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Event Related Potentials (ERP) Study to Understand Function to Object Mapping for Engineering Student

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Investigating the N400 Event Related Potential as a Measure of Creativity in Engineers

1. Introduction

Creativity has long been considered a key competency in engineering [1]–[3], and multiple recent articles have underscored the need for engineers to be “creative” and “innovative,” in addition to possessing solid technical skills [4]–[7]. Creativity will be crucial to providing solutions to the new and increasingly difficult challenges of a rapidly developing technological era. It is critical that creativity be part of engineering education to prepare the next generation of engineers, but how can a student’s creative ability and growth be measured?

One way to measure creative cognition is through neuroscientific techniques. Most published neuroscientific studies of creativity use high spatial/temporal resolution techniques, such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). Creativity studies using EEG tend to focus on investigating the total signal power to measure cognitive activity in various regions and within specific frequency bands, such as the alpha band (8-13Hz) [8]–[10]. Few studies have used high temporal resolution techniques such as event related potentials (ERPs) to investigate the exact timing of creative cognitive processes. ERPs are processed from EEG data and are time-locked components relative to a stimulus noted as positive or negative signal amplitude peaks [8], [11].

One set of studies that used the ERP technique was by Rutter et al.[12] and Kröger et al [13]. They investigated the N400 ERP relative to conceptual expansion, a process related to creativity, and the novelty and appropriateness of a stimulus [12], [13]. They investigated the N400 ERP, a negative peaking potential occurring between 300-500 ms after stimulus presentation associated with the processing of semantic mismatches and violations of prior knowledge. Novelty and appropriateness are the two most commonly agreed upon aspects of conceptual expansion. Novelty represents the uniqueness within a context and appropriateness is value or usefulness within a context [8], [12], [13]. In their studies, the N400 was responsive as a function of novelty to stimuli featuring metaphorical phrases and the alternate uses task (AUT). A post-N400 component, a negative varying response directly following the N400 component, was also explored interpretation processes and concept integration [12], [13]. More work is needed to understand how these components can be used to measure conceptual expansion and other creative processes, especially in engineers.

Several studies in recent years have focused on creativity and engineering, with majority of these use high spatial resolution techniques like fMRI and EEG to identify the specific cognitive regions and networks most active during creative processes [14]. One study conducted by Goucher-Lambert et al. [15] used fMRI to explore the differences between design ideation with and without inspirational analogies. Participants were presented with a simplified design problem and asked to generate solutions for this experiment. Five words were presented after each design task, which included analogically near words, analogically far words, and control words, to provide solution inspiration. Results showed that brain activation differed for participants when successfully inspired to generate creative concepts and those not inspired [15].

A few studies have explored ERPs concerning creativity in engineering [14], and results showed activation of N400 component for appropriateness [16], the N200 was associated with categorization of preference [17], and the N400 and P3 components associated with idea recognition and memory recall [18]. This study's goal was to investigate how creative processes can be measured in engineers during a design task, specifically using ERPs.

2. The experiment

2.1 Designing the current study

This study was designed based on Kröger et al.'s 2013 [13] study in conjunction with Goucher-Lambert et al.'s [15] study. Kröger et al. [13] investigated conceptual expansion, which they defined as the ability to broaden the bounds of a semantic concept beyond its typical characteristics. They used the modified AUT task, in which participants were asked to judge the novelty and appropriateness of an alternative "use" or "function" for an object. In their research, they found that the N400 component modulated depending on whether the stimulus was perceived as common (low novelty, high appropriateness), creative (high novelty, high appropriateness), or nonsense (high novelty, low appropriateness). The most positive N400 responses occurred when stimuli were perceived as common, while more negative N400 responses resulted when stimuli were designated creative or nonsense. Only differences between creative-common and nonsense-common were statistically significant [13].

Goucher-Lambert et al. investigated analogical reasoning, which they defined as the process of applying information from a source to a target through shared connections, relationships, or representations [15]. They used inspirational word sets collected from their 2017 study, text-mined from crowd sourced responses to obtain near vs. far inspirational stimuli. The frequency of appearance of a keyword within their data set was used to measure the analogical distance, i.e., its novelty. The frequency of appearance of analogically near keywords in submissions accounted for the top 25% of the frequency distribution of all submitted keywords, while analogically far, or novel, keywords only appeared once within the data set. [19].

