high scoring participants on measures of imagery also rated false alarms as being more vivid than correct recognition of imagined stimuli, but due to a low sample size and sub-optimal distribution of scores, we did not see a difference in the number of false alarms between groups. In future iterations of this study, it would be best to recruit a larger sample of participants and pre-select participants for high and low imagery ability groups instead of performing a median split. Additionally, running the task in a single sensory domain would allow for a greater number of imagery observations, further increasing the reliability of results.

Several alternative explanations could also account for the null results we observed in either domain. It is possible that our task did not sufficiently capture the relationship between imagery vividness and false alarms because it was a complicated task which included several different encoding conditions. Although participants were given a practice task and an opportunity to ask questions about the task, it remains a possibility that they could have been confused during the encoding phase or simply found it difficult to engage in imagery with the level of detail we asked of them. Since the previous iteration of this experiment, changes were made to the protocol which included removing the blurred condition from the visual encoding portion and removing the attentional response slides from both conditions. Furthermore, the introduction of a memory test was a novel component of this experiment. While the memory test was based on the methods used in Fulford et al. (2018), our test varied from theirs in three key ways. First, our memory test was administered to participants after they returned to the lab following a 72 hour delay, whereas Fulford and colleagues tested memory immediately following encoding. The delay was meant to simulate a life-like source monitoring scenario in which a person may not be asked to engage in recall until several days after encoding an event. Second, on our memory test participants were cued to recall using written descriptions of what they experienced and imagined during encoding, whereas Fulford and colleagues showed participants the exact same stimuli that appeared during encoding. Again, we sought to simulate a life-like situation in which a person would be asked to make a source monitoring judgement based on a description of what they encoded rather than fully re-experiencing the same stimulus. Third, our tasks and memory tests spanned two sensory domains, in effect doubling the difficulty when compared to the task and memory test employed by Fulford and colleagues. Being asked to remember both visual and auditory stimuli and then to distinguish between whether the stimuli were experienced or imagined following a 72 hour delay is orders of magnitude more difficult than doing so in just the visual domain with no delay. It is thus possible that due to the complexity of the task, we were unable to capture the effect of vivid imagery contributing to an increase in reality monitoring errors.

5.1 Neuroimaging Results

5.1.1 Auditory Imagery

For the fMRI analysis we expected to observe activity in the middle temporal gyrus and the superior temporal gyrus for false alarms to imagined events in the high auditory imagery group as these regions were previously identified as playing a role in false alarms for imagined events in the auditory domain (Sugimori et al., 2014). We observed no results that passed the threshold for cluster-wise significance in either of the auditory imagery groups. This is likely due to a combination of not having a sufficient number of participants in our sample and the use of a median split instead of pre-selecting for high and low vividness groups.

Sub-threshold activity was observed in the right cerebellum, the right inferior frontal lobe, the right superior medial frontal lobe, the right precentral gyrus, and the middle cingulum at a threshold of 0.06 uncorrected in the high BAIS-V group. Although these regions were not previously found to be related to reality monitoring, Fulford and colleagues (2018) describe that activity in frontoparietal regions supports the attention and cognitive control necessary to initiate and maintain an imagined event which could account for the observed activity in the frontal lobe. While these regions are not related to the reality monitoring literature, activity in these regions suggests that our participants were actively engaged in mental imagery during the imagination portions of the task.

The low BAIS-V group displayed activity in the left supplementary motor area, the left middle temporal lobe, the left middle frontal lobe, the left inferior frontal lobe, the right cuneus, the left medial superior frontal lobe, and the left precuneus at a threshold of 0.02 uncorrected. Several of these regions, including the frontal lobe, supplementary motor area, and precuneus are not related to false alarms per se but are commonly observed in studies of mental imagery as they support imagery in general, imagination of actions, and internally directed thought further confirming participant engagement in the imagery tasks. The left middle temporal lobe, however, is related to false alarms for auditory imagination. The presence of this activity in the low vividness condition but not the high vividness condition suggests that participants in the low vividness condition may have been engaging in imagery that is more vivid than participants in the high vividness condition. This may be due to our BAIS-V sample not forming a bimodal distribution resulting in the low vividness group having a range of participants both high and low in auditory imagery.

The main effect of false alarms in the auditory domain displayed activity in the right inferior occipital gyrus at a threshold of 0.01 uncorrected. This was an unexpected finding, as activity in occipital gyri is typically associated with visual experience and imagery. There are two potential explanations for this finding, both of which have to do with the stimuli used in the auditory task. Participants were cued to imagine an auditory stimulus by reading text describing what they were supposed to imagine. Simply reading the text may have engaged the occipital lobe as participants were looking at the text. Alternatively, the content of the stimuli may have led participants to inadvertently engage in visual imagination as several of the auditory stimuli could easily have been visually imagined. For example, auditory stimuli included sentences like, “The lake’s water was beautiful to look at” or “Houses are being built in the old village”. It is possible that these stimuli evoked visual imagery, as they described scenes that were easy to imagine visually. In future iterations of the study, auditory stimuli should be revisited to control for the potential for participants to engage in visual imagination when cued for auditory imagery.

