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PILOT STUDY: INVESTIGATING EEG BASED NEURO-RESPONSES OF ENGINEERS VIA A MODIFIED ALTERNATIVE USES TASK TO UNDERSTAND CREATIVITY

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ABSTRACT

Assessing creativity is not an easy task, but that has not stopped researchers from exploring it. Because creativity is essential to engineering disciplines, knowing how to enhance creative abilities through engineering education has been a topic of interest. In this paper, the event related potential (ERP) technique is used to study the neural responses of engineers via a modified alternative uses task (AUT). Though only a pilot study testing two participants, the preliminary results of this study indicate general neuro-responsiveness to novel or unusual stimuli. These findings also suggest that a scaled-up study along these lines would enable better understanding and modeling of neuroresponses of engineers and creative thinking, as well as contribute to the growing field of ERP research in the field of engineering.

Keywords: Creativity, AUT, EEG, ERP

1 INTRODUCTION

Creative thinking is important, and arguably necessary, to increase the quality of living in the 21st century [1, 2]. However, even though intelligence has been increasing over time, creativity has been in steady decline and action needs to be taken to end this decline [3, 4]. Engineers should not be excluded from this prevention of creativity loss. In fact, the National Academy of Engineering has noted that there is a need for creative, as well as competent, engineers [5, 6]. The demand for creative engineers has been highlighted since before the 1960s [7-9] and creativity continues to be a desirable characteristic [10, 11]. In spite of this demand, it appears that higher education is not preparing students for this type of thinking and students graduating from engineering fields are lacking creative ability [12-14]. Surveys from the University of Connecticut found that students thought instructors focused too much on the use of conventional solutions to problems rather than novel solutions and found that the curriculum taught lacks creativity [14]. Similarly, another study reported that as students moved further down their engineering paths, they believed that there was little value placed on creativity [15]. A multitude of other studies and investigations found that the engineering discipline has become more focused on rote memorization and learning as well as convergent thinking as opposed to other, more innovative approaches [6, 16-24]. Creativity and innovation are trademarks of engineering and creativity is considered to be an imperative prerequisite to innovation, which means that a decline in creative ability will correspond to a decline in the number of innovative engineers [25, 26]. Fortunately, research has shown that creative ability can be enhanced via certain types of exercises and techniques. Through the use of behavioral and neurological approaches, studies have demonstrated changes in brain activity and behavioral outcomes after using creativity enhancing exercises and techniques [27, 28]. Though using behavioral approaches to study the impact of these exercises and techniques on creativity is useful, behavioral approaches do not provide a direct way to investigate the neural mechanisms that underlie creativity. Neurological approaches can provide a direct way to study these underlying processes.

Using neurological approaches allows researchers to obtain visible, physical results that connect stimuli or prompts related to creativity to biological processes and structures. These approaches also allow researchers to test whether or not methods claiming to improve creativity or aid in problem solving actually do so. That is, the effectiveness of methods that claim to aid in innovative design or problem solving could be critically tested utilizing neurological approaches that provide neurological and quantifiable measurements.

In this paper, a pilot study using event-related potentials to investigate the neural responses of engineers completing a modified alternative uses task (AUT) is presented. First, in Section 2, electroencephalography (EEG) and event-related potentials (ERPs) will be introduced, along with a review of the literature concerning neuroimaging, design, concept generation, and problem solving. In Section 3, the pilot study will be described, and the outcomes will be presented. Finally, the paper concludes with a discussion of the outcomes and future directions (Section 4).

2 BACKGROUND

2.1 Electroencephalography (EEG) and Event Related Potentials (ERPs)

One technique used to study neural activity of the brain is the electroencephalogram (EEG). An EEG is a device used to measure and record the electrical potential created when neurons release neurotransmitters and other ions [29]. These electrical signals are collected through electrodes placed on scalp, as shown in Fig. 1. From these signals, responses to stimuli can be extracted and analyzed, providing high temporal resolution of brain activity. In the majority of studies, EEG signals are analyzed based on frequency, amplitude, and electrode position. Frequency bands such as delta (0.1-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-100 Hz) relate to specific states of brain activity. Figure 2 shows raw EEG data and corresponding electrical activity head maps.

Most EEG research surrounding creative ideation focuses around alpha waves, since alpha waves have been noted in various studies to correlate to tasks requiring creative responses [31]. The majority of these studies have examined a phenomenon called alpha synchronization, a period when alpha frequency (activity around the alpha band of 8-13 Hz) increases in power. The synchronization period is associated with periods of cognitive idling or rest. Alpha desynchronization, on the other hand, is related to a loss of power in the alpha frequency band and typically presents when cognition is actively engaged. Increased alpha synchronization has been linked to greater creative ability [32, 33] as well as more original ideas [34-36]. Higher alpha activity has also been related to creativity training tasks, thus indicating the possibility that the creative ability can be enhanced [34, 37]. Though studies regarding alpha activity have greatly contributed to useful knowledge in the field of creativity research, there is another technique using EEG that could be used to understand the creative process: event-related potentials (ERPs). ERPs are signals that are time-locked to a stimulus and provide a step by step visualization of the brain processes at each electrode during a trial [31]. They are direct measurements, down to the millisecond, of neural activity [38]. Several components, noted as positive or negative signal amplitude peaks or fluctuations correlated to specific times, have been discovered that relate to specific brain processes. Specifically, the N400 has been related to cognitive processes essential to creativity. The N400 is a negatively (signified by the "N") peaking potential that occurs between 300-500 ms after stimulus presentation.

