

Internal vs. External Attention and the Neurocognitive Processes of Subsequent Memory

Sade Abiodun

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Abstract:

The capacity to store large amounts of information is increasingly relevant in today's data-saturated society. Two subtypes of our attentional mechanisms are known as internal and external attention, and are respectively characterized by the way we externally attend to relevant sensory information and how we focus inwardly to process and generate mental interpretations of this information. The nature of both external and internal attention and their respective roles in the perception and mental consolidation of sensory information have become integral components of the discussion of learning mechanisms, illustrating the importance of both the initial presentation and subsequent reproduction of stimuli over the course of encoding. We aim to look at the correlation between these two subtypes of attention and successful encoding and retrieval by eliciting steady-state visually evoked potentials (SSVEP) – notable EEG spikes that coincide with the specific frequency of stimuli presentation – during a visual memory task. Improved memory performance was found to increase alongside with image vividness, and SSVEPs were shown to serve as a reliable marker of attentional diversion from external stimuli during internal visualization processes, with greater decreases in SSVEP power corresponding with subsequently remembered words in comparison to forgotten words. Using high temporally resolute EEG, we hope to uncover whether shifts in attentional loci reflect in differences in our memory performance.

INTRODUCTION

In today's data saturated world, the ability to learn and proficiently retain information is integral for staying up to date and to achieve one's behavioral goals. Whether in the classroom, in the boardroom, or on the web, our attention to relevant inputs is critical to our long-term success, directly influencing our capacity to process and subsequently utilize these details in future circumstances. A subtype of our attentional mechanisms is known as internal attention, and is defined as the mechanism by which we focus 'inwardly' on mental representations (Benedek et al. 2015). External attention, on the other hand, directs the allocation of our attentional resources to the external environment (Chun, 2011). The nature of both external and internal attention and their respective roles in the perception and mental consolidation of sensory information have become integral components of the discussion of learning mechanisms, illustrating the importance of both the initial presentation and subsequent reproduction of stimuli over the course of encoding (Roth, Johnson, Raye, & Constable, 2009)

Activation Patterns Related to Attention

Many studies have focused on the neuro-oscillatory frequency bands that are associated with attention, using electroencephalography (EEG) and other tools to analyze alpha (8-12Hz), theta (4-8 Hz), and gamma (>30Hz) wave activity. Generally, Alpha oscillations have been shown to inversely correlate with attentiveness and alertness, while greater theta activation in frontal cortices has been linked to improved reaction times and error rates during attentional tasks. A reduction in posterior alpha activity contralateral to target locations, in particular, has been shown to decrease during activities requiring spatial attention (Dockree, Kelly, Foxe, Reilly, & Robertson, 2007; Foucher, Otzenberger, & Gounot, 2004). These oscillatory fluctuations may also be characteristic of the shift in attention from external stimuli perception to

internal representation. Research has demonstrated that during certain attentional exercises, bursts in alpha wave activity have occurred parallel to internal attention, where subjects were focused on generating internal thoughts, compared to external attention (when subjects were instructed to focus on the external stimuli changes in task demands from attending to stimuli to encoding the relevant inputs for later recall (Villena-González, López, & Rodríguez, 2016). The importance of these shifts has also been highlighted because of their implications in the differential activation during external target attendance versus mind-wandering (Stawarczyk, Majerus, Maquet, & D'Argembeau, 2011) and may hold the key to distinguishing between patterns of successful vs. unsuccessful encoding.

Neural Correlates of Attention

Combined EEG and Functional Magnetic Resonance Imaging (fMRI) research has shed some light on the neuroanatomical substrates of attention and learning, highlighting the contributions of the dorsolateral prefrontal and intra-parietal cortices in the maintenance of attention during task completion (Corbetta & Shulman, 2002; Foucher et al., 2004). Both sets of areas have been implicated in top-down attentional biasing and proactive control of attentional resources (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver, 2012), in addition to regulating task relevant vs. irrelevant inputs (Corbetta & Shulman, 2002). Studies have also highlighted the differential activation patterns of subject's during tasks that require higher levels of internal or external focus. In one study, participants were tasked with utilizing 'goal-directed internal cognition' in a task that required the mental continuation of a visuospatial task after the original visual stimuli was removed from the screen (Benedek et al., 2016). This study – which analyzed both the neural correlates during the more externally focused (initial stimulus presentation) and internally focused (subsequent mental continuation) – found that higher brain

activation in the parietal and dorsal attention network (DAN) correlated with the externally directed portions of the task, while the internal attention components were accompanied by activity in regions that comprise the default (mode) network (DN), such as the medial prefrontal cortex, medial temporal lobes and posterior inferior parietal cortex (Benedek et al., 2016). There has also been research on the activation differences between goal-directed (incidental) and spontaneous attention. Spontaneous, or ‘unprompted,’ internal attention can be characterized by a lack of focus on external cues even without executing a specific internal goal, with processes such as absent-mindedness and ‘day-dreaming’ exemplifying this particular type of attention. Goal directed internal attention has been characterized by the top-down task-specific attentional demands related to the internalization of relevant external information, processes more closely correlated with the DN activation (Benedek et al., 2016; Chun, 2011). This type of incidental attention is particularly interesting because of the implications for influence over subsequent memory. Internal focus may be key to generating salient mental images linked to SME; however this direct connection can only be determined by directly analyzing memory-linked activity during tasks that explicitly demand goal-directed internal attention.

Subsequent Memory

Numerous studies examining attention have also investigated successful memory encoding (SME) – a correlation comparison of activity at encoding for subsequently remembered vs. forgotten items – in relation to attention processes (Chun, 2011; Fell et al., 2011; Fell, Ludowig, Rosburg, Axmacher, & Elger, 2008). SME has been linked to decreased alpha and increased theta activation in the frontal-midline areas during encoding, a pattern that mirrors the oscillatory behavior accompanying increased alertness and decreased distractedness during attentional tasks (Fell et al., 2008; Sauseng, Hoppe, Klimesch, Gerloff, & Hummel, 2007). One

EEG study examined SME in relation to alpha and beta activation patterns in the rhinal and hippocampal cortices and found that the successful formation of memories was correlated with decreased power in the alpha and beta bands (Fell et al, 2008). Another study highlighted the differential activation for encoding success vs. retrieval success, with SME activity most prominent in the anterior hippocampus and ventrolateral prefrontal cortex, and retrieval success activation (RSA) present in the parahippocampal cortex and dorsolateral prefrontal cortex (Prince, Daselaar, & Cabeza, 2005). Although these studies emphasized SME in relation to general or task-specific attention processes, the characteristic parallels between differential oscillation and memory activation support the use of frequency-band activity as a hallmark of attention and subsequent memory.

