# Differential Neural Correlates of EEG Mediate the Impact of Internally and Externally Directed Attention in a Dual-task Working Memory Paradigm

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## Abstract

Spontaneous internally directed attention, such as mind wandering, typically hinders performance in cognitive tasks. The impact of intentional internally directed attention (IDA) – for instance, deliberately thinking about past or future events – on task performance, however, remains unclear. In our study, we employed a dual-task paradigm that involved self-referential stimuli in a color-recall visual working memory task. This approach revealed that intentional IDA more significantly influences performance compared to intentional externally directed attention (EDA). We observed larger late positive potentials (LPP) over medial frontal sensors, suggesting sustained stimulus processing over frontal sensors under IDA. Additionally, we noted a pattern of neural activity associated with internal attention: event-related desynchronization (ERD) in the alpha band (8-12 Hz) during the encoding phase and event-related synchronization (ERS) in the delay phase. In contrast, the EDA condition was marked by theta (4-8 Hz) band ERS during the delay period. These findings highlight distinct behavioral impacts and neural patterns associated with internally versus externally directed attention in dual-task settings.

**Keywords:** Intentional internally directed attention; visual working memory; dual-task; EEG; ERP; time-frequency

## Introduction

We frequently engage in introspection to embark on a train of thought, categorized as internally directed attention (IDA). The selection, modulation, and maintenance of information generated internally, such as task rules, long-term memory, working memory, and responses, are referred to as internally directed attention (Chun, Golomb, & Turk-Browne, 2011; Dixon, Fox, & Christoff, 2014). It is distinct from externally directed attention (EDA) as the latter refers to the selection and modulation of sensory information. Dixon et al. proposed that internally and externally directed cognition can occur in two states, i.e., intentional (voluntary) or spontaneous (involuntary). These states thus affect the relationship of internally and externally directed cognition. Internally directed cognition competes with externally directed cognition when they both involve a high degree of intentionality. At the same time, they can co-occur if one or both involve spontaneous processing (see Dixon et al., 2014 and Verschooren, Schindler, De Raedt, & Pourtois, 2019 for review).

Spontaneous IDA, such as mind-wandering, is shown to impair the intentional EDA processes, including text comprehension (Killingsworth & Gilbert, 2010; Kane & McVay, 2012; Kam & Handy, 2014; Rummel & Boywitt, 2014; Smallwood, McSpadden, & Schooler, 2008). Using self-referential stimuli in a dual-task paradigm, Huijser *et al.* reported that internally directed thoughts impair performance in the spatial working memory task (Huijser, van Vugt, & Taatgen, 2018). They further proposed that self-referential processing can promote self-generated thoughts and thus interfere with task performance in a dual-task paradigm. Spontaneous EDA (e.g., bottom-up attentional capture by salient perceptual stimuli) during the delay period of a working memory task also acts as a distractor and impairs performance (Chein, Moore, & Conway, 2011; Jarrold, Tam, Baddeley, & Harvey, 2010; Klauer & Zhao, 2004). However, how intentional IDA (e.g., directed thinking about future and past events) affects performance in a cognitive task still needs to be clarified.

Neuroimaging evidence suggests a differential processing of internally and externally directed attention in the brain (Braboszcz & Delorme, 2011; Baird, Smallwood, Lutz, & Schooler, 2014; Kam, Solbakk, Endestad, Meling, & Knight, 2018; Kam, Helfrich, Solbakk, Endestad, Larsson, Lin, & Knight, 2020). ERP studies have reported that internally directed attention in self-referential processing tasks elicits higher amplitude in late positive potentials (LPP) beyond 350ms of stimulus presentation over frontal electrodes as compared to externally directed attention in a font judgment task (Katyal, Hajcak, Flora, Bartlett, Goldin, 2020; Magno & Allan, 2007; Mu & Han, 2010). In the frequency domain, internally directed attention increases power in the alpha band, while externally directed attention is accompanied by theta power increase (Kam et al., 2018; Mu & Han, 2010; O'Connell, Dockree, Robertson, Bellgrove, Foxe, & Kelly 2009).