FIGURE 1 – MOBILE EEG CAP WITH 24 CHANNELS AND CORRESPONDING ELECTRODE LAYOUT. ELECTRODES OF INTEREST ARE CIRCLED. SEE SECTION 3.2 FOR MORE INFORMATION ABOUT THESE ELECTRODES. (TAKEN FROM [30]).

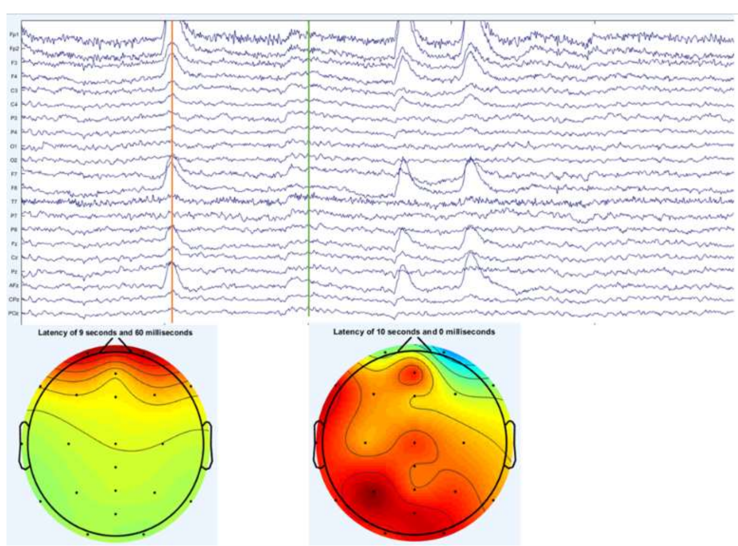

FIGURE 2 - RAW EEG DATA FROM 24 ELECTRODES FILTERED BETWEEN .5-100 HZ (TOP) AND CORRESPONDING ELECTRICAL ACTIVITY HEAD MAPS AT TWO POINTS (BOTTOM).

The N400 component has been related to the processing of semantic mismatches and violations of prior knowledge [31]. Additionally, a study by Rutter et al. linked the N400 component to conceptual expansion and noticed it responds to unusual stimuli [39]. Similarly, Kroger et al. reported the N400 as responsive as a function of unusualness or novelty to their experimental stimuli while investigating conceptual expansion through the use of the AUT [40]. Because of their high temporal precision, the use of EEG and ERP in studies are ideal for providing data about the neural processes that occur between stimulus presentation and neural response. For example, ERP has been used to understand language processing and Alternative Uses Task experiments (such as in [40]). Overall, measuring the temporal variation of neuro-responses during idea generation can provide a better understanding of creative thinking and a way to measure creative ideas and relate them directly to neuro-responses.

In a broader scope, neuro-responses can be utilized to enhance engineering design education by studying the effect of teaching alternative approaches at different stages of the design process on students' creativity as shown in Fig. 3. By noting the effect of each approach on each student's cognitive processes during each stage of the design process and linking that to the creative outcome produced, more personalized instructions can be developed based on differences in personality and learning styles, knowledge, and/or environmental factors such as team, classroom, and instructor.

2.2 Literature Review

Before diving in to the current study, it is important to include a literature review of past studies. Even though there are many neuroimaging techniques, we will touch on only a select few: functional magnetic resonance imaging (fMRI), functional near infrared spectroscopy (fNIRS), and EEG. For more comprehensive reviews of fMRI and EEG, see [31, 41-44]. It is important to note that fMRI and fNIRS focus on spatial resolution as opposed to temporal. Spatial resolution allows researchers to investigate which areas of the brain are most active during specific processes. EEG, on the other hand, has high temporal resolution which makes it ideal for providing data about the neural processes that occur between stimulus presentation and neural response. More specifically, temporal resolution refers to the granularity of time detail obtained when brain activation is occurring. Due to the high temporal resolution of EEG, we are able to measure ERPs down to the millisecond.