The design questions and matching keywords from Goucher-Lambert et al.'s [15] study were combined with Kröger et al.'s [13] for this experiment. Keywords were initially designated according to the results of the Goucher-Lambert et al. [19] and [15] studies: “analogically near” were “common,” “analogically far,” were “creative,”and “nonsense” keywords were taken from other design questions or from the categories designated in a study by Alhashim et al. [14], [20]. The keywords were used as potential functions a solution to the design task might incorporate. First, a design question was presented to the participants, in a random order, followed by the matching functions listed in Table 1. Participants responded "yes" or "no" to whether a presented function was "Unusual" and/or "Appropriate" in relation to the design question while their EEG signals were recorded [14].

Table 1: Design Problems and Associated Common, Creative, and Nonsense Keywords [14].

Problem	Common (Usual-Appropriate, Near)	Creative (Unusual-Appropriate, Middle)	Nonsense (Unusual-Inappropriate, Far)
1. Design a lightweight exercise device that can be used while traveling (Linsey & Viswanathan, 2014).	Pull, Push, Resist	Roll, Tie, Convert	Dry, Decay, Smash
2. Design a device that can collect energy from human motion (Fu et al., 2013).	Store, Charge, Pedal	Compress, Shake, Attach	Reflect, Decorate, Clean
3. Design a new way to measure the passage of time (Tseng et al., 2008).	Count, Fill, Decay	Drip, Pour, Crystallize	Scratch, Smash, Entertain
4. Design a device that disperses a light coating of a powdered substance over a surface.	Spray, Blow, Shake	Wave, Pressurize, Atomize	Dry, Close, Balance
5. Design a device that allows people to get a book that is out of reach (Cardoso & Badke-Schaub, 2011).	Extend, Hook, Reel	Hover, Stick, Angle	Tie, Drink, Decorate
6. Design an innovative product to froth milk (Toh & Miller, 2014).	Spin, Whisk, Shake	Pulse, Churn, React	Dry, Resist, Cut
7. Design a way to minimize accidents from people walking and texting on a cell phone.	Alert, Flash, Sense	Reflect, React, Emit	Cut, Decorate, Clean
8. Design a device to fold washcloths, hand towels, and small bath towels (Linsey, Markman, & Wood, 2012).	Press, Stack, Rotate	Deposit, Cycle, Funnel	Pedal, Drip, Scratch
9. Design a way to make drinking fountains accessible for all people (Goldschmidt & Smolkov, 2006).	Adjust, Lift	Shrink, Catch	Flash, Entertain
10. Design a measuring cup for the blind (Jansson & Smith, 1991; Purcell, Williams, Gero, & Colbron, 1993).	Touch, Beep, Sense	Recognize, Cover, Preprogram	Decay, Compress, Smash
11. Design a device to immobilize a human joint.	Wrap, Hold, Harden	Shrink, Condense, Pressurize	Cook, Destroy, Entertain
12. Design a device to remove the shell from a peanut in areas with no electricity.	Crack, Crank, Squeeze	Melt, Wedge, Wrap	Communicate, Reach, Unclog

2.2 Experimental procedures

Participants were seated in a chair in front of a computer. The EEG cap was then fitted, and the electrodes were prepared for data collection. Participants were verbally instructed through the experiment protocols, including what stimuli to expect, how to respond, and avoid excessive body movements to reduce artifacts. Each participant then completed a self-paced tutorial which included two example design tasks. After the tutorial, participants completed ten design tasks as part of the experiment. Each task was structured as shown in Figure 1.