Imaging studies have shown that EDA includes the activation of primary and associative sensory cortices to gather



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information from the external world. The frontal eye fields (FEFs) and intraparietal sulcus (IPS) are essential in regulating external attention by enhancing the processing of behaviorally relevant spatial locations and sensory stimuli. (Corbetta & Shulman, 2002; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider 1999). In addition to primary and associative areas, the lateral prefrontal cortex (lPFC) is shown to encode task-specific information of rules and modulate the processing in the sensory and motor cortices toward a common goal (Buschman & Miller, 2007; Braver, 2012; Dixon et al., 2014; Miller & Cohen, 2001). IDA states involving self-referential processing activate areas of the default-mode network (DMN) (Davey, Pujol, & Harrison 2016, Harrison et al., 2008), while episodic memory retrieval engages both DMN and medial temporal lobe (MTL) (Andrews-Hanna, Saxe, & Yarkoni, 2014; Kuhl, Johnson, & Chun, 2013). Interestingly, the lPFC is also reported to engage in mind-wandering (Stawarczyk, Majerus, Maquet, et al., 2011) and future planning (Spreng et al., 2010). Kam et al. reported that lesion in lPFC leads to dysregulation of both types of attention, thus making it an important region for internally and externally directed attention (2018). Therefore, the role played by the frontal regions in modulating both states of attention need to be studied further.

The present study utilizes behavioral and EEG measures to understand how intentional internally directed attention affects the performance in a color recall working memory task. We have used a delayed-estimation color recall working memory paradigm with an intermediate processing task during the delay period. The processing in the intermediate task, which consists of processing a personality trait adjective, involves either internally or externally directed attention and is mediated using a cue at the start of the trial. First, we compared behavioral measures, including accuracy and reaction times, to assess the effects of internal and external directed attention during the delay period on the recall of the color. Subsequently, we compared the LPP in the event-related potentials to check if, based on the cue, participants processed the personality adjective differentially in the internally or externally directed attention condition. Finally, we compared the time-frequency response in the theta and alpha bands in internally and externally directed attention conditions. This was done to confirm if the manipulation of attention in the intermediate task with the cue is reflected in neural data. We hypothesized that the internally directed processing of the personality trait would lead to a higher amplitude of LPP beyond 350ms of stimulus presentation. We further hypothesized that IDA would lead to an increase in alpha power and EDA would lead to increased theta power.


**Figure 1**: Behavioral paradigm. Each trial begins with a fixation, followed by a cue, either ‘Self’ or ‘Vowel.’ Then, after a variable fixation duration, a personality adjective is presented in a font color. They then respond to a question according to the cue on a 7-point scale. After a fixed delay of 1 sec., a color wheel is presented to probe the word's font color. In half of the trials, a thought probe is presented at the end of the trial (see text for details).

# Methods

## Participants

Nineteen participants (8 females and 11 males, mean age = 25.7 years, SD = 2.09 years) participated in an EEG study. The inclusion criteria used to recruit participants were that they must have a university degree with English as the medium of instruction. All the participants reported normal or corrected-to-normal vision, were right-handed, and declared no history of neurological or psychiatric disorders. EEG Data of the first block of one participant was removed because of unidentifiable noise. All participants signed informed consent approved by the Institutional Human Ethics Committee (IHEC), National Brain Research Centre, India.

## Behavioral paradigm

We designed a complex color-recall working memory task (see Figure 1). The task comprised two conditions cued by a word displayed in the center of the screen. After a variable delay, a personality adjective from a list of frequently used trait adjectives (Anderson, 1968) was presented in the center of the screen in a particular font color. In the EDA condition, cued by the word ‘vowel’, the participant had to count the number of vowels in the word and respond on a seven-point scale. Personality adjectives were restricted to having no more than 4 and no less than 2 vowels. This was done after piloting to equalize the reaction times of the rating task for the two conditions thus making the overall delay duration the same in both conditions. In the IDA condition, cued by the word ‘self’, the participant responded to the question ‘How much does this word describe your personality?’ on a seven-point scale. After a fixed delay of one second, the participants were presented with a color wheel that probed their memory for font color. Instructions to the participants were to be as accurate and as quick as possible. In half of the trials randomly, after the response on the color wheel was taken, a thought probe was presented to sample thought content during the delay period prior to recall (Huijser et al., 2018). The thought probe is based on the question used by Stawarczyk et al., 2011; Unsworth and Robison, 2016; and