2.2.1 fMRI

fMRI is the most common technique used to investigate creativity [44], yet its use of studying solely engineers, engineering-based problems, or design is limited. One of the first investigations of design and fMRI was used to investigate cognitive processes used for design versus non-design tasks [45]. While this paper was not a study of creativity, the authors found that different cognitive processes were used for design tasks and non-design tasks. The cognitive processes pointed out here were linked to different regions of the brain, where there was extensive activation when solving the design tasks compared to the non-design tasks. A 2013 study utilized fMRI to determine which areas of the brain were activated when participants were asked about products that varied in product form, product function, or both [46]. This form-function tradeoff investigation revealed that choices based on products that vary in both aspects (form and function) involve not only unique, but also common, brain networks as compared to choices that were based only on form or only on function. Specifically, the activated regions were those related to emotion when form and function conflicted with one another. Specifically, the activated regions were those related to emotion when form and function conflicted with one another.

In a more recent fMRI paper related to engineering and design, Hay et al. sought to investigate which regions of the brain were activated in product design engineers with professional experience [47]. In this study, brain activation

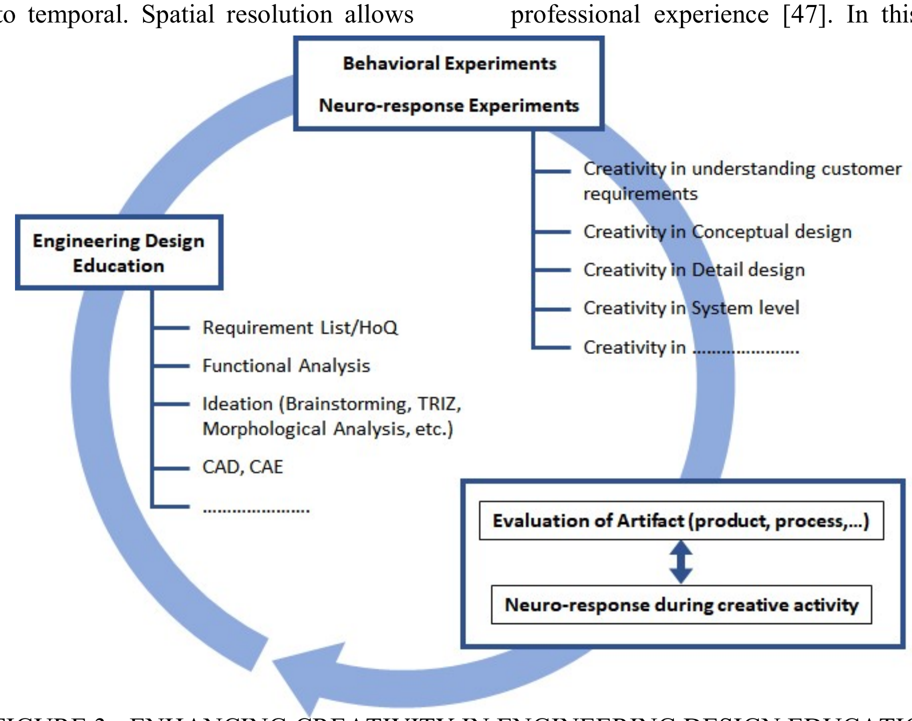

FIGURE 3 - ENHANCING CREATIVITY IN ENGINEERING DESIGN EDUCATION.

patterns of open-ended and constrained tasks were compared. The key findings were that product design en gineer ideation was associated with greater activity in left cingulate gyrus, but no significant differences were observed between constrained or open-ended tasks. Furthermore, there was preliminary association with activity in the right superior temporal gyrus for concept generation during ideation tasks. Finally, an fMRI study by [48] tested graduate-level students specializing in engineering, design, or product development to investigate design ideation and concept generation with and without the support of inspirational stimuli (e.g., analogies). Here, brain activation differed for participants that were able to successfully use the inspiration to generate an insightful design and those that were unsuccessful, most of which did not receive inspirational stimuli.

2.2.2 fNIRS

A few notable investigations have used fNIRS to explore the brains of engineering students. One of the earlier investigations of fNIRS and engineering found that freshman-level engineering students had five times greater activation in regions of the brain related to memory, planning, decision making, and ability to think about multiple concepts at once than seniors [49]. Seniors, on the other hand, had ten times the activation in areas associated with behavior control, uncertainty management, and self-reflection in decision making. Another study looked at neuro-cognitive differences among engineering students when using different concept generation techniques. This study indicated intra-hemisphere connectivity in the left hemisphere for unstructured techniques, intra-hemisphere connectivity in the right hemisphere for partially structured techniques, and inter-hemisphere connectivity between both the left and right hemisphere for structured techniques [50].

Another investigation has focused on hemisphere differences for brainstorming, morphological analysis, and TRIZ [51]. With respect to concept generation, there is left hemisphere dominance. More specifically, the left dorsolateral prefrontal cortex (dlPFC), which is central to spatial working memory and filtering information, was active. In terms of the concept generation techniques, the left dlPFC was again active during morphological analyses and TRIZ, the right dlPFC and medial PFC for brainstorming. The right dlPFC is related to divergent thinking and mPFC facilitates memory retrieval.