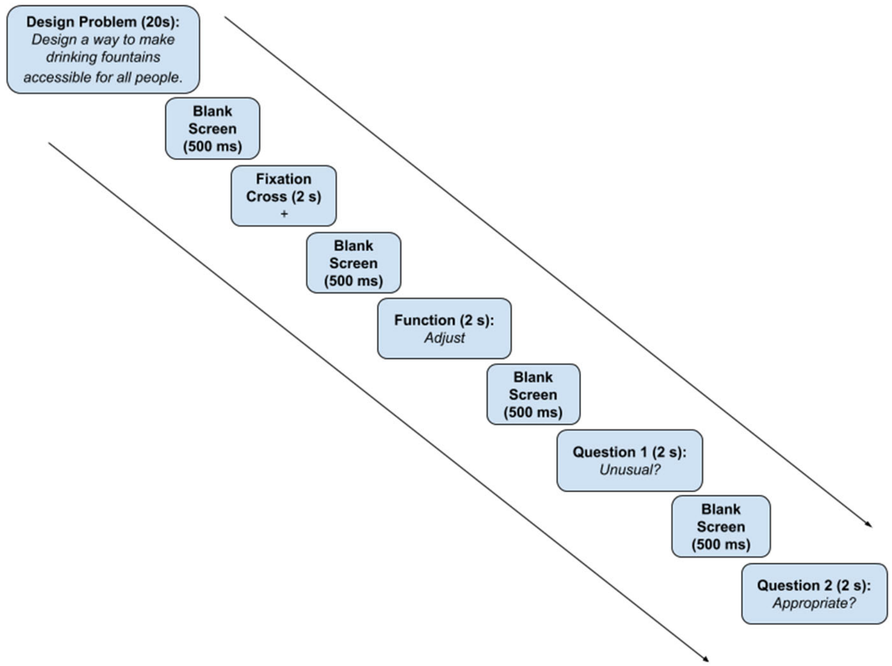

Figure 1: Experimental Design

After the design problem was shown, nine functions were presented in random order, including three creative, three common, and three nonsenses options. The questions were followed by a 500 ms blank screen and 2 second fixation cross before continuing to the next design task. Participants responded by pressing the right touchpad button on the laptop for "yes," and the left for "no." To prevent misunderstandings with preconceived definitions for "unusual" and "appropriate," participants were told to classify a function as "unusual" if it was novel or unfamiliar to them within the presented context and "not unusual" if it was known or familiar. A function would be classified as "appropriate" if it fit within the presented context and "not appropriate" if it was unfitting or irrelevant. It was expected that "common" functions would be "not unusual" and "appropriate," "creative" functions "unusual" and "appropriate," and "nonsense" functions "unusual" and "inappropriate."

2.3 Participants

There were four participants from a large public institution for this initial study, including two male students, one female student, and one male Mechanical Engineering professor, all right-handed. No compensation was given. Male participants spoke English as a second language. All participants self-reported normal or corrected to normal vision, no history of neurological or psychiatric illness, and no drug use. All gave written informed consent prior to participation; no identifiable personal information was kept in the data. The experiment followed the Institutional Review Board guidelines and was approved by the responsible committee of the University of Oklahoma.

2.4 Data collection setup

Data collection took place in a low-noise environment. A wireless 24 channel SMARTING EEG acquisition system, with amplifier and recording software from MBrainTrain, was used for this experiment. Data was sampled at 500 Hz, recorded from all 24 electrodes positioned according to the international 10-20 placement map. Neurobs Presentation software (Neurobehavioral Systems, Inc., Albany, CA) synchronized with the EEG acquisition system was used to present stimuli. A low impedance of about 5-10 kΩ was kept for each electrode during the experiment. A 64-bit Dell Latitude laptop with i5-8250U CPU 1.8 GHz with 7.86 GB ram was used to present stimuli and record participant responses via the left and right touchpad buttons. Lab personnel monitored signal data collection real-time through a separate connected monitor.

2.5 Data analysis

EEG data was processed using Matlab's EEGlab plugin. First, a band pass filter from 0.1-100 Hz and a 60 Hz notch filter was applied to exclude unclear data and line noise. Next, an independent component analysis (ICA) was performed to reject signal components caused by eye or muscle movement, line noise, and other common artifacts. Matlab's ERPlab plugin was then used to create 1150 ms ERP segments from 150 ms before stimulus presentation to 1000 ms after. The 150 ms before stimulus onset were used to baseline-correct the following 1000 ms segments. Last, a 30 Hz low-pass Butterworth filter with a slope of 24 dB/Oct was applied to remove additional artifacts with amplitudes exceeding +/-100 μV. After pre-processing, the ERPs were grouped by the condition (common, creative, or nonsense) assigned by the participant, allowing for individual validation of the experimental design. Data was not rejected based on a required minimum number of trials per condition due to the small number of participants.