Huijser et al., 2018. The question was, 'What were you thinking before you were prompted to answer?'. The following options were given for response: 1. I tried to remember the color of the word; 2. I was still thinking about the word from the decision task; 3. I was evaluating the aspects of the task; 4. I was distracted by the environment or by my physical state; 5. I was daydreaming/ I thought of task-unrelated things; 6. I was not paying attention, but I did not think about anything specific.

## Stimuli and procedure

The experiment was designed in Matlab (The MathWorks, Inc., Natick, MA), using the Psychophysics Toolbox (Brainard, 1997; Kleiner et al, 2007; Kleiner, 2007; Pelli, 1997) and displayed on a 22-inch LED monitor screen (75 Hz; 1440 x 900 pixels) at a viewing distance of approximately 75 cm. The stimuli were presented on a gray background (128,128,128; RGB255) and all text was generated in 50pt. Arial font. The color wheel was designed in RGB color space with hue angles mapped on the spatial angles (a total of 360 hues from 0º to 360º, inner radius = 6.44º, outer radius = 7.85º). The hue angle and spatial angle were kept constant throughout the experiment. The font color of the personality adjective was randomly selected from the 360 hues of the color wheel. We presented a total of 120 trials: 60 trials for each condition. The experiment was divided into 3 blocks of 40 trials each. There was a separate practice block of 12 trials with a different personality adjectives list.

## EEG data acquisition

EEG and behavioral data were acquired in a sound-attenuated room, and the ambient light was kept the same in all the recording sessions. EEG was acquired at 1000Hz using a 64-channel ActiChamp (Brain Products, Germany) with active electrodes for a better signal-to-noise ratio. The electrode placement used the 10% electrode placement system. The impedance was maintained below 15kΩ and checked before and after the experiment. Electrode FCz was taken as a reference while recording the data. The Psychtoolbox was synchronized to the EEG acquisition system by sending triggers through parallel ports from the computer used to present stimulus to the EEG data acquisition computer.

## Behavioral data analysis

Color recall accuracy was assessed through angular error, while reaction times for both responses were analyzed. Angular error in color recall was calculated as the spatial angle difference between the color hue presented and the hue reported by the participant. We used the interquartile range (IQR) method to remove outlier responses in the color recall. IQR was calculated by subtracting the first quartile (Q1) from the third quartile (Q3). The normal angular error range was defined with a lower limit as Q1-1.5*IQR and an upper limit as Q3+1.5*IQR. Any response outside this range was considered an outlier and removed from further analysis. The non-uniformity of the circular data was tested using the Rayleigh test (Fisher, 1995). We then computed the concentration parameter kappa ($\kappa$) of the von Mises distribution, which is a measure of "precision", using the *circ_kappa* function of the CircStat toolbox (Berens, 2009) using customized MATLAB scripts. Lower values of $\kappa$ reflect a more dispersed distribution and, thus, a lower accuracy in the color recall. Kappa and reaction times were analyzed statistically using the Wilcoxon signed-rank test. Similarly, accuracy in color recall was also computed within different conditions. In the IDA condition, accuracy was computed as a function of the level of self-reference based on the ratings on the adjective-personality fit scale. The responses were divided into three categories, i.e., Low self-reference (rating of 0 and 1), Mid-self-reference (rating of 2, 3, and 4), and high self-reference (rating of 5 and 6). In the EDA condition, accuracy was calculated as a function of the number of vowels in the personality adjective. For thought-probe analysis, the response frequencies of each option were calculated. Consistent with Huijser et al., 2018, the response option 1 was labeled as *on-task*, option 2 as *mental-elaboration*, option 3 as *task-related interference*, option 4 as *external distraction*, option 5 as *mind-wandering*, option 6 as *inattentiveness*. All the responses, excluding *on-task,* were referred to jointly as *off-task.*