2.2.3 EEG and ERP

Researchers at Concordia University have done several EEG studies of design activities. In one of their case studies, a participant was asked to arrange a room based on a set of parameters while EEG was recorded [52]. They reported that the participant showed more efforts in the prefrontal lobe in solution evaluation and high visual high visual thinking effort in solution generation compared to solution evaluation. In one of their follow-up studies, EEG was recorded while engineering students were asked to design a house that could fly [53]. This experiment used a technique called clustering that examined the power spectral density in the different halves of the brain, but there were no significant results. A third study recorded EEG as well as heart rate while engineering students worked on a design problem of their choice, however most picked the same house design problem as listed before. Results here indicated that mental effort (which they used as an indirect measure of creativity and measured via EEG) was lowest when mental stress is highest, as indicated by the heart rate monitor [54].

A study by [55] attempted to investigate the influence of different problem statements on designers' cognitive behaviors from three perspectives, namely divergent thinking, convergent thinking, and mental workload. This task-related alpha power investigation found higher alpha power in the temporal and occipital regions with open-ended problem statements compared to decision-making or constrained statements. Activity in the left hemisphere was stronger for decision-making and constrained statements. Moreover, designer's mental workload was the highest for constrained problem statements.

Vieira and colleagues looked at an open design task that included free-hand sketching [56]. Testing 18 mechanical engineering students and 18 architects, their findings indicated that design neurocognition differed when comparing problem-solving versus designing, particularly in the sketching task, as indicated by transformed power and task-related power within the EEG readings. Fritz, Deschenes, Pandey [57] used EEG to evaluate an individual's performance in a group setting. EEG data revealed a correlation between raw amplitude and level of team contribution, a higher variation in the channel power spectral density during individual versus team tasks, and a degradation of alpha activity moving from individual to group work. Results from another EEG data set point out that design activities were associated with beta-2, gamma-1, and gamma-2 bands between 20-40Hz while resting is mostly associated with alpha band (8-14Hz) [58].

As for ERPs, there is limited research in this area. Search results showed a few studies related to package design and products. For instance, Rojas and colleagues used EEG and eye tracking to explore the combination of ERPs, eye-tracking techniques, and visual product perception [59]. No significant differences were found. A 2015 inquiry was able to predict participants' choice of two products based on ERPs [60]. They found and increase in the N200 component of a mid-frontal electrode and a weaker theta band power that correlates with a more preferred product. Finally, a third paper examined EEG and ERPs, but did not list a specific ERP for their investigation [61]. Instead, they list times in which there were positive or negative going waveforms during their experimentation and mention that the activation they find around 400ms might be the P3 component. They also mention the possibility of the FN400 component. At this time, no papers were found applying ERP to engineering design type problems. At this time, no papers were found applying ERP to engineering design type problems, so more research is needed.

2.3 Utilizing ERPs to Study Creativity

The pilot study presented in this paper is based off the study in [40] that implemented an ERP experimental design in order to investigate conceptual expansion. Their team investigated cognitive expansion as a central component of creative thinking based off a 2012 study by [39], which found that conceptual expansion was linked to the N400 component. The study in [40] used ERP to relate the N400 component to unusualness or novelty of stimuli. They utilized 24 students from their university with unspecified majors and implemented a modified alternative usage task (AUT). Traditionally for the AUT, participants generate as many alternative uses as possible for a common object, such as a pen. This task may be repeated for several objects, one object at a time, with each object recorded as a separate trial. Instead of generating uses for a given item, though, participants were shown a word of an object in conjunction with a potential use for that object as a stimulus. Participants were then asked to decide if the given use was unusual and if it was appropriate. Participants would answer these questions by pushing buttons. Our pilot study narrows the general focus of the article [40] to investigate results of individuals solely from the field of engineering.

It is important to notice that the studies mentioned in the literature review mainly focus on design, concept generation, and problem solving. Even though a few of the papers listed above mention divergent thinking or creativity, none of the studies put a particular emphasis on creativity or novelty. Additionally, none of them were ERP tasks. Given that, it is necessary to utilize ERP and understand how the brain reacts to unusualness, novelty, or creative stimuli. This is something that we aim to do. Furthermore, it is of great importance to research solely engineers in order to build up research in this area. Results from [40] analyzed data form participants with unnamed majors or degree programs. Thus, this study (and future studies like it) will focus only on engineers.

3 THE PILOT STUDY

In this section we present the experimental procedure, data analysis, and the results for our pilot study. This study followed a similar procedure to [40] with a few minor differences as noted in the following sections. These changes were made in order to simplify the experiment, reduce the programming and written code behind the experiment, and ensure a shorter experiment time. Two male individuals in the engineering college participated in one trial each for this pilot study, and their results were averaged for further analysis.

3.1 Participants

Two engineer volunteers, one from Aerospace and Mechanical Engineering (AME) and the other from Industrial and Systems Engineering (ISE), participated in this case study consisting of two trials. Participants were both right-handed, bilingual, and spoke English as a second language. Both participants have normal vision and neither had a history of neurological or psychiatric illness. This study followed the University of Oklahoma Institutional Review Board guidelines and was approved by the responsible committee. No identifiable personal information was kept in the research data.