The centro-parietal electrodes Cz, CPz, and Pz were selected to analyze the N400 and post N400 components based on Kröger et al.'s 2013 study. This experiment was a within-subject design with two factors: condition (common, creative, nonsense) and electrode (Cz, CPz, Pz). A two factor repeated measures ANOVA was performed for time windows of interest and Mauchly's Test of Sphericity was used to verify that the variances were equal for both the N400 and post-N400. Effects sizes including Cohen's d, partial eta squared (η_p^2), and partial omega squared (ω_p^2) are reported with all significance levels.

3. Results and discussion

In Figure 2 is shown the grand-averaged ERPs of the Cz, CPz, and Pz electrodes of all participants. As observed in previous studies, the signal displays a negative dip for creative and nonsense conditions in the N400 (300-500ms) time window, with similar amplitudes at their negative peaks. [12], [13], [21], [22].

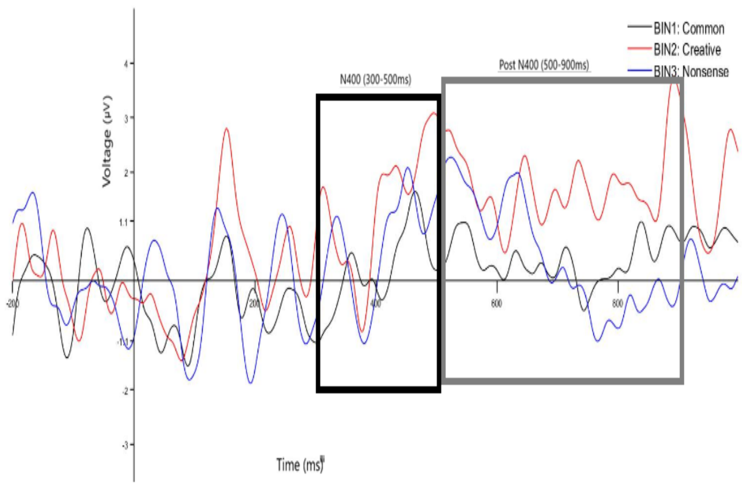

Figure 2: Grand Average Signal of Cz, CPz, and Pz Electrodes for All Subjects

The repeated measures ANOVA revealed significant main effects for the factor electrode ($F(2,6) = 11.79$; $p = .033$; $\eta_p^2 = .797$; $\omega_p^2 = .09$), however main effects were not significant for the factor condition ($F(2,6) = .392$; $p = .663$; $\eta_p^2 = .116$; $\omega_p^2 = -.06$) or the condition-electrode interaction ($F(4,12) = 1.614$; $p = .234$; $\eta_p^2 = .35$; $\omega_p^2 = .00$). Size effects are reported, but all were small enough to be considered negligible.

3.1 The n400 component

In Figure 3 the average mean amplitude during the N400 time window for the three electrodes for all participants is displayed.

The common condition had the least negative mean amplitude of 0.128μV, the mean amplitude for the creative condition was -0.677μV, and the nonsense condition had the greatest negative mean amplitude at -1.137μV. Although the differences in the means for all pairs were insignificant (common-creative: p=1, d=.32; common-nonsense: p=1, d=.42; creative-nonsense: p=1, d=.16), this follows the trends in previous studies [12], [13], [21], [22]. A linear trend in the modulation of the N400 for the factor condition was reported in the Rutter et al. 2012 [12] study, but no significant linear trend ($F(1,3) = 1.28$; $p = .339$; $\eta_p^2 = .3$) for condition was observed in this study. These results show that the N400 ERP modulated similarly to previous studies with respect to the perceived novelty and appropriateness of a function associated with a given design problem.