## EEG data pre-processing and analysis

EEG data was analyzed in Matlab using the EEGLAB toolbox (Delorme & Makeig, 2004) and custom scripts. Data was first downsampled to 250hz, high-pass filtered to 0.05hz, and low-pass filtered to 45hz. The data was then visually inspected to remove noisy segments and re-referenced using a common-average re-referencing scheme. We used the *runica* algorithm in the EEGLAB to perform independent component analysis (ICA). Components were inspected visually and the components corresponding to ocular and muscle artifacts were removed (mean number of components removed = 3.76; standard deviation = 2.0). To compute event-related potentials (ERP), we epoch the segment 500ms preceding the stimulus and 1200ms after the onset of the stimulus (personality adjective). The pre-stimulus duration (-500 to 0ms) was used as a baseline for baseline subtraction. Decoding analysis was done using the ERPLAB toolbox (Lopez-Calderon & Luck, 2014), where time series from all 63 electrodes and all the time points were used to train a support vector machine. We used three cross-validation blocks, and this procedure was repeated 100 times. To determine a single classifier accuracy score for every participant, we then averaged the accuracy attained for each iteration. Since there were only two conditions, the theoretical chance level was 50%. Event-related spectral perturbation was computed using the *newtimef* function of the EEGLAB toolbox. The data was decomposed in a time-frequency domain across a frequency range from 3hz to 40hz using a complex Morlet wavelet. For the epoch corresponding to the presentation of personality adjective, the number of cycles in the wavelet increased linearly from 2 Hz at the lowest frequency to 12.5 Hz at the highest frequency. Baseline correction was applied by subtracting the mean power in the pre-stimulus (-400 to 0ms) from the power in the post-stimulus. We tested for statistical significance in ERP using paired t-test and permutation testing with false-discovery rate (FDR) correction for multiple comparisons. In the time-frequency analysis, we used the fieldtrip toolbox's *ft_statistics_montecarlo* function along with cluster correction for multiple comparisons to estimate time-frequency clusters that were significantly different between conditions. We computed 10000 permutations, and the false positive (alpha) threshold was kept at 0.05 in all the statistical analyses.

## Results

### Behavioral results

The results showed lower accuracy for color recall in the IDA condition (Wilcoxon signed-rank test, Z = -1.97; $p<0.05$; see Figure 2a). As intended, the participants' reaction time in the rating task was not significantly different between the conditions (Wilcoxon signed-rank test, Z = 1.28; $p = 0.19$; see Figure 2c). The reaction time in the color recall was also not significantly different between the conditions (Wilcoxon signed-rank test, Z = 1.20; $p = 0.22$; see Figure 2d). Thought-probe analysis revealed that participants were more off-task during the IDA condition ($\chi2$ (5) = 10.81; $p = 0.055$; see Figure 2e). The frequency of mental elaboration of the personality adjective in the delay period was higher in the IDA condition.