3.2 Task Design/Procedure

The experiment was coordinated in a low noise environment. Participants were seated in a chair in front of a computer where the EEG Cap was fitted. Participants were told about what they would see during the experiment and the corresponding buttons they would push. The experiment on the computer would further go over these buttons as a reminder. To reduce EEG artifacts participants were asked to avoid uncontrolled body movements.

In order to familiarize the participant with the experimental procedure and the experiment stimuli, there was a short practice segment presented before the start of the experiment on the computer. After the practice session, participants could start the experiment at their own pace. Each trial started with a fixation cross (+) presented in the middle of the screen for 1000 ms. After a 500 ms blank screen, the participant would see an item use pair ("item > use") for 2000 ms followed by another blank screen for 500 ms. Participant would see the first question ("Unusual?") for 1700 ms followed by another blank screen for 500 ms followed by the second question ("Appropriate?") for 1700 ms followed by another blank screen for 500 ms. The cycle would then repeat, but individual stimulus pairs would not. Unlike in [40], the item alone was not presented by itself before the presentation of the item-use pair. Furthermore, there was no self-paced pause after the stimulus presentation. See Table 1 for the experimental time differences.

TABLE 1 - STIMULUS PRESENTATION ORDER IN [40] VERSUS CURRENT STUDY. TIME IS IN MILLISECONDS (ms).

	Kroger et al. [40]		Currenty Study	
		Time		Time
1	Fixation	700-1000	Fixation	1000
2	Blank	200	Blank	500
3	Item	1000	Item > Use	2000
4	Blank	500	Blank	500
5	Item -> Use	1000	Unusual?	1700
6	Blank	1000	Blank	500
7	Unusual?	1500	Appropriate?	1700
8	Blank	500	Blank	500
9	Appropriate?	1500	Return to (1)	
10	Blank	500		
11	Pause	Self-Paced		
	Return to (1)			
	Total time (no pause)	8400-8700	Total Time	8400

Many of the item-use pairs were taken from [40], but some were discarded due to unclear translations from German to English. Additionally, some item-use pairs were created by our lab, but were not tested for word length or frequency of occurrence in the English language as was mentioned in [40]. Overall, stimuli consisted of 162 item-use pairs as compared to 135 stimuli in [40]. Item-use pairs were presented randomly, but did not repeat. To be clear, item-use pairs shown to the participant never repeated and were unique even though each item has one use of each type (each item has its own creative, common, and nonsense use), as seen in Table 2. Subjects were asked to give a yes/no answer to each of these questions by pressing either the left or the right mouse buttons, respectively. As stated in [40], to prevent misunderstandings with what was meant with the words "unusual" and "appropriate", participants were told that a use was to be classified as "unusual" if it was novel or unfamiliar to them and "not unusual" if it was known or familiar. They were also instructed that a use was to be classified as "appropriate" if it was fitting or relevant and "not appropriate" if it was unfitting or irrelevant. The item-use pairs were thus categorized into three categories: common use (no-yes response), creative use (yes-yes response), and nonsense use (yes-no response). See Table 2 for an example.

TABLE 2 - EXAMPLE OF AN ITEM AND THE THREE USE TYPES WITH EXPECTED PARTICIPANT RESPONSES. SEE APPENDIX A FOR A FULL LIST OF ITEMS AND THEIR USES.

Item	Use	Type	Expected response for "Unusual?" and "Appropriate?" questions, respectively
Shoe	Clothing	Common	No - Yes
Shoe	Pot Plant	Creative	Yes - Yes
Shoe	Easter Bunny	Nonsense	Yes - No

3.3 EEG Recording

A wireless SMARTING amplifier [30] with a 24 channel EEG acquisition system and the company's corresponding recording software was used for this experiment. EEG caps of appropriate sizes were selected to fit the subject's head, and conductive gel was used for proper electrical conduction between the scalp surface and cap electrodes. Low impedance around 5-10kΩ was kept during the experiment. The recording was sampled at 500 Hz and recorded from 24 electrodes positioned according to the international 10/20 placement map shown in Fig. 2. Stimulus presentation was synchronized with EEG acquisition via Neurobs Presentation software (Neurobehavioral Systems, Inc., Albany, CA). Stimuli presentation duration and the practice segment in the experiment differ slightly from [40] but should not interfere with results.

3.4 Data Analysis

The overall data analysis can be illustrated by the following diagram, Fig. 4.

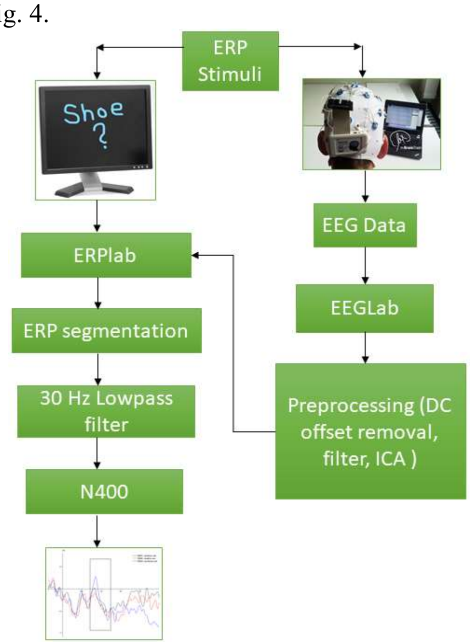

FIGURE 4 - BLOCK DIAGRAM OF THE DATA ANALYSIS PROCESS.