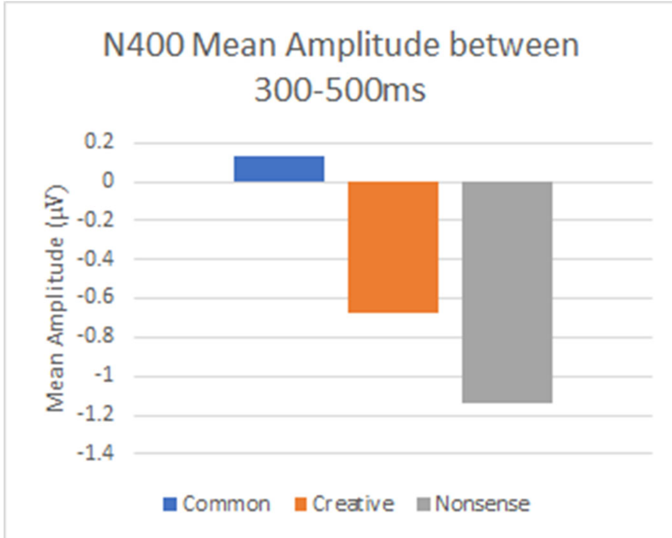

Figure 3: Mean Amplitudes for the N400 Component

3.2 The post-n400 component

No significant main effects for condition ($F(2,6) = 1.08$; $p = .395$; $\eta_p^2 = .266$; $\omega_p^2 = .01$), electrode ($F(2,6) = 3.286$; $p = .109$; $\eta_p^2 = .523$; $\omega_p^2 = .02$), or the condition-electrode interaction ($F(4,12) = 3.02$; $p = .061$; $\eta_p^2 = .502$; $\omega_p^2 = .00$) were observed for the post-N400 component, and size effects were negligible. The average mean amplitude for the post N400 time window, for the three electrodes, for all participants is shown in Figure 4.

The common condition had the least negative mean amplitude of 0.264µV, the mean amplitude was -1.438µV for the creative condition, and the nonsense condition's mean amplitude was most negative at-1.778µV. The differences in the means for all pairs were insignificant (common-creative: p=1, d=.63; common-nonsense: p=.958, d=.76; creative-nonsense: p=1, d=.15), and there was no significant linear trend for the factor condition. However, the overall responsiveness of the post-N400 component was similar to previous studies [12], [13]. In Figure 4, the nonsense condition continued a more negative trend after 500ms, while the creative condition exhibited a more positive shift during the post- N400 time window. This could be the result of failing to integrate nonsense stimuli into existing semantic networks, but successfully being able to integrate creative stimuli [12], [13].

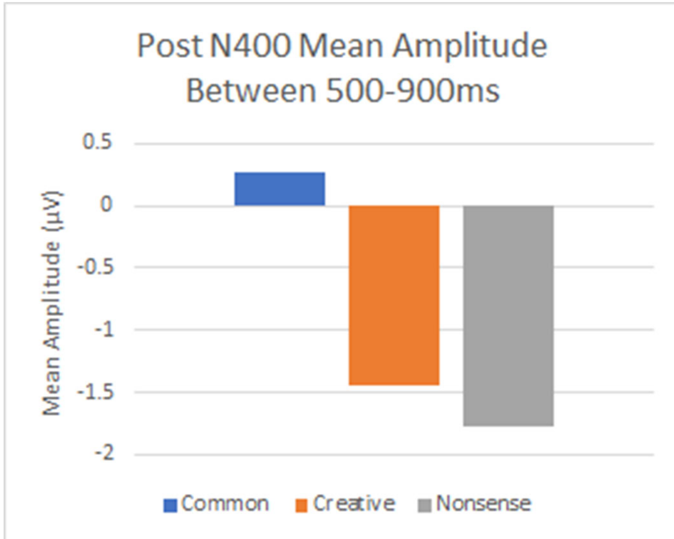

Figure 4: Mean Amplitudes for Post N400 Component

3.3 Contour maps and alpha band power

Data collected from CPz, Pz, and POz electrodes were used to investigate the modulation of the N400 and post-N400 ERPs. The generated contour maps from the data are shown in Figures 5 and 6. In this case, data for the designated time period was mapped from all electrodes to understand the relative neural activity across the brain.