More specifically, looking at the oscillatory patterns related to successful vs. unsuccessful memory performance may shed light on the way in which reorientation of attention influences subsequent memory. These correlations point towards the potential differences in internal vs. externally centered attention and how variation in these may impact later memory retrieval performance. If an individual were to devote more time to conjuring a strong mental representation of specific stimuli at encoding – therefore heightening their time internally focused – it may lead to better subsequent memory.

SSVEPs

Another key component of attentional analysis is the use of behavioral paradigms to elicit steady-state visual evoked potentials (SSVEP). SSVEPs have been shown to be an indicator of increased attention to stimuli and useful markers of attentional-biasing (Rosenberg et al., 2015). One useful characteristic of these potentials is their ability to modulate at the specific relevant frequency of a particular stimulus. This was demonstrated in one study where SSVEPs over

parietal and occipital brain regions would fluctuate in amplitude based on the corresponding flickering rate of one of two visual displays to which subjects selectively attended, both of which were set to different frequencies (Zhang et al., 2010). This targeted behavior was also highlighted in another study which measured SSVEPs elicited by an alphanumeric rapid serial visual presentation task (RSVP) to a single hemisphere during simultaneous concurrent sequence presentation to the opposite hemisphere. Researchers noted a significant SSVEP presence towards all forms of visual stimuli within the target visual field, indicating a heightened neural response to targets falling within the spatial attention spotlight (Morgan, Hansen, & Hillyard, 1996). Some studies have also examined the temporal course of SSVEPs, looking specifically at their modulation during a rapid attentional shift task and concluding that temporal activity of SSVEPs is closely correlated with target discrimination and attentional biasing during task completion (Müller, Teder-Sälejärvi, & Hillyard, 1998). This ‘target specificity’ allows us to employ SSVEPs as a marker of attentiveness toward steady-state flickering stimuli that can be manipulated and monitored within and across trials, further supplementing the oscillatory patterns used to detect attentional shifts in real time.

The Present Study

While a number of studies have delved into the mechanisms of attention and their connection to memory performance, we still have limited understanding of encoding processes in the specific context of internally or externally directed attentional behavior. Linking the two may provide integral insight into the mechanisms of learning, both in how we encode information and how lapses in attention can detrimentally influence this encoding process. Keeping in mind the potential benefits of SSVEP when reviewed in context with attention, this study investigated

attentional shifts (via SSVEP) and SME (via subsequent recall tasks) to further characterize the effects of both internal and external attention on informational encoding.

More specifically, we recorded EEG data during memory encoding of object words in subjects instructed to read and mentally imagine the series of words. During a period of flickered word presentation, subjects were tasked with conjuring up a mental image of the presented word and subsequently rating the quality of that mental image. We compared this data to the continuous recording of their attentional patterns over the course of the trial to characterize fluctuations between internally and externally focused attention. We hypothesized that higher levels of internal attention would correlate with better subsequent memory recall (as reflected by modulation of the elicited SSVEPs), and that this pattern would be reflected in a higher number of hits for stimuli that subjects were able to mentally imagine more confidently.

METHOD

Subjects. Subjects were selected from a pool of Duke University students and staff. Ten total subjects were run. Minimum requirements for participation included being 18-35 years of age with no history of neurological or psychiatric disease. Two subjects were excluded for failure to complete more than 60% of the trials, and one was excluded for exceptional memory (greater than 90% hits), leaving too few missed trials for analysis. Eight subjects were included in the final analysis, ranging from ages 20-25 (7 female 1 male; $M=21.74$). All subjects had normal or corrected to normal vision and were right-handed. This study was conducted in compliance with a protocol approved by the Duke Institutional Review Board

Stimuli and Task. Stimuli were presented with Presentation software on a 24-inch, 144Hz refresh rate LCD computer monitor at a viewing distance of 80 cm. During data collection, subjects were isolated in a dimly lit, electrically shielded room and instructed to fixate their gaze on a

central fixation point, with stimuli appearing just below fixation. Subjects completed an encoding and retrieval phase, separated by a 10-15 minute break. Throughout both phases, the background remained a constant black color with the stimuli presented in white. The details of the encoding paradigm are outlined below in **Figure 1**:

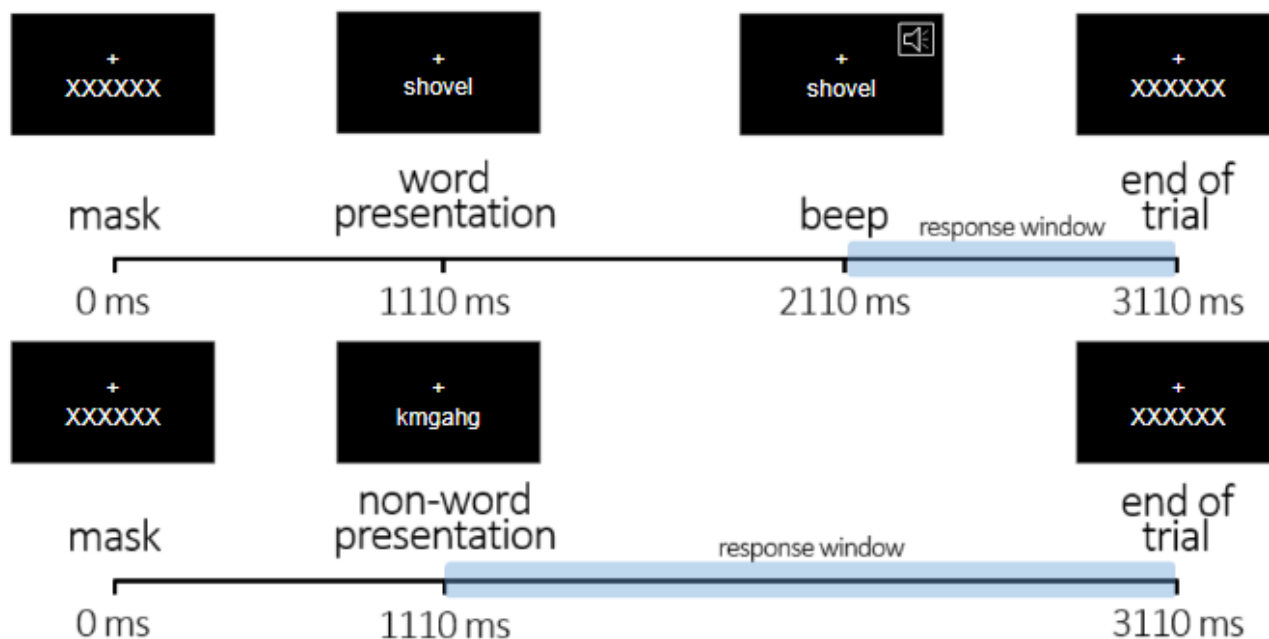


Figure 1: Visual Task Paradigm During Encoding

Standard trial (percent): Mask appeared on the screen (just under fixation) for 1100ms (550 ms 50% static, then 550 ms (RIGHT?) 50% flickered??) before being replaced with a flickering word stimulus. At the 2110 ms mark, an auditory tone indicated the beginning of the response window, where subjects rated the vividness of their mental image of the word. Trial ended after a response is made or after 1000ms of no response

