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REDUCING SKETCH INHIBITION DURING CONCEPT GENERATION: PSYCHOPHYSIOLOGICAL EVIDENCE OF THE EFFECT OF INTERVENTIONS

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ABSTRACT

This research investigated the effect of warm-up activities on cognitive states during concept generation. Psychophysiological tools including electroencephalography (EEG) and galvanic skin response (GSR) were used along with self-report measures (NASA TLX). Participants were divided into 3 test conditions: 1) no warm-up activity; 2) simple warm-up activities; 3) sketch-inhibition reducing activities. All participants did the same short design task. Results show that those who did a warm-up prior to ideation had a decrease in stress, especially for those who were personally familiar with the design problem. The art activities especially improved engagement for younger participants. We also saw that females who used the art-based activities reported lower mental workload during ideation and greater pride in their sketches. However, the warm-ups did not produce any difference in the number of ideas or other metrics of performance. These preliminary results indicate that warm-up activities, especially the art-based ones, help reduce inhibition by calming the cognitive state.

INTRODUCTION

Concept generation is an integral part to the design process, and has been studied for decades [1]. An active area of research within this field is the effect of sketching on concept generation and thinking. For example, sketching has been shown to improve communication [2] and visual thinking [3]. While the importance of sketching has been known for a long time, the ubiquity of CAD has increased the need for formal instruction in sketching [4, 5]. Several interventions have been proposed to improve sketching in designers [6–10].

Many of these studies have found that students new to sketching are often reluctant to sketch. There are several causes of this inhibition, and Booth et al. have done some initial work to identify interventions to overcome this inhibition [11]. Their work is based on art techniques that help prepare artists for a creative session. They conducted a study to see how these interventions affected the sketching behavior of students over a semester, showing some promising results.

We wanted to see if the inhibition-reducing methods proposed by Booth et al. also had a direct, measurable effect on concept generation. In this study, we explore a few of the proposed methods in a controlled laboratory environment. We use an EEG headset, a GSR sensor, the NASA-TLX survey, sketches, and notes to measure the effect the activities have on a concept generation task. We hypothesize that if the activities reduce inhibition, as supposed, we will see a relatively low mental workload, low level of stress, and a high level of engagement.

In the background section we introduce related work on creativity and ideation, and how EEG may be a powerful tool for examining creative mental processes. We discuss the experimen-

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tal setup, procedures, and equipment in the methodology section. We describe results from the EEG/ GSR measurements and the NASA-TLX and demographic survey. Finally, we summarize important findings and future works in the conclusions section.

BACKGROUND

Ideation and creativity is a commonly studied topic in engineering design research. Decades of research have yielded important findings. For example, researchers have found that concept generation is enhanced when done with a group [12,13]. We also know that designers commonly rely on heuristics to navigate a design space [14]. Other researchers have explored the impact of specialized ideation methods such as systematic methods [15], biology-inspired design methods [16], and near and far analogy [17, 18]. More cognitive aspects have also been explored, such as the impact of the design prompt [19–21], and external stimuli [22–24]. Others have analyzed internal influences such as personality [25]. Significant effort has also been put into understanding and mitigating design fixation [26,27]. The tools that are used during ideation have an effect on the outcome [28, 29].

Virtually all these findings have been done through the study of participant behavior. For example, the FBS model [30], ideation metrics [31], and linkography [32] all measure various aspects of the external, observable behavior of a designer. Think-aloud protocols come closer to actual measurement of cognitive states, are subject to reporting errors and may alter the thinking of the participant. Psychophysiological methods offer the advantage of collecting data simultaneously with the participants' actions and thoughts. For example, observations suggest that insight comes suddenly and rather unpredictably. However, studies using fMRI and EEG have shown that insight occurs after a predictable sequence of cognitive states; states which are not able to be expressed or derived by other methods [33]. Some initial design research with psychophysiological methods has been done using fMRI [1]. There are also some efforts to correlate EEG signals, or electroencephalograms, with specific design behaviors [34]. Signals that have been correlated with specific behaviors are called Event Related Potentials [35]. We build on research in the design community by using EEG to measure the neurological effects of warm-ups on concept generation.