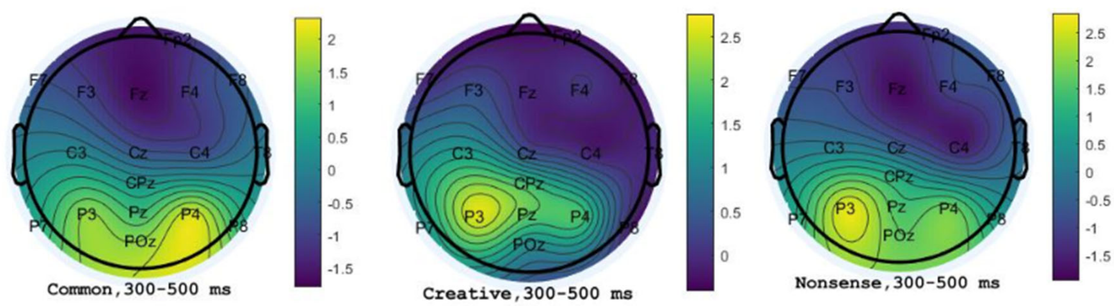

Figure 5: Contour Maps of Mean Amplitude of N400 Time Window

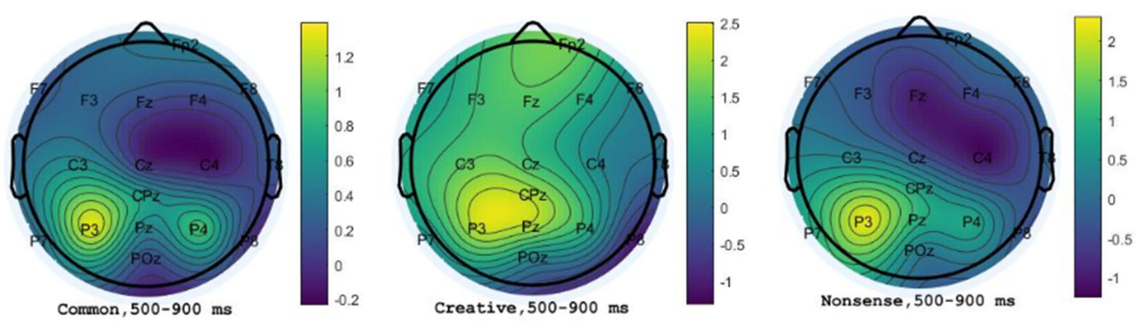

Figure 6: Contour Maps of Mean Amplitude of Post-N400 Time Window

For all conditions during the N400 time window, the most negative potential was located in the right frontocentral distribution. Positive activity was observed in the parietal-occipital area, in the right hemisphere for the common conditions and the left for creative and nonsense conditions. Future studies could investigate N400 in the fronto-central area and P400 in the parietal-occipital region in relation to creativity. During the post-N400 time window, positive potential activity was observed in the left parietal area. In the future, this area could be studied for the P600 component, which is known to relate to processing and syntactic structure in this area [11].

Additionally, the task-related power was calculated for the alpha-frequency band, which has been related to creative cognition [8]. A 9x2x3 ANOVA was performed to find any brain regions that experienced significant alpha task-related power (TRP, Please see Figures 7 and 8).