Catch trial (percent?): Mask appeared on the screen (just under fixation) for 1100 ms (550 ms 50% static, then 550 50% flickered) before being replaced by a pseudo word stimulus. Subjects' task was to immediately respond, identifying the stimulus as a non-word. Trial ends after a response is made or after 2000ms of no response

Visual Presentation. Task presentation consisted of a single condition. An initial mask (consisting of a series of X's) appeared on the screen for 1110ms (555ms static, and then 555ms flickered), after which it was immediately being replaced by a target word (flickering at 18Hz). During the target-word presentation time span, subjects were tasked with reading and conjuring a mental image of that word. After 1000ms, subjects were

prompted with an auditory tone cuing the beginning of the ‘response window’ period. For this 1000ms portion of time, the word continued to be flickered on the screen and subjects were required to make a response rating indicating the vividness of their imagined picture of the word. These rating options ranged from 1 to 4 (1 = no image/poor image 4 = excellent image). At the end of the response window, the mask appeared again, prompting the subject to prepare for the presentation of the next word. In addition to these standard trials, 5% of the trials were ‘catch trials,’ the paradigm for which is outlined in Figure 1b. During these catch trials – occurring on average once every 20 trials – the mask was followed by a flickering non-word. Subjects were instructed to press a button immediately as soon as they identified the word as nonsensical. No matter when they made their responses, all trials lasted the same fixed length. In total, 570 words and 30 non-words with 5-7 letters each were presented at a frequency of 18Hz with 4 breaks throughout, making the total duration of the task 35 minutes.

Following the 10-15 minute rest period, subjects completed the memory retrieval phase. During this incidental memory test, subjects were presented with all 570 old words randomly intermixed with 285 new words and instructed to make 6-point recognition responses (1=definitely new – 6=definitely new). Similar to the encoding phase, 5% of the trials were catch trials, bringing the total number of trials to 900.

EEG Acquisition. EEG Apparatus included a 64-channel custom-layout active-electrode cap (Acticap) with extended scalp coverage, acquired using the Brain Products Actichamp Amplifier System (Munich, Germany) with all electrode impedances set below 15kOhms (using the right mastoid as reference, vertical EOG site was below left eye). Data were acquired using a sampling rate of 500 Hz and a low-pass anti-aliasing filter with ~130 Hz cutoff (no high-pass

filtering was done online). EEG was recorded during memory encoding simultaneous to presentation of 600 stimuli. Data was filtered offline with a .05 highpass causal FIR filter. Independent component analysis (ICA) was performed using EEGLab to correct for eye blinks.

EEG Analysis. For EEG Analyses, offline filtering was done with high-pass (0.05 Hz cutoff) and low pass (70 Hz cutoff) filters using the EEGLab software package (La Jolla, CA), and data were down-sampled to 250 Hz. Data were re-referenced to the algebraic average of the left and right mastoids, and channels with noise artifacts were interpolated using spherical spline interpolation. The data were segmented into 3.5 s epochs time-locked to the word presentation and spanning the width of time from initial mask presentation to the appearance of the mask, cueing the beginning of a new trial. Independent components analysis (ICA) was used to correct for eye-blinks, with no more than three components subtracted. Epochs that had voltage artifacts greater than +/- 120 (microvolts: **insert the symbol here**) were excluded. Trials with encoding reaction times lower than 1000 ms (prior to the beginning of the response window) or retrieval reaction times lower than 200 ms (almost immediately following word presentation) were rejected. In addition, all trials with no response were rejected.

To analyze ERPs, data were additionally low-pass filtered with a half-amplitude cutoff at 8 Hz and a 2 Hz transition zone (7-9 Hz). ERPs were then selectively averaged using the Fieldtrip toolbox (Oostenveld et al., 2011). For the time frequency analysis, data were high-pass filtered with a half-amplitude cutoff at 15 Hz and a 2 Hz transition zone (14-16 Hz). SSVEP oscillatory power data were extracted using a fast Fourier transform (FFT) method with a Hanning taper window (five cycles per window, from 14 to 30Hz in steps of .5 Hz and from 1.25 s prior to word onset and 2.25 s after word onset in steps of 100 ms). Absolute power values were then converted to decibels using a logarithmic scale $10 \cdot \log_{10}(\text{Power}_f)$. Statistical analysis involved

repeated-measures analysis of variance (rANOVAs) on the memory results, vividness ratings and mean SSVEP power amplitudes for selected electrodes.

RESULTS

Image Vividness

Analysis of image vividness ratings based on the subject's report of their ability to visualize word stimuli revealed a considerable distribution in image strength across the subjects. As shown in Figure 2, results averaged from the valid encoding trials of all subjects showed a majority of the corresponding mental images being described as either 'excellent' or 'good' in vividness/clarity. Less than 40% were categorized as weaker images (either 'poor' or 'ok'). This suggests that of the 570 real words shown, there was general reproducibility of the word stimuli in visual form.

Figure 2.