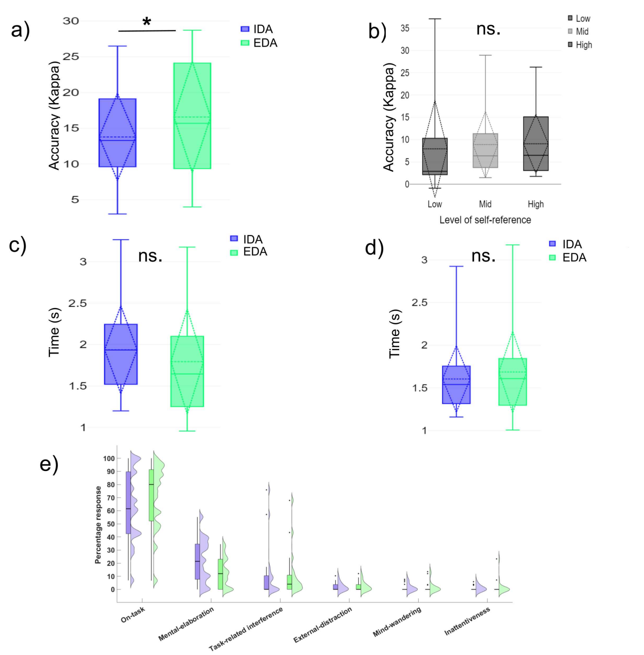


**Figure 2**: Overview of the behavioral results. a) Participants performed better in EDA condition. b) No significant difference in accuracy as a function of self-reference; thus, no self-reference effect observed. c) No significant difference in reaction time in the rating task. d) No significant difference in reaction time in color recall. e) Percentage response on different options in thought-probe; higher mental elaboration of a word in the IDA condition.

Within the IDA condition, there was no significant difference in color-recall accuracy in low, mid, and high-self-reference rating trials ($\chi2$ (2) = 4.65, $p = 0.10$; see Figure 2b). The accuracy in color recall did not differ significantly in the EDA condition, where the number of vowels in the personality adjectives increased from two to four ($\chi2$ (2) = 0.72, $p = 0.69$). Reaction times in the rating task in low, mid, and high-self-reference rating trials were not significantly different (Kruskal-Wallis chi-squared, $\chi2(2) = 4.65$, $p = 0.097$) however, in the EDA condition, reaction time in rating task with four number of vowels was significantly higher than the trials in which personality adjective has two and three vowels ($\chi2(2) = 25.26$, $p < 0.0001$). This might result from increased cognitive load with the increasing number of vowels.

### Event-related potentials

Motivated by the lower accuracy for color recall in the IDA condition, ERPs were computed for the encoding epoch and compared between the conditions (EDA vs. IDA). The late positive potentials (LPP) over frontal sensors post 450ms of the stimulus onset (Katyal et al., 2020; Naumann et al., 1992; Schupp et al., 2000) showed significantly higher amplitude in the IDA condition compared to that in the EDA condition (t

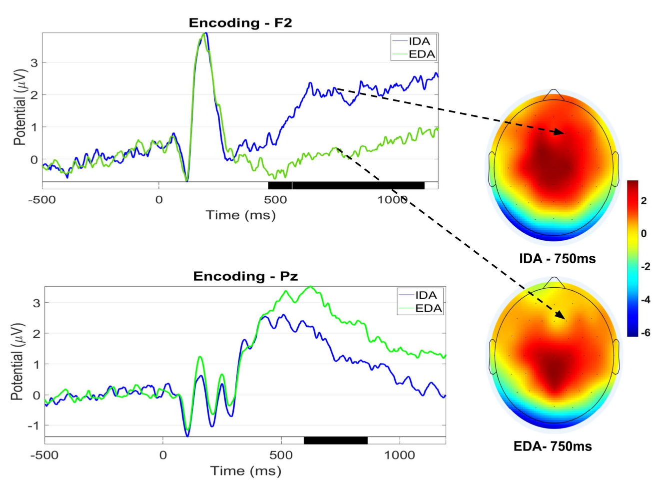


**Figure 3**: Event-related potential during encoding the word. The upper panel shows the voltage at the frontal channel (F2 plotted for representation). The lower panel shows the voltage at posterior channels (Pz plotted for representation). Black bars below the ERP plots statistically significant differences. Topo-plots show instantaneous voltage at 750 ms in different conditions.

(18) > 2, $p < 0.05$; see Figure 3). The P200 component did not differ significantly between the conditions (t (18) = 1.06,

$p$ = 0.32). Over the parietal sensors, we observed a reverse trend where the amplitude of the LPPs was higher in the EDA condition than in the IDA condition (t (18) = -3.25, $p$ = 0.08). We also performed the decoding analysis with the time series from the word encoding epoch. Interestingly, the decoding accuracy was above the chance level consistently post 350ms (group-averaged decoding accuracy>65%).