For category grouping and processing purposes, only stimuli that participants answered "correctly" were included in the data analysis, i.e. participant answered no-yes to a common use, yes-yes to a creative use, and yes-no to a nonsense use. Each participant had a minimum of 25 "correct" responses for each stimulus type for data processing. This is different from the minimum of 30 in [40] due to the limited number of participants and continuous EEG recordings.

EEG data was processed using EEGlab plugin on Matlab. Raw data was filtered from 0.1-100 Hz in order for the experimenter to visually inspect data and reject any messy parts. An independent component analysis (ICA) was then performed in order to investigate components and remove the ones not related to brain data, i.e. eye and muscle movements. Data was then processed via ERPlab in Matlab to obtain ERP segments. Data was epoched into 1150 ms segments, with each segment starting 150 ms before presentation of item-use pair. Segments were baseline-corrected using the 150 ms time window before the onset of the item-use pair. A 30 Hz low-pass filter with a slope of 24 dB/Oct was applied and additional artifacts were removed with amplitude exceeding +/-100 µV. ERP waveforms were averaged for each participant and each condition. Subsequently grand-averaged ERPs of all participants were calculated in time windows of interest. The N400 component was the main interest of this paper and post-N400 components were not analyzed at this time. Electrodes of interest included Cz, CPz, Pz, and POz based on electrodes identified in [38], the circled electrode sites in Fig. 2. The number of electrodes examined in this study differ from [38] due to differences in the total number of electrodes utilized; 24 total channels in this study versus 64 total channels in [40], which is simply due to the fact that different EEGs were used.

3.5 Results and Discussion

Statistical tests were not performed at this time due to the small sample size, but data indicates similar results to those from [40] with slight differences in the N400 component for all three item-use conditions The mean amplitude for the two trials was generated. The average for the nonsense uses produced the largest response (ave = -1.4), followed by the creative uses (ave = -0.74), then common uses (ave = -0.59). It is stressed here that this is not a significant difference, only a different average number for the mean amplitudes. Though not definite, these preliminary results point towards sensitivity of the N400 to semantic difference as well as novelty, which is indicated by the different mean amplitudes of the four electrodes of interest for each stimulus type. See Fig. 5. The waveforms of single electrode sites Cz and CPz from one of the trials are depicted below in Fig. 6. In the future, with more participants, the post-N400 effect (500-900 ms) would also be investigated.

The aim of the current pilot study was to investigate the N400 ERP component in engineers by the creative process of conceptual expansion when compared to the information processing of mere novelty or appropriateness, similar to [40] with the main difference of interest being the focus on engineering-based participants. The mean amplitudes values suggest that stimuli that were classified as nonsensical or creative elicit larger N400s than the common uses. The numerically larger amplitudes for the nonsense and creative uses as compared to the common uses suggest that the N400 is sensitive to levels of novelty or unusualness. Again, we stress that the data was not tested for significant differences at this time due to the small sample size of two participants. Additional data would be needed in order to obtain more definite results.

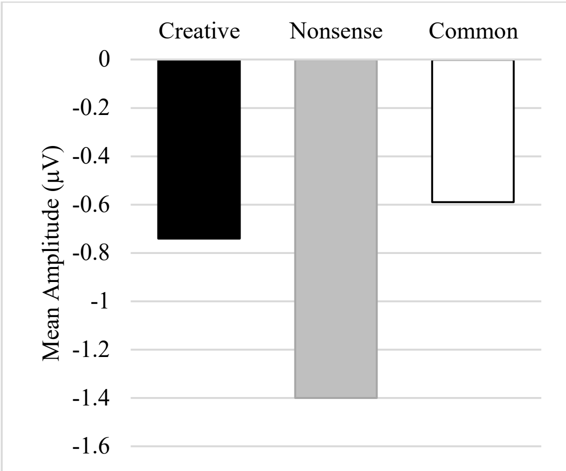

FIGURE 5 - MEAN AMPLITUDES FROM FOUR ELECTRODES (Cz, CPz, Pz, AND POz) FOR THE THREE TYPES OF ITEM-USE PAIRS FOR THE 300-500 MS TIME WINDOW.