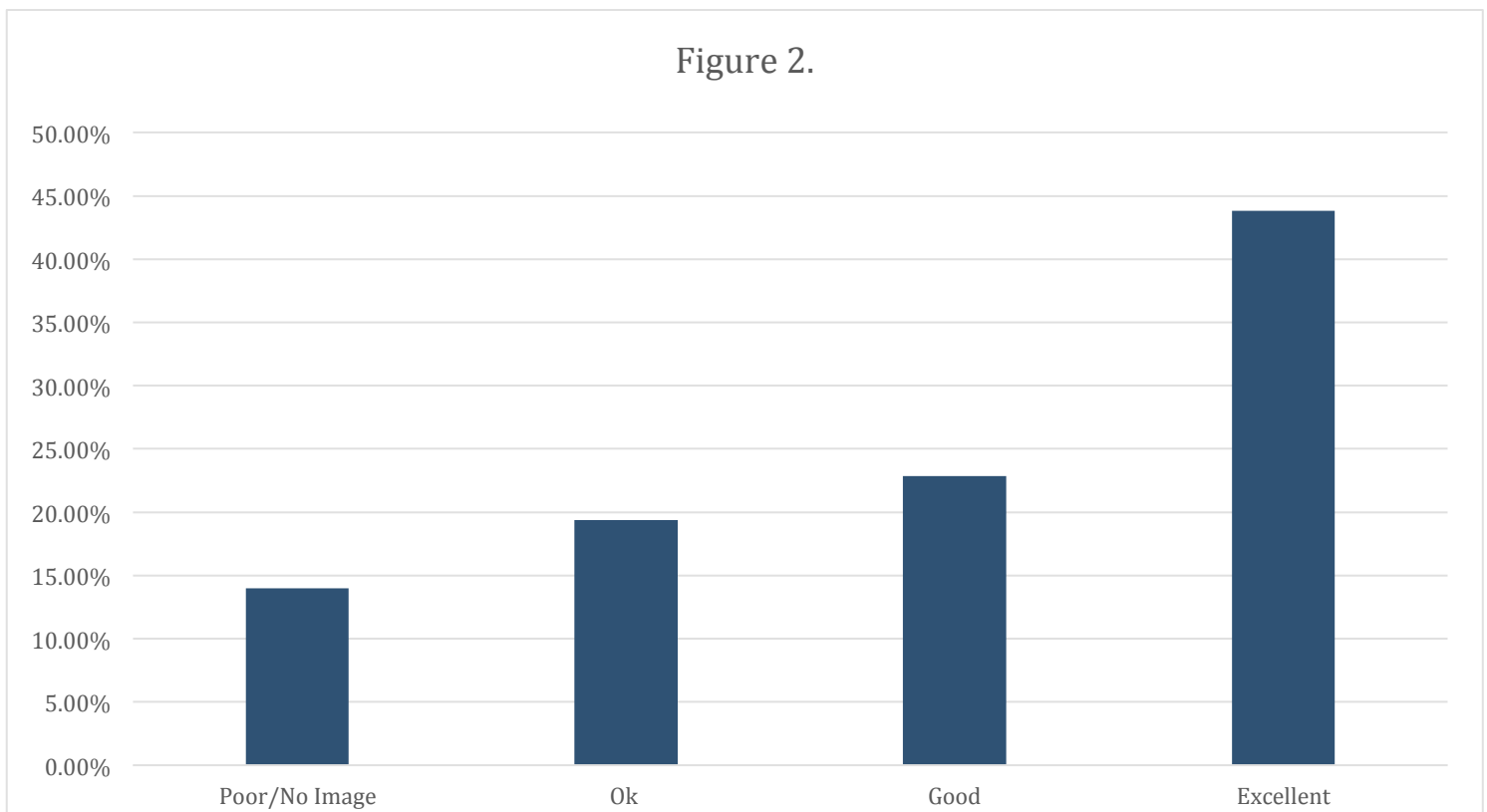


Figure 2. Image Vividness Ratings during Encoding Task

Distribution of ratings for the strength of the mental images corresponding with word stimuli. A majority of words were accompanied by strong mental representations (Excellent/Good).

Subsequent Memory

Memory task performance was analyzed as a function of hits, misses, correct rejections, and false alarms (Figure 3). Overall hit rates were high, with a probability of 77.1% for hits at all confidence levels ($SD \pm 13.7\%$) and 23% for probability of a miss. Correct rejection rate was 75% ($SD \pm 0.137$) across subjects, while false alarms were at 26% ($SD \pm 9.3\%$), indicating a consistent pattern in subject's ability to distinguish between old and new words.

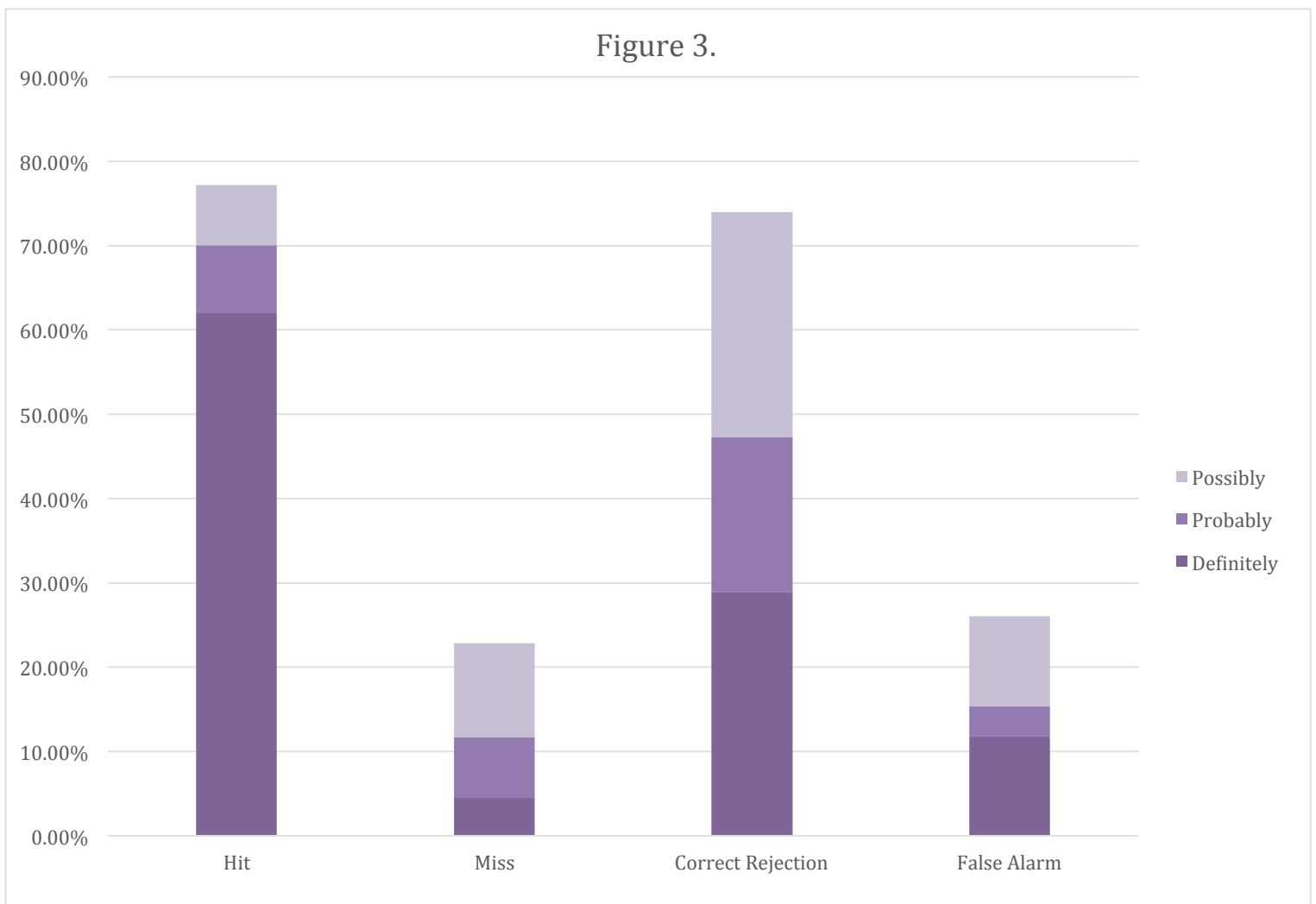


Figure 3. Memory Performance

Data showed a larger number of successful hits for words with high confidence memory ratings. Although the overall percentage of correct rejections was also high, there was more distribution in the confidence ratings that fell into this category, with a larger proportion of correct rejections coming from low confidence responses.