## Time-frequency differences

Next, we tested for time-frequency differences in the two conditions in the personality adjective encoding epoch and the delay period prior to the color recall. Taking cues from the ERP results reported in the previous section, we focused our analysis on frontal and parietal electrodes for the encoding epoch. During the encoding epoch, significantly ($p < 0.05$) higher event-related desynchronization (ERD) was observed in the alpha band (8-12 Hz) over frontal sensors (Fz, F2, F1; see Figure 4a) in IDA condition around 300-500ms post-stimulus presentation. A significantly higher event-related synchronization (ERS) was observed in the theta band (4-8 Hz) and beta band (18-23 Hz) at 600-800ms post-stimulus presentation in the EDA condition. In the delay period prior to color-recall, significantly higher theta ERS was observed over mid-frontal electrodes in the EDA condition at around 100-250ms post-onset of the delay period (see Figure 4b).

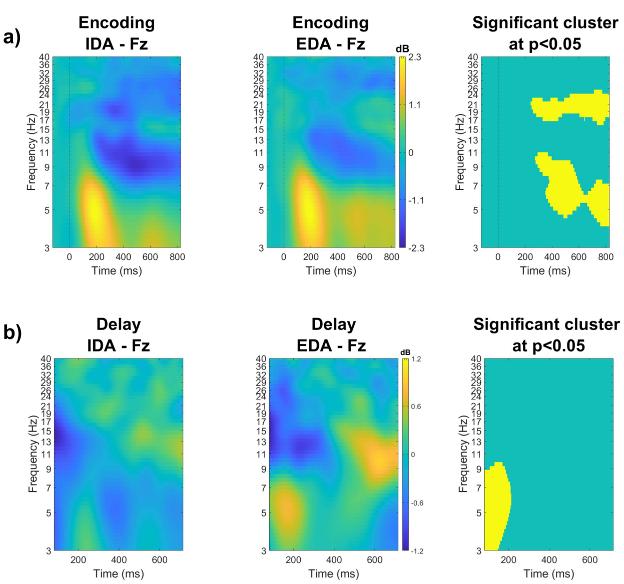


**Figure 4**: Time-frequency differences in encoding and delay epochs. a) Event-related spectral perturbations in encoding epoch. Higher theta event-related synchronization (ERS) in the EDA condition at 500-800ms; higher event-related desynchronization (ERD) in the alpha band in the IDA condition at 300-600ms; higher beta ERS in the EDA condition. b) Higher theta band ERS in EDA condition during the delay period. The right-most plot shows significance at p<0.05.

Over the occipito-parietal electrodes (P5, PO7) and the right-frontal electrodes (F4, F6), the alpha band ERS was significantly higher at 300-400ms in the delay period before color recall in the IDA condition (see Figure 5).

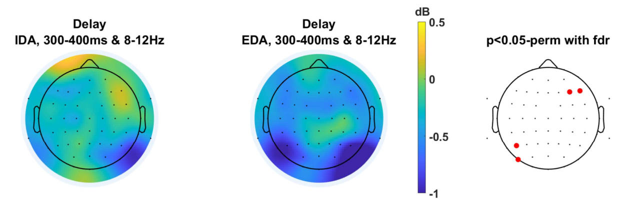


**Figure 5**: Topo plot showing higher alpha power during the delay period in IDA conditions. The right-most plot shows significant sensors in red.

## Discussion

Our study investigated behavioral and neural correlates of the effect of internally directed attention on color recall in a dual-task working memory paradigm. We observed that the participants were less accurate in recalling the color in the IDA condition than in the EDA condition, where the distracto r task required external or stimulus-directed attention. These results are in line with other studies (Daamen et al., 2016; Huijser et al., 2018) and support the claim that IDA processing distractor tasks can lead to more off-task thoughts, thus impairing the rehearsal process and lead to lower accuracy as compared to EDA processing distractor task. The time spent on the distractor task was not significantly different between the conditions, thus keeping the overall delay duration consistent between the conditions. This implies that the differential effect on recall accuracy cannot be attributed to different delay timings and is likely due to the nature of processing itself. Consistent with Huijser et al., 2018, we kept the thought probe in half of the trials to sample the effect of IDA/EDA processing during the distractor task. We found that participants were more off-task in the delay period following the IDA processing task in the IDA condition.