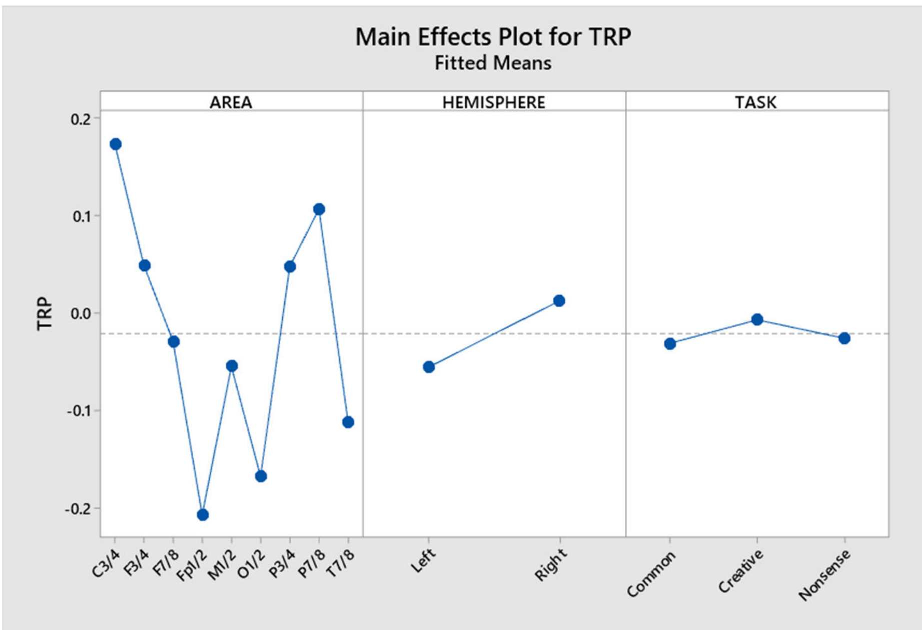

Figure 7: General Pattern of TRP for the Task Across Electrodes

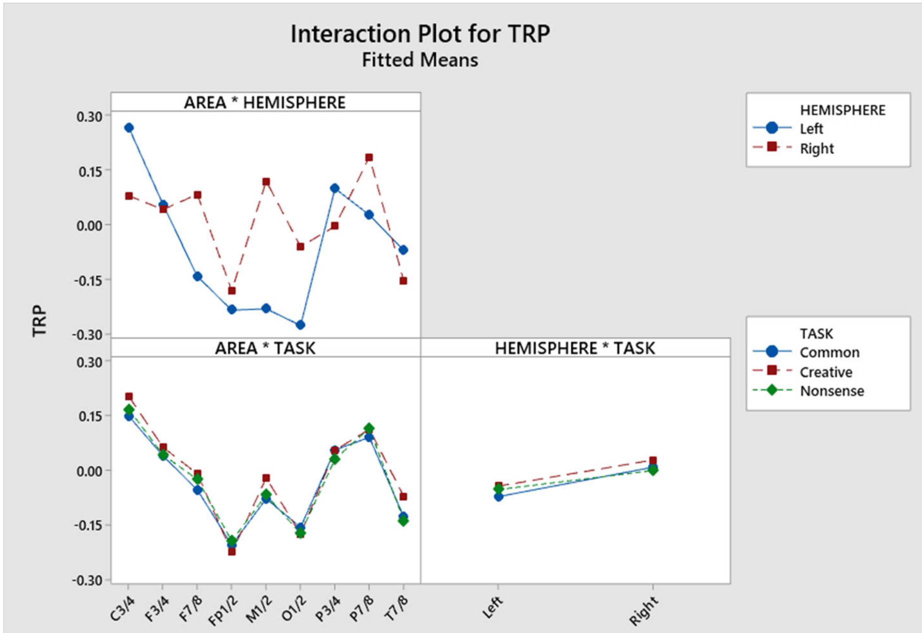

Figure 8: General Pattern of TRP Interactions for the Task Across Electrode Locations

This analysis showed a significant main effect for the factor AREA (F (8,162) = 2.30, p = .024, ηp2 =.102), indicating decreased alpha power over Anterio-frontal cortical sites and increased alpha power over Centro-temporal. A significant main effect was observed for the factor HEMISPHERE (F (1,162) =1.48, p=.226, ηp2 =.009), which displayed greater alpha power decreases on left-hemispheric than right-hemispheric sites. Lastly, the interaction AREA × TASK had a significant main effect (F (16,162) = .02, p = 1.0, ηp2 = .002), revealing a notable decrease in alpha power on Anterio-frontal cortical sites and increased alpha power over Centro-temporal ones.

4. Conclusions and future work

This study aimed to investigate how creative processes can be measured in engineers during a design task, specifically using ERPs. Participants were presented with a design question, then asked to evaluate whether the functions were "unusual" and "appropriate" within that context. Previous studies reported individual's N400 component for creativity, where as this study used functions. Though the post-N400 components were not statistically significant, they can be compared to the grand-average ERP and the mean amplitude of the group. It is hypothesized that if an individual is creatively processing an idea, they will have a negative N400 amplitude similar to the group mean amplitude for that condition followed by a positive shift in the post-N400 component. Current experiment shows promising results of using the N400 to evaluate the creativity of an engineering design solution. Though the

number of participants was small and the differences in ERPs were found to be statistically insignificant, the general trends in the data support previous studies, showing the viability of this experiment. Future work may include gathering data from more participants to see if these preliminary results hold true. Future research could also include processing data in relation to other specific brain regions and frequency bands during this time period, as well identifying other ERPs in relation to the creative process. In this study, contour maps of the brain were generated, and alpha band power calculated for the time windows of interest. More work could be done to understand the relationships among other measures to develop a holistic picture of the creative process. Not one measure alone will unlock the mysteries of creativity, but perhaps understanding the relationship between different measures will advance the path towards understanding how to measure creativity in engineers.

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References

[1] F. E. Jones, “Predictor variables for creativity in industrial science.,” *Journal of Applied Psychology*, vol. 48, no. 2, p. 134, 1964.

[2] C. D. McDermid, “Some correlates of creativity in engineering personnel.,” *Journal of applied psychology*, vol. 49, no. 1, p. 14, 1965.

[3] T. B. Sprecher, “A study of engineers’ criteria for creativity.,” *Journal of Applied Psychology*, vol. 43, no. 2, p. 141, 1959.