Memory and Image Strength

When comparing vividness ratings with memory performance, no correlations were found to be statistically significant; however, there was a trend observed between memory confidence and image vividness. Data showed an increasing number of high confidence hits for words that subjects were able to visualize more vividly. This is demonstrated in Figure 4, where the overall high confidence hit rates (words that subjects rated to be ‘definitely old’) were significantly higher in all vividness categories; however, the hit percentage steadily increased from words that subjects conjured poor/no images (56.3%) to words that subjects could visualize excellently (71.5%). The opposite trend is seen for high confidence misses (old words which subjects rated as definitely or probably new), where miss rates decreased as image vividness increased.

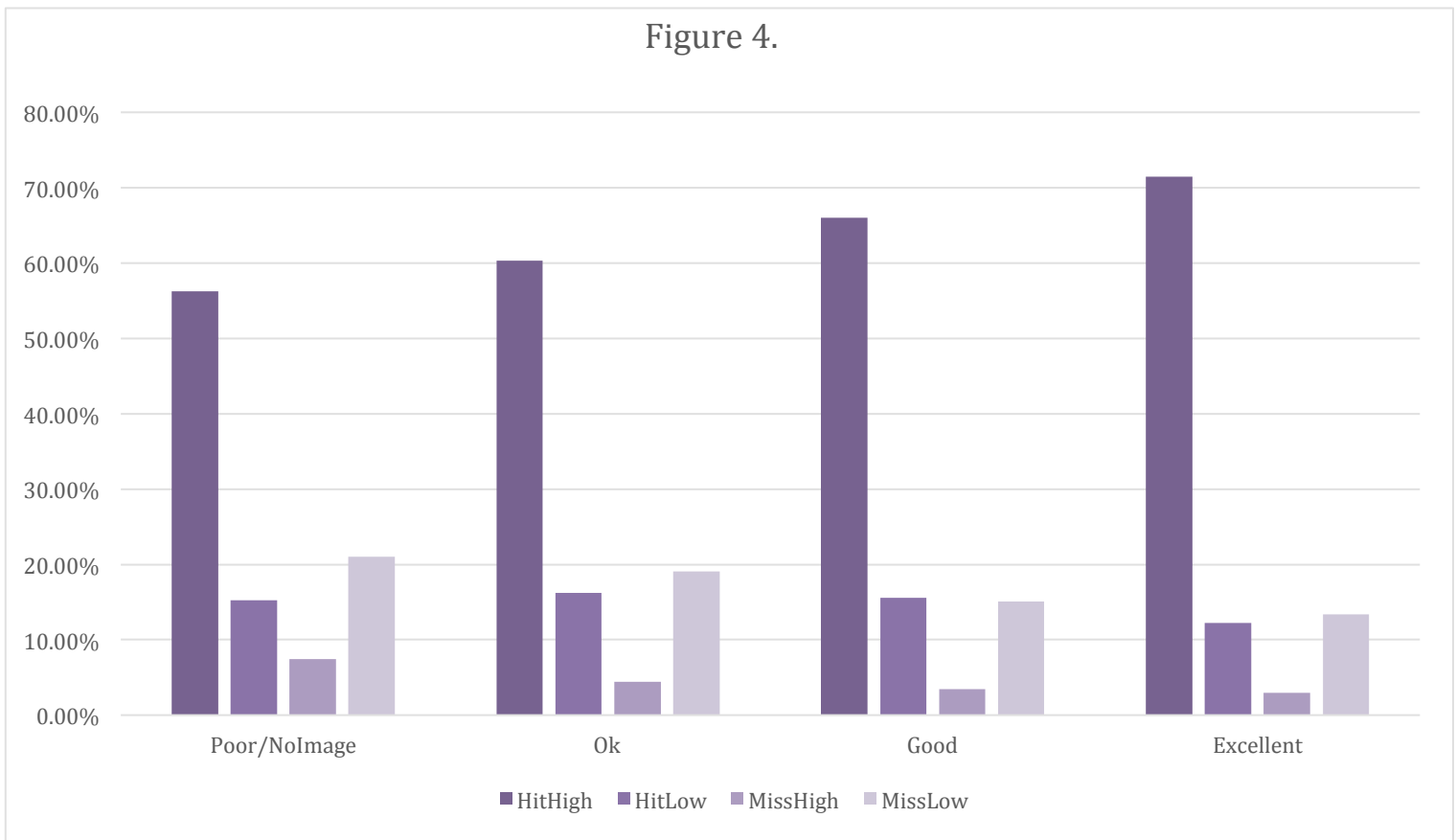
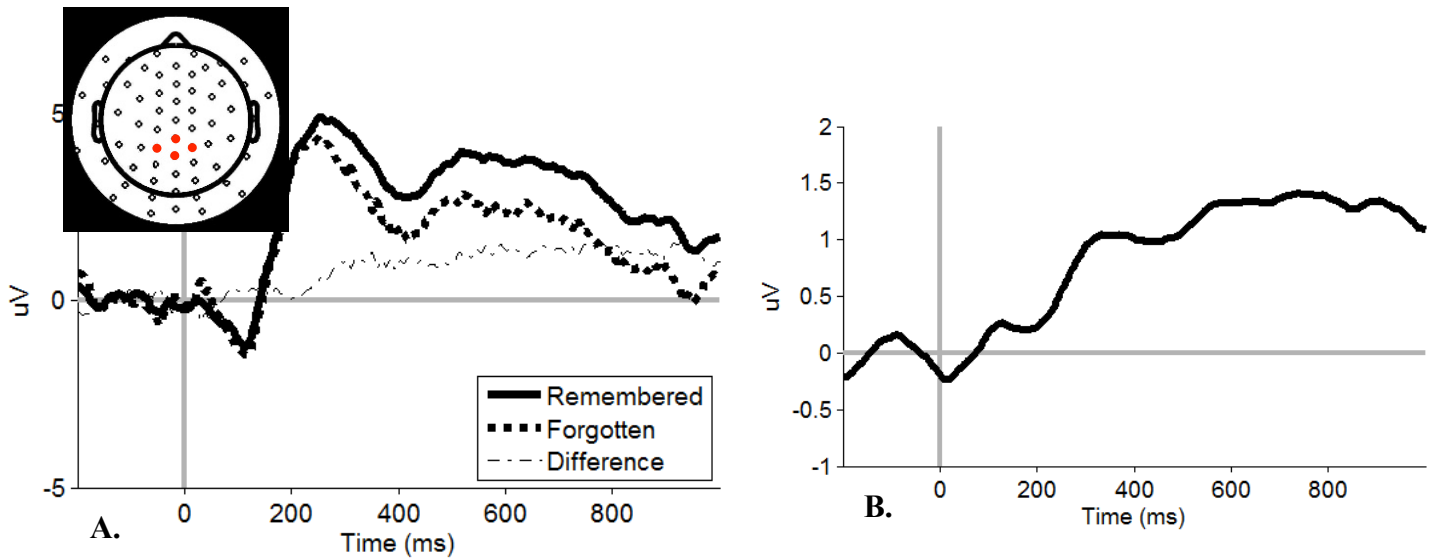