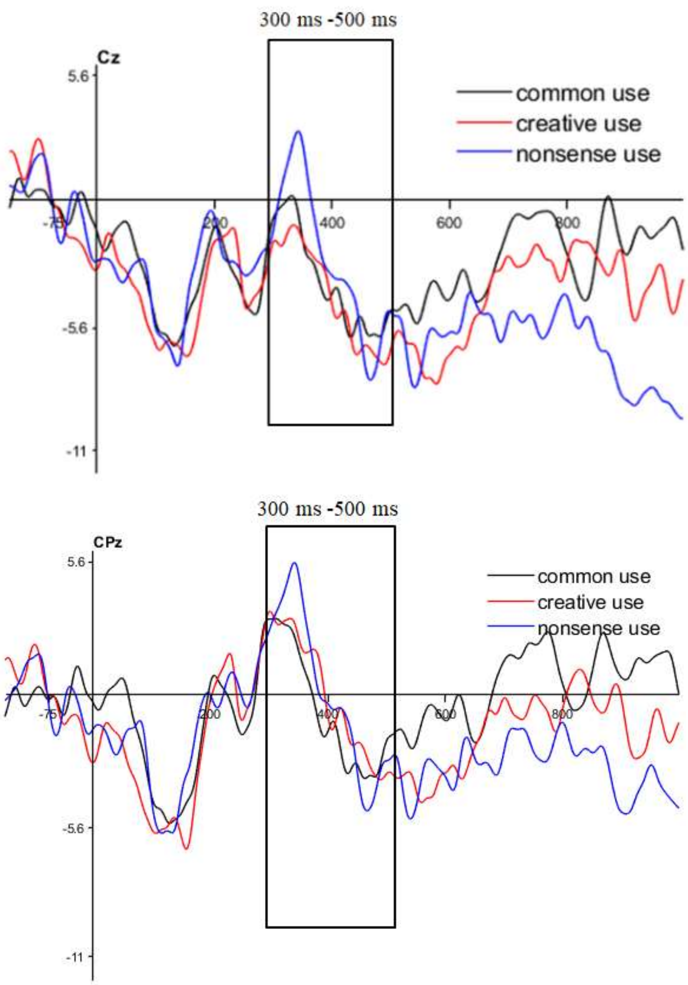

FIGURE 6 - ERPS FROM THE CZ (TOP) AND CPZ (BOTTOM) ELECTRODES FROM ONE INDIVIDUAL. THE BOX OUTLINE INDICATES THE 300-500 MS WINDOW OF INVESTIGATION OF THE N400 EFFECT.

4 CONCLUSIONS AND FUTURE DIRECTIONS

Data from this pilot study seems to indicate that the N400 component in engineers is influenced by novelty and unusualness. Statistical tests would be necessary to determine whether these results are significant or not. More subjects and further investigation of the post-N400 component is also necessary to obtain a better understanding of the results and gain a better understanding of the post-N400 component. As noted in [40], the N400 window would reflect the novelty or unusualness of the stimuli (not the appropriateness) and the post-N400 would reflect the processing of the appropriateness (not novelty/unusualness). This rationale behind the post-N400 analysis is based on the findings of [62-65], which show slow wave effects long after stimulus presentation (up to 1000ms post stimulus). This late processing was mostly linked to interpretation, comprehension, and cognitive computations. While there might not be definite ERPs in this time slot (around 500-900ms post stimulus), it would be interesting to see if there are lasting effects long after stimulus presentation. Given this rationale, it is likely important for these two components to be analyzed together in order to get the entire picture of neural processing of unusualness and appropriateness.

Future studies would include these analyses. Furthermore, in the future we will consider a subject-based selection of which stimuli belong in which of the three categories, rather than only including “correct” responses for the common, creative, or nonsense category. By this, we mean that the category of the item-use pair (common, creative, or nonsense) was “predetermined” and responses that were “incorrect” were not used. Changing this so that the subject determines which item-use pair goes in to which of the three categories will ensure the individual validation of the experimental design.

Even though there is a relatively small number of investigations between neuroimaging and the field of engineering, interest is starting to bud. Once the basics are covered, there are many different possibilities for neurological research in engineering. Potential experiments include studying creativity at different stages of the engineering design process, studying the effects of different models and techniques (such as EMS, TRIZ, etc.) on ideation, studying creative responses and idea generation within teams, studying the effects of diversity within teams on the engineering design process, and studying the effect of experience on creative responses and idea generation. The neuro-responses during concept generation and steps of the engineering design process could also be used to understand how the brain operates during these activities.

Even though this is a work in progress, we hope that down the line, as the data from these future investigations becomes available, results can be used to improve engineering education. Furthermore, this data will aid researchers in understanding what cognitive processes are used in the engineering design process. Additionally, creativity improving techniques could be measured using neuroscientific means. These techniques could then be incorporated into engineering education curriculum to promote creativity in engineers. Overall, there are a plethora of uses for neuro-scientific research in the field of engineering that would have profound impacts on engineering design and education.

The main problem standing in the way of all of this potential research is the fact that it is not a straightforward task to design experiments to study the neurological responses on engineering design, creativity, and concept generation. Since no ERP studies related to engineering have been completed, there is a need for further investigations into this area. In designing ERP experiments, it is important to identify components of interest (i.e. N400). As mentioned throughout, the N400 or post-N400 components would be a good place to start since studies have shown there is some relation to novelty, unusualness, and conceptual expansion [39, 40].