5.1.2 Visual Imagery

For our visual imagery analyses, we expected to observe activity in the anterior cingulate cortex and the middle temporal gyrus for false alarms to imagined events in the visual domain. These predictions were based on previous work showing that individuals with greater visual imagery ability showed increased activity in these regions for false alarms to imagined events (Kurkela & Dennis, 2016; Gonsalves 2004). We observed no results that passed the threshold for cluster-wise significance in any of our groups. Much like in the auditory imagery sample, this is likely due to having too few participants in our sample and using a median split instead of pre-selecting for high and low vividness groups. While participants were engaging in vivid visual imagery, as evidenced by the visual trial-by-trial vividness results, we were unable to detect any significant activations which is likely due to not having enough participants to observe any differences in our analysis. Furthermore, since trial-by-trial vividness ratings appear to be more closely related to false alarms for imaged events than performance on standardized measures of imagery, further analyses could be conducted to examine how differences in subjective ratings of vividness relate to activity in the brain for false alarms for imagined events. Similarly to previous predictions, I would expect the high vividness group to display activations in a small number of regions associated with reality monitoring errors and the low vividness group to display wide ranging activations as the brain regions recruited during processing is reduced with proficiency.

Although we did not observe the expected activity in the anterior cingulate and the middle temporal gyrus, across the visual imagery groups both high and low scoring participants displayed sub-threshold activations that would be expected during visual imagination. This includes activity in regions like the frontal gyri and somatosensory areas. While these sub-threshold activations do not replicate findings from the reality monitoring literature, they do confirm that participants were engaging in visual imagery. In contrast to the findings of Fulford and colleagues (2018), the visual results showed that the high imagery groups recruited a more widespread set of regions than the low imagery groups in every measure. This is likely due to the wide distribution of scores included in each group and the low thresholds that were used to explore non-significant activations.

The main effect of false alarms in the visual domain displayed activations in regions typically associated with visual imagery at a threshold of 0.001 uncorrected. This included regions like the supplementary motor areas, the frontal gyri, and the occipital gyri. Although these areas are not specifically related to false alarms in the literature, much like the results of the interaction effects, they confirm that participants were engaged in visual imagery during the task conditions. The lack of activity in the ACC and the MTG suggests that although participants were engaged in imagination, it is possible that their imaginations may not have been vivid enough to later be misremembered for reality. Instead, we could be observing an effect of participants misattributing a memory's source simply because they forgot the source following the delay between encoding and recall. To address this possibility, further analyses should be conducted to examine only false alarms for imagined events in which participants were highly confident in their answer. Alternatively, it is possible that activity in the occipital gyri during encoding has a relationship with false alarms for imagined events that has not previously been examined in the literature. This could be a potential explanation for the occipital activity that was observed during false alarms in both the auditory and visual domains. This seems unlikely, however, as previous meta-analytic research encompassing several encoding-based studies of false alarms for imagined events did not associate occipital activity with false alarms.

5.2 Limitations

Our main limitations in this study were a relatively small sample size and an inadequate distribution of scores across our measures of mental imagery. While we were able to capture some of the variability in vividness via trial-by-trial responses, it would have been ideal to pre-select groups on the basis of their imagery ability instead of performing a median split. The issue of sample size contributed to nearly every limitation in this study. We were unable to preselect imagery groups because we simply did not have enough participants to do so. Furthermore, we had to remove several participants from various analyses due to having incomplete data sets, excessive movement, and memory tests with no false alarms or correct recognitions, which reduced our initial sample of 25 participants to as few as 16 in some cases.

Despite these limitations, we were able to make one key observation demonstrating that false alarms in the visual domain were related to higher subjective trial-by-trial vividness ratings. We also identified moderate correlations between scores on imagery measures and subjective vividness ratings. This finding informs the larger context of the imagery literature by confirming that vivid visual imagery is related to false alarms; however, a larger sample with a greater distribution of scores is needed to demonstrate significant effects. Additionally, our task made several improvements over similar studies, the most pronounced being trial-by-trial vividness ratings taken in scanner. Future mental imagery studies should incorporate trial-by-trial vividness responses, even if they do not utilize neuroimaging, as these responses are related to imagery ability as measured by standardized assessments and may account for variance in imagery ability not captured by standardized assessments.

5.3 Aphantasia Case Study

After collecting the initial sample, data was also collected from two participants who self-reported experiencing aphantasia, a condition in which people experience no mental imagery (Zeman et al. 2015). While no statistical tests were run since there were only two participants, we decided to compare findings from our main sample to our Aphantasia sample to identify how a complete lack of imagery ability relates to reality monitoring.

For auditory imagery, aphantasics had BAIS-V scores between two and three standard deviations below controls. They also commonly reported vividness ratings that were lower than controls by three to four standard deviations. Regarding false alarms in the auditory domain, one participant had 6 false alarms, which is close to the mean for both the high and low BAIS-V groups, while the other had just 3.

For visual imagery, aphantasic participants scored between four and five standard deviations lower than controls on the OSIQ-O and three to four standard deviations lower on the VVIQ. Scores on the OSIQ-S were relatively consistent between the aphantasia sample and the controls. During visual imagery, again the aphantasic participants' subjective vividness ratings were between three and four standard deviations lower than the controls. Regarding false alarms in the visual domain, again one participant had 5 false alarms, which was relatively consistent with the rest of the sample, while the other had just 2.

This limited case study comparing participants with ahantasia to the rest of our sample shows that while participants with aphantasia tended to score lower across the measures of imagery ability, their imagery deficits may only apply to certain imagery abilities as visual-spatial imagery was consistent with the rest of the sample. Furthermore, the reality monitoring results suggest that individuals with aphantasia may be less prone to reality monitoring errors as they experience less interference from imagined events when making source judgements. Although preliminary data and the source monitoring framework support the idea that people with aphantasia would not experience interference from imagined events when making source judgements more research is needed to determine if that is indeed the case.

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