Creativity and insight are key considerations of concept generation. Martindale [36] extensively reviews several other studies of psychophysiological indicators of creative thinking. One of the findings over the last century is that the level of creativity is related to the level of psychological arousal, with lower arousal being associated with higher creativity. However, the relationship is an inverted U-curve, where too high and too low arousal correspond to low creativity, and a moderate level of arousal is associated with high creativity. Additionally, the optimal level changes with the difficulty of the task. Another physiological response is stress levels, which can be detected by the galvanic skin response (GSR). Martindale concluded that increased stress reliably decreases the originality of generated ideas. Additionally, more creative subjects tend to show more fluctuations in GSR, arousal, and in some cases alpha amplitude. Defocused attention is also a feature of creative thought, and this seems to be caused by low cortical activation (arousal). Much of the brain activity during a creative task is centered in the right-hemisphere of the brain. There is some evidence that procedures known to increase right-hemisphere activation can also facilitate creativity. Martindale lists hypnosis, music, and creativity improving courses as some known activities that induce right-brained thinking.

While many studies have explored creativity using EEG, to the best of our knowledge, only one research team is studying design processes using EEG. In one of their earlier studies, Nguyen and Zeng suggested that EEG can be used to partially replace protocol analysis. Their study demonstrated that visual perception could be distinguished from solution evaluation during a concept generation task [37]. Later work identified further correlations between EEG signals and specific design tasks derived from protocol analysis [38]. They later found that EEG measures of mental effort are low when the stress levels are high, though this relationship did not hold for other levels [34].

EEG has also been used in other engineering contexts. Several researchers have investigated how to use EEG to dynamically map brain signals with sketch strokes and perceiving certain visual features, with the end goal of enhancing multi-modal CAD interfaces [34, 39, 40]. Similarly, other researchers have employed EEG to improve adaptive, interactive computer-user systems [41], including EEG assisted image and video evaluation [42]. Some efforts have also been made to see how brain signals can be used to evaluate computational creativity support tools [43]. In industrial engineering, Ma et al. used EEG to evaluate the differences in brain activity between novices and experts when engaged in an assembly process on an actual production line [44]. They found that the novice group has a much higher workload in the right hemisphere of the brain, and that the asymmetry index was also higher for this group. The GSR data also showed a higher level of negative emotions for the novice group [44].

METHODOLOGY

To assess cognitive states while generating design concepts associated with the sketching inhibition-reducing activity, a randomized, controlled study was conducted. The experimental procedure is shown in Figure 1. Participants were randomly assigned to one of the following 3 test conditions: 1) no warm-up activity (Control 1); 2) simple warm-up activities (Control 2); and 3) sketch-inhibition reducing activities.

The first group did not have any warm-up and so these subjects began generating concepts immediately after the calibration and rest period. The second group was instructed to draw lines

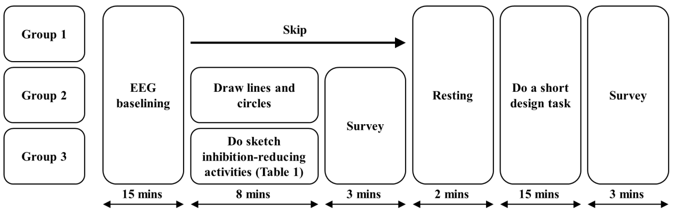


FIGURE 1: Experimental setup for discovering the effect of activities for reducing the inhibition to sketch during concept generation

and circles. In order to make sure the relative time spent doing warm-ups was about the same, the lines and circles group was asked to continue this activity for 8 minutes. The third group was guided through a reduced selection of activities proposed by Booth et al. [11] (see Table 1). These activities are based on warm-ups found in sketching books and in art classes at Purdue.

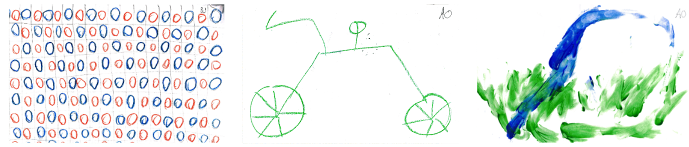
Subjects

We recruited participants through fliers and email lists. Some subjects invited friends to contact us. Participants were compensated at a rate of $10/hr. Our sample consisted of 21 adults (15 males and 6 females) ranging in age from 18 to 40 years old (mean: 24.7 years, SD: 5.9 years). All participants are from the College of Engineering or the College of Technology at Purdue University. We categorized the departments into three groups: mechanical (11 subjects), electrical (4), and other (6). We also grouped participants by year in school: first to third year (6), fourth year (5), and graduate (10).

Experimental Procedure

To begin each session, participants signed a statement of informed consent, and we reiterated that they would be wearing an EEG headset (Figure 3) and GSR sensor. We also video recorded sessions, but informed subjects that the frame only contained the work area their papers and materials were in. After giving consent, the GSR sensor was placed on the non-dominant hand and the EEG system was applied over the hair. These systems are described below. Following this, the subjects performed a