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APPENDIX A: DATASET USED IN THE PILOT STUDY

Item-use pairs were presented randomly to the participants. Number in the first column is solely for count.

#	Item	Common Use	Creative Use	Nonsense Use	Status
1	Billiard Ball	Billiards	Doorknob	Rocket	Practice
2	Shoe	Clothing	Pot Plant	Easter Bunny	Practice
3	Screwdriver	Screwing	Pry Bar	Dragon	Practice
4	Toilet Seat	Seating	Picture Frame	Golf Club	Experimental
5	Brick	Construction Material	Paper Weight	Electronic Device	Experimental
6	Aluminum Foil	Cover Food	Hat	Pen	Experimental
7	Hanger	Hang Clothing	Unlock Car Door	Telephone	Experimental
8	Helmet	Protect Head	Basket	Bus	Experimental
9	Pencil	Writing With	Stir Stick	Backpack	Experimental
10	Pipe	Transfer Liquid	Weapon	Library	Experimental
11	Cardboard Box	Storage	Play Fort	Car Engine	Experimental
12	Shoe Lace	Tie Shoe	Belt	Sunglasses	Experimental
13	Band-aid	Cover Wound	Tape	Chair	Experimental
14	Rolling Pin	Cooking Tool	Muscle Massager	Hair	Experimental
15	Rubber Band	Hold Items Together	Slingshot	Charger	Experimental
16	Sock	Footwear	Sock Puppets	Time Machine	Experimental
17	Mirror	Reflection	Signal For Help	Camel	Experimental
18	Magnifying Glass	Magnify Image	Start Fire	Food	Experimental
19	Sandpaper	Smooth Surface	Nail File	Trampoline	Experimental
20	Paint Brush	Painting	Broom	Coffee Maker	Experimental
21	Toothpick	Clean Teeth	Craft Item	Spring	Experimental
22	Mason Jar	Preserve Food	Light Bulb Cover	Train	Experimental
23	Lipstick	Makeup	Writing Utensil	Amplifier	Experimental
24	School Bus	Transportation	Mobile Home	Sandals	Experimental
25	Water	Drink	Generate Electricity	Baseball Bat	Experimental
26	Safety Pin	Fastener	Earring	Fire Hydrant	Experimental
27	Chewing Gum	Breath Freshener	Putty	Fertilizer	Experimental
28	Scissors	Package Opener	Pizza Cutter	Toothbrush	Experimental
29	Artificial Turf	Football Turf	Bath Mat	Newspaper	Experimental
30	Coca-cola	Beverage	Toilet Cleaner	Typewriter	Experimental
31	Cd-rom	Disk	Coaster	Gas Can	Experimental
32	Scuba Flippers	Swim Aid	Fan Blades	Toaster	Experimental
33	Coconut	Food	Bocce Ball	Keyboard	Experimental
34	Ice Skate	Ice Skating	Cleaver	Extinguisher	Experimental
35	Credit Card	Means Of Payment	Butter Knife	Monitor	Experimental
36	Nail File	Manicure	Carrot Peeler	Duct Tape	Experimental
37	Paddle	Rowing	Pizza Oven Slider	Cube	Experimental
38	Nylon Stocking	Women's Clothing	Filter	Balloon	Experimental
39	Toilet Paper	Hygiene Product	Padding	Punch	Experimental
40	Tennis Racket	Sports Equipment	Colander	Shower Curtain	Experimental
41	Knitting Needles	Knitting	Chopsticks	Cigar	Experimental
42	Record Player	Music Player	Pottery Wheel	Horoscope	Experimental
43	Trampoline	Gymnastic Apparatus	Bed	Scooter	Experimental
44	Ironing Board	Ironing Pad	Shelf	Water Heater	Experimental
45	Fork	Eat	Comb	Doghouse	Experimental
46	Thermos	Coffee Warmer	Vase	Plastic Bag	Experimental
47	Matches	Lighter	Cheese Skewers	Hubcap	Experimental
48	Door	Passage	Ping Pong Table	Wheelbarrow	Experimental
49	Surfboard	Surfing	Ironing Board	Cooking Pot	Experimental
50	Watering Can	Gardening Equipment	Wine Decanter	Cap	Experimental
51	Spatula	Kitchen Utensil	Putty Knife	Remote Control	Experimental
52	Ruler	Measurement	Curtain Rod	Ball	Experimental
53	Bottle Cap	Bottle Topper	Cookie Cutter	Hammock	Experimental
54	Cotton Ball	Make-up Removal	Christmas Decorations	Lantern	Experimental
55	Canoe	Boat	Bathtub	Razor	Experimental

56	Spoon	Cutlery	Trowel	Wallet	Experimental
57	Antlers	Wall Decorations	Coat Hook	Calculator	Experimental