Since our IDA condition required the participant to process the personality adjective in self-reference, we checked for the self-referential effect both between conditions and within the IDA condition. Self-referential information is processed preferentially than non-self-referential information, leading to better recall performance, known as the self-reference effect. The reason for such an effect is that self-reference leads to a rich encoding, both in the depth of processing and syntactic processing, and thus functions effectively during information processing (Rogers et al., 1977). Our study did not find the self-reference effect in the IDA condition compared to the EDA condition. One possible explanation could be that the self-generated thoughts that emerged after the IDA processing in the IDA condition interfered with the color rehearsal during the delay period before the color recall. This idea is also supported by the fact that the participants reported more mental elaboration of the personality adjective in the IDA condition than in the EDA condition.

In the IDA condition, processing the personality adjective in self-references, as cued at the beginning of the trial, leads to higher amplitudes of the late-positive potentials (LPP) post 450ms of stimulus onset over the medial frontal electrodes. LPP are linked to the sustained attentional and emotional engagement with the stimulus (Dennis & Hajcak, 2009; Hajcak, Dunning, & Foti, 2009; Katyal et al., 2020). However, in the EDA condition, the amplitude over the medial-frontal electrodes reached baseline after 450ms. Thus, we observed sustained processing of personality adjectives in the IDA condition over medial-frontal electrodes compared to the EDA condition. The P200 component, which is thought to reflect automatic semantic processing (Crowley & Colrain, 2004; Foti et al., 2009; Paulmann et al., 2013), was not significantly different between the conditions, suggesting that early-stage processing of the word in both conditions might not be different. Only the later processing stages beyond 450ms (LPPs) might contribute to the differential effects in behavior.

These results align with the time-course model proposed by Grainger and Holcomb (2009). Considering the ERP literature, the model suggests that the visual word is processed semantically only after 400ms of presentation. We further carried out decoding analysis using the EEG time series from all the electrodes and observed that the classification accuracy was above the chance level only after 350ms of stimulus presentation. Thus, as suggested by higher amplitude of the LPP and decoding analysis, we speculate that in the IDA condition, the personality adjective is being processed affectively compared to the EDA condition and this might be the reason for higher mental elaboration of the word during the delay period thus affecting the color recall. Interestingly, we found a reversed trend over the posterior electrodes: beyond 400 milliseconds, the amplitude in the EDA condition was significantly higher compared to the IDA condition.

We further looked for the oscillatory changes in encoding the word in the two conditions. As hypothesized based on the literature, we observed higher theta power in the EDA condition during encoding of the personality adjective. We observed higher event-related desynchronization (ERD) in the alpha band while encoding the word in the IDA condition. The alpha band ERD is a signature of general attentional demand and active cognitive processing in contrast to alpha band ERS, which reflects a state of inhibition helping to establish a highly selective activation pattern (Klimesch et al., 2007; Mu & Han, 2010).

The extant literature suggests that frontal theta is involved in successful working memory manipulations and is a mechanism of cognitive control (Cavanagh & Frank, 2014; Itthipuripat et al., 2012). During the delay period prior to the recall of the color, we observed higher amplitude in the theta band in the EDA condition, which is likely responsible for higher accuracy of color recall compared to the IDA condition. Further, we also observed an increase in alpha power over posterior sensors during the delay period in the IDA condition. This alpha increase, as a signature of internal attention (Kam et al., 2018; O'Connell et al., 2009), coupled with an increased frequency of self-reported off-task thoughts suggests that the participants engaged in internally directed attention during the IDA condition which likely decreased the accuracy of color recall.

## Conclusion

Our study combined behavioral, experience sampling, and electrophysiological measurements in a triangulation approach. We manipulated attention experimentally in a color-recall working memory paradigm. By using intentional externally directed attention as a comparison, we demonstrated that intentional internally directed attention has a greater impact on cognitive task performance than externally directed attention. Further, we used ERP and time-frequency analysis to validate our experimental paradigm. However, further analysis is required to establish the causal role of neural oscillation involved in intentional IDA distractor condition.

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