Figure 4. Effects of Vividness on Memory

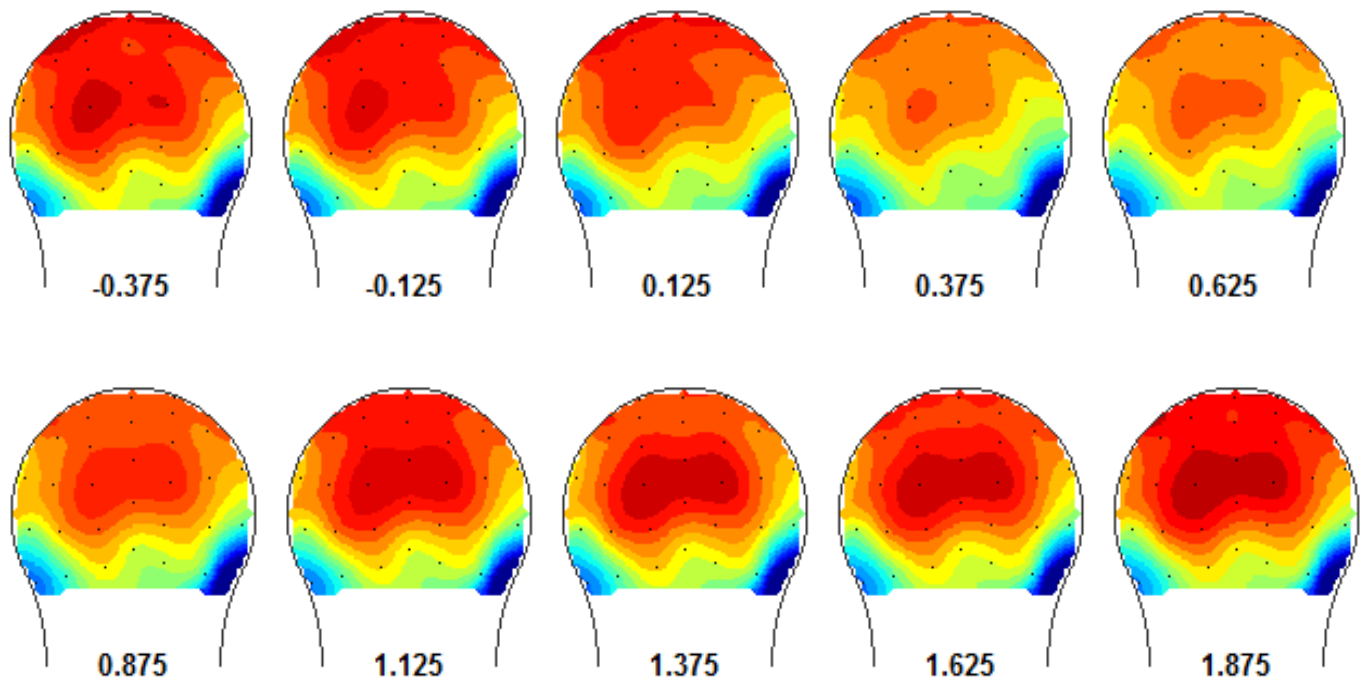
A graph of the distributions of memory performance for different categories of vividness. Memory performance improved as image vividness increased vivid image ratings, while low confidence misses subsequently decreased, though neither of these trends were shown as significant.

Figure 5.

**Figure 5. ERP Components of Remembered vs. Forgotten Words during Retrieval**

Data was grand averaged from centro-parietal electrodes (CP_z , $P2'$, $C1_p$) time locked to word presentation (1100ms) **5A.** ERP waveform for subsequently remembered vs. forgotten words. There was observable differential activation for words at encoding that subjects were able to subsequently recall when compared to those these subsequently forgot. **5B.** ERP waveform of difference (Remembered-Forgotten). Increasing positivity of graph illustrates enhanced processing at encoding for the subsequently remembered words.

Figure 6.

**Figure 6. Topographical Distribution of Activation over Time Course**

Topographical Distribution of grand-averaged power spectrum for 17-19 Hz frequencies. The time course of the SSVEP is observed over occipital electrodes.

Figure 7.