[4] M. A. Robinson, P. R. Sparrow, C. Clegg, and K. Birdi, “Design engineering competencies: future requirements and predicted changes in the forthcoming decade,” *Design Studies*, vol. 26, no. 2, pp. 123–153, 2005.

[5] B. Trilling and C. Fadel, “National Academy Of Engineering.(2004). The Engineer of 2020: Visions of Engineering in the New Century,” *21st century skills: learning for life in our times*.

[6] S. Olson, *Educating engineers: Preparing 21st century leaders in the context of new modes of learning: Summary of a forum*. National Academies Press, 2013.

[7] P. Petrone, “Why creativity is the most important skill in the world,” *LinkedIn, The Learning Blog*, 2019.

[8] A. Abraham, *The neuroscience of creativity*. Cambridge University Press, 2018.

[9] M. T. Ahad *et al.*, “Behavioral Pattern Analysis between Bilingual and Monolingual Listeners’ Natural Speech Perception on Foreign-Accented English Language Using Different Machine Learning Approaches,” *Technologies*, vol. 9, no. 3, Art. no. 3, Sep. 2021, doi: 10.3390/technologies9030051.

[10] M. T. Ahad, *An EEG-based Comparative Analysis of Natural Speech Perception by Native Speakers of American English vs. Bilingual Individuals*. Lamar University-Beaumont, 2018.

[11] S. J. Luck, *An introduction to the event-related potential technique*. MIT press, 2014.

[12] B. Rutter, S. Kröger, H. Hill, S. Windmann, C. Hermann, and A. Abraham, “Can clouds dance? Part 2: An ERP investigation of passive conceptual expansion,” *Brain and Cognition*, vol. 80, no. 3, pp. 301–310, 2012.

[13] S. Kröger, B. Rutter, H. Hill, S. Windmann, C. Hermann, and A. Abraham, "An ERP study of passive creative conceptual expansion using a modified alternate uses task," *Brain research*, vol. 1527, pp. 189–198, 2013.
[14] M. Marshall, "An Investigation of the N400 Component as a Measure of Creativity in Engineering Design," 2020.
[15] K. Goucher-Lambert, J. Moss, and J. Cagan, "A neuroimaging investigation of design ideation with and without inspirational stimuli—understanding the meaning of near and far stimuli," *Design Studies*, vol. 60, pp. 1–38, 2019.
[16] J.-C. Rojas, M. Contero, J. D. Camba, M. C. Castellanos, E. García-González, and S. Gil-Macián, "Design perception: combining semantic priming with eye tracking and event-related potential (ERP) techniques to identify salient product visual attributes," in *ASME International Mechanical Engineering Congress and Exposition*, 2015, vol. 57540, p. V011T14A035.
[17] A. Telpaz, R. Webb, and D. J. Levy, "Using EEG to predict consumers' future choices," *Journal of Marketing Research*, vol. 52, no. 4, pp. 511–529, 2015.
[18] C. Yang, F. An, C. Chen, and B. Zhu, "The effect of product characteristic familiarity on product recognition," in *IOP Conference Series: Materials Science and Engineering*, 2017, vol. 231, no. 1, p. 012016.
[19] K. Goucher-Lambert and J. Cagan, "Using crowdsourcing to provide analogies for designer ideation in a cognitive study," in *DS 87-8 Proceedings of the 21st International Conference on Engineering Design (ICED 17) Vol 8: Human Behaviour in Design, Vancouver, Canada, 21-25.08. 2017*, 2017, pp. 529–538.
[20] A. G. Alhashim and M. Marshall, "WIP: Assessing Creativity of Alternative Uses Task Responses: A Detailed Procedure," 2020.
[21] T. Hartog, M. Marshall, A. G. Alhashim, M. T. Ahad, and Z. Siddique, "Work in Progress: Using Neuro-responses to Understand Creativity, the Engineering Design Process, and Concept Generation," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Sep. 17, 2020. [Online]. Available: https://peer.asee.org/work-in-progress-using-neuro-responses-to-understand-creativity-the-engineering-design-process-and-concept-generation
[22] T. Hartog *et al.*, "Pilot Study: Investigating EEG Based Neuro-Responses Of Engineers via a Modified Alternative Uses Task to Understand Creativity," 2020, pp. 1–10.