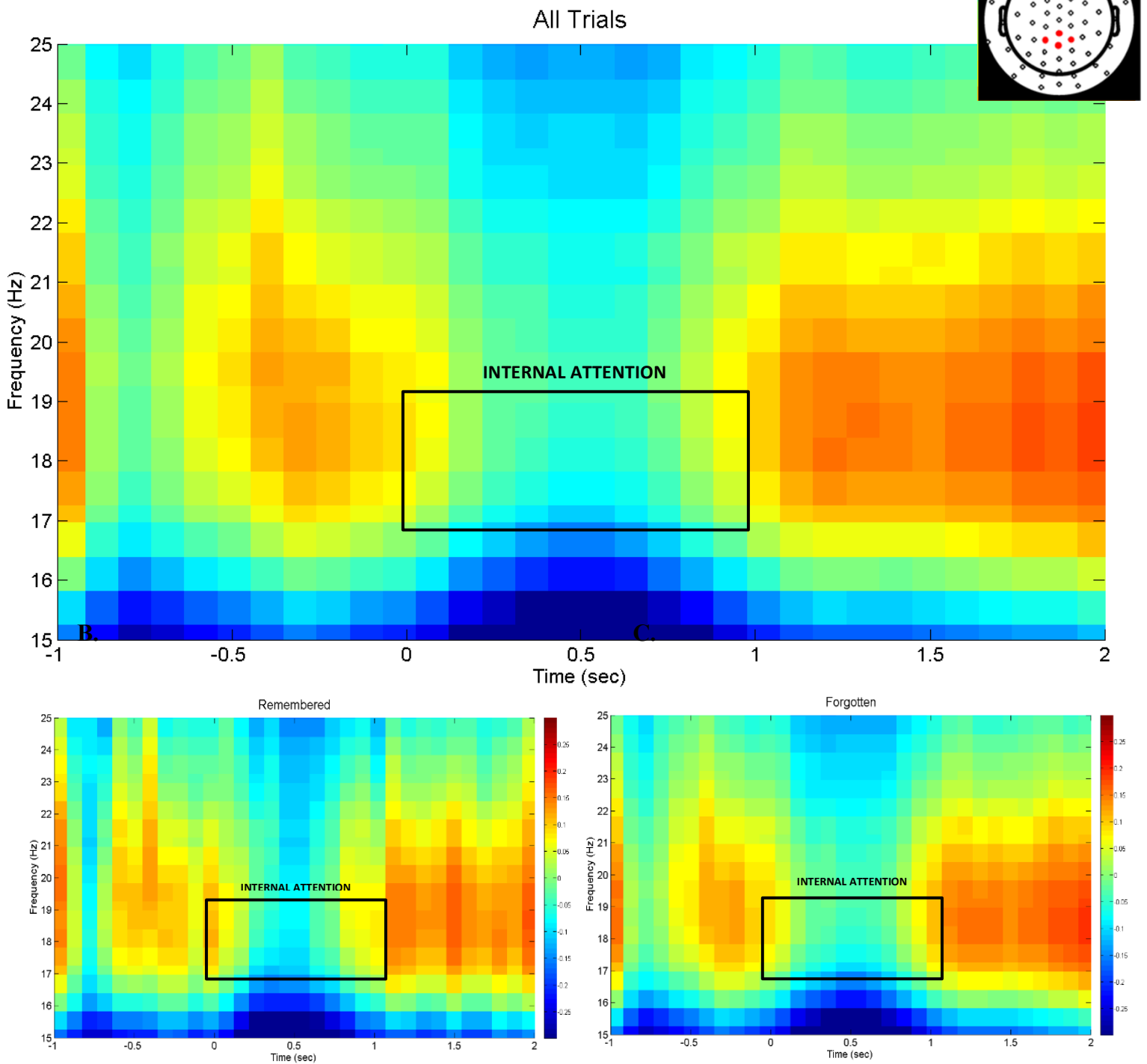


Figure 7. Spectrogram of Activation over Time Course

Oscillatory power over the course of the trial from occipital site O2' (box highlights periods of internal attention, as reflected by decreased driven SSVEP power at 18 Hz). **7A.** Power analysis for activity across all trials. SSVEP power is shown to drop sharply during the 0-1 second timespan, prior to the allotted response window. **7B/C.** Spectral Graphs for activity during retrieval for Remembered (B) vs. Forgotten (C) Words, showing a greater decrease in power at 18Hz (SSVEP Range) for subsequently remembered words, indicative of a shift of attention away from the visual stimuli. A similar dip is seen for subsequently forgotten words, but with noticeably less of a contrast than the change for remembered words.

Neural Activation

Analysis of event related potentials (ERP) at encoding was conducted as a function of subsequently remembered vs. forgotten words during the retrieval task. Data was analyzed using a low-pass FIR filter at 8Hz with a 2 Hz transition zone. As shown in Figure 5A, this waveform analysis showed a difference due to memory component over centro-parietal electrodes (CPz, P2', C1p) with greater positive activation for remembered words ($M=1.92 \pm 0.23$) compared to forgotten words ($M=0.95 \pm 0.25$). This differential activation was further depicted by the subsequently remembered minus subsequently forgotten difference wave (5B), illustrating enhanced processing from 400-800ms for subsequently remembered vs forgotten activation.

SSVEP

Analyses revealed that the entrainment was selective around 18 Hz and varied in time course at right occipital site O2'. Overall, an increase in the SSVEP was observed during the flickered period of the mask presentation. A consistent decrease in SSVEP power occurred during the imagery period (Figure 7A), which we infer as reflecting a shift in attention from the external stimuli to internal processes as subjects imagined each word. Attention was then directed externally once again after the tone was presented, reflecting external attention towards the screen in anticipation of the next word. Although this correlation was not seen to reach statistical significance, there was an observable difference between the power decrease for subsequently remembered words when compared to forgotten words. This is seen when comparing figures 7B and 7C, where a more notable decrease in SSVEP power was observed in the pre-response window for remembered vs. forgotten words. This data may suggest that subjects were focusing more internally during the encoding of the subsequently remembered words vs forgotten words.

DISCUSSION

All in all, our results yielded several informative insights with respect to our original hypotheses. This experiment was designed to characterize shifts between internal and external attention, and how these shifts could affect subsequent memory. The behavioral data analysis showed a trend between image vividness and improved subsequent memory. This finding, although speculative, may suggest that subjects were able to more confidently recall words that correlated with strong mental representations, a fact that agrees with previous literature on the effects of associative memory on subsequent recall (Chun et al., 2011). One interesting finding was the relatively high hit rate for words that corresponded with poor or no visualized images. In this category subjects had over 60% Hits in comparison to their overall Miss rate. One potential reason behind this fact, as corroborated by subject's own explanations, is that it was also easy to recognize words that were difficult to mentally visualize, as their unique nature left an impression. Overall, however, the upwards trend in performance paralleling with increased image vividness agrees with our initial predictions, confirming that stimuli salience during encoding can impact subsequent recall during memory retrieval.

The inclusion of 18Hz Steady State Visually-Evoked Potentials via the flickering of stimuli allowed us to monitor fluctuations in attention to and from the screen during our encoding task. Frequency analysis showed decreases in 18Hz power during the integral pre-response window. This dip in power indicates a diversion of attention from the on-screen stimulus, towards the task of internally visualizing the presented word prior to the required response window. This observation supports the theory of decreased attention to the flickering visual stimuli on the screen during the internal task, consistent within the results of Villena-González et al. (2016), where sensory processing was significantly attenuated during inwardly-

oriented task completion. Interestingly, however, we did not find a significant difference between SSVEP activity for remembered vs. forgotten words. Theoretically, subsequently remembered words would be expected to be accompanied by a larger decrease in SSVEP power, indicative of greater internal focus during encoding; this is a theory that was corroborated by our observed trend of SSVEP power changes for remembered vs. forgotten words, although more data would need to be collected to see if this trend reaches significance. One other explanation for this may be the need for further analysis to compare the interactional effects between both retrieval success and encoding confidence, to see if SSVEP activity was similarly consistent for subsequently remembered vs. forgotten words dependent on their categorization as excellently or poorly visualized. Otherwise, there may be another mechanism of internal attention that we have not yet considered as the defining factor for memory success, such as the delay between encoding and retrieval or time allowed for response.

With these results in mind, it is evident that these promising findings will need to be supplemented by the collection of a large set of subjects and by further analysis to draw definitive conclusions related to the difference between internal and external attention. Our results further support the use of SSVEPs as indicators of attentional shifts and help corroborate the theory of the decrease in external focus during goal-oriented internal tasks ([Mora-Cortes et al., 2017](#)). To further characterize these SSVEP shifts in relation to internal vs. external attention, however, it is equally important for us to also evaluate changes in alpha/theta power over the course of each trial, and also compare these effects to overall memory performance.

Overall, our investigation came with several setbacks, some of which should be addressed in future studies. One such issue is that we must acknowledge that the observed EEG data will depict activation patterns that are not solely representative of either internal or external

attention, but rather various types of perceptual experiences – such as task-dependent focus, interfering thoughts and mind-wandering could also be occurring during visual task ([Stawarczyk et al., 2011](#)). This ambiguity was somewhat evidenced by the limited difference between SSVEP power differences for subsequently remembered versus forgotten words, indicating that the factors affecting subject's memory performance may extend beyond our two chosen subtypes. We aimed to design our paradigm in a way that gives us as much confidence as possible in the specific nature of the observed attentional behavior – a goal which motivated the addition of the catch-trials (to motivate participants to maintain focus on task) and the response trial cue (to allot a specific period during which participants are able to fully orient inwardly and respond to the task). However, future experimental designs should aim to further dispel this ambiguity.

Another drawback of our design is the subjective nature of the associations that individuals have with particular words, and how this may influence their ability to visualize that word. Research has shown that our exposure and personal experiences can cause subjective associations with certain words and concepts, and that these schemas can impact our memory ([Hasher & Zacks, 1979](#)). Our use of common/neutral words and participant confidence ratings aimed to account for this; however the use of less associative stimuli, such as pictures of random faces or scenes, may yield more objective results of subject's recollection abilities.

In many ways, this particular investigation serves as only the first step in a much longer series of studies of the relationship between attention and memory. Although our particular approach suits this particular relationship, this same study could very well be conducted to specifically identify the relationship between memory confidence and attentional allocation. One future study we hope to pursue related to the effects of waxing and waning over time of sustained attention on subsequent memory. The current study focused on the mechanisms of

incidental memory and its relation to the locus of attention within a trial, but an investigation of directed memory encoding over extended periods of time could yield integral information on the nature of internal and external attention when sustained and uninterrupted for long periods of time.

WORKS CITED

- Benedek, M., Jauk, E., Beaty, R. E., Fink, A., Koschutnig, K., & Neubauer, A. C. (2016). Brain mechanisms associated with internally directed attention and self-generated thought. *Scientific Reports*, *6*, 22959. <https://doi.org/10.1038/srep22959>
- Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652. <https://doi.org/10.1037/0033-295X.108.3.624>
- Braver, T. S. (2012). The variable nature of cognitive control: a dual mechanisms framework. *Trends in Cognitive Sciences*, *16*(2), 106–113. <https://doi.org/10.1016/j.tics.2011.12.010>
- Chun, M. M. (2011). Visual working memory as visual attention sustained internally over time. *Neuropsychologia*, *49*(6), 1407–1409. <https://doi.org/10.1016/j.neuropsychologia.2011.01.029>
- Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews. Neuroscience*, *3*(3), 201–215. <https://doi.org/10.1038/nrn755>
- Dockree, P. M., Kelly, S. P., Foxe, J. J., Reilly, R. B., & Robertson, I. H. (2007). Optimal sustained attention is linked to the spectral content of background EEG activity: greater ongoing tonic alpha (approximately 10 Hz) power supports successful phasic goal activation. *The European Journal of Neuroscience*, *25*(3), 900–907. <https://doi.org/10.1111/j.1460-9568.2007.05324.x>
- Fell, J., Ludowig, E., Rosburg, T., Axmacher, N., & Elger, C. E. (2008). Phase-locking within human mediotemporal lobe predicts memory formation. *NeuroImage*, *43*(2), 410–419. <https://doi.org/10.1016/j.neuroimage.2008.07.021>
- Fell, J., Ludowig, E., Staresina, B. P., Wagner, T., Kranz, T., Elger, C. E., & Axmacher, N. (2011). Medial temporal theta/alpha power enhancement precedes successful memory encoding: evidence based on intracranial EEG. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *31*(14), 5392–5397. <https://doi.org/10.1523/JNEUROSCI.3668-10.2011>
- Foucher, J. R., Otzenberger, H., & Gounot, D. (2004). Where arousal meets attention: a simultaneous fMRI and EEG recording study. *NeuroImage*, *22*(2), 688–697. <https://doi.org/10.1016/j.neuroimage.2004.01.048>
- Hasher, Lynn & T. Zacks, Rose. (1979). Automatic and Effortful Processes in Memory. *Journal of Experimental Psychology: General*. *108*. 356-388. [10.1037/0096-3445.108.3.356](https://doi.org/10.1037/0096-3445.108.3.356).
- Mora-Cortes A, Richard Ridderinkhof K, Cohen MX. Evaluating the feasibility of the steady-state visual evoked potential (SSVEP) to study temporalattention. *Psychophysiology*. 2018;55:e13029. <https://doi.org/10.1111/psyp.13029>
- Morgan, S. T., Hansen, J. C., & Hillyard, S. A. (1996). Selective attention to stimulus location modulates the steady-state visual evoked potential. *Proceedings of the National Academy of Sciences of the United States of America*, *93*(10), 4770–4774.

- Müller, M. M., Teder-Sälejärvi, W., & Hillyard, S. A. (1998). The time course of cortical facilitation during cued shifts of spatial attention. *Nature Neuroscience*, *1*(7), 631. <https://doi.org/10.1038/2865>
- Prince, S. E. (2005). Neural Correlates of Relational Memory: Successful Encoding and Retrieval of Semantic and Perceptual Associations. *Journal of Neuroscience*, *25*(5), 1203–1210. <https://doi.org/10.1523/JNEUROSCI.2540-04.2005>
- Rosenberg, M. D., Finn, E. S., Scheinost, D., Papademetris, X., Shen, X., Constable, R. T., & Chun, M. M. (2015). A neuromarker of sustained attention from whole-brain functional connectivity. *Nature Neuroscience*, *19*(1), 165–171. <https://doi.org/10.1038/nn.4179>
- Roth, J. K., Johnson, M. K., Raye, C. L., & Constable, R. T. (2009). Similar and dissociable mechanisms for attention to internal versus external information. *NeuroImage*, *48*(3), 601–608. <https://doi.org/10.1016/j.neuroimage.2009.07.002>
- Sauseng, P., Hoppe, J., Klimesch, W., Gerloff, C., & Hummel, F. C. (2007). Dissociation of sustained attention from central executive functions: local activity and interregional connectivity in the theta range. *The European Journal of Neuroscience*, *25*(2), 587–593. <https://doi.org/10.1111/j.1460-9568.2006.05286.x>
- Stawarczyk, D., Majerus, S., Maquet, P., & D'Argembeau, A. (2011). Neural Correlates of Ongoing Conscious Experience: Both Task-Unrelatedness and Stimulus-Independence Are Related to Default Network Activity. *PLoS One; San Francisco*, *6*(2), e16997. <http://dx.doi.org.proxy.lib.duke.edu/10.1371/journal.pone.0016997>
- Villena-González, M., López, V., & Rodríguez, E. (2016). Orienting attention to visual or verbal/auditory imagery differentially impairs the processing of visual stimuli. *NeuroImage*, *132*, 71–78. <https://doi.org/10.1016/j.neuroimage.2016.02.013>
- Zhang, D., Maye, A., Gao, X., Hong, B., Engel, A. K., & Gao, S. (2010). An independent brain–computer interface using covert non-spatial visual selective attention. *Journal of Neural Engineering*, *7*(1), 016010. <https://doi.org/10.1088/1741-2560/7/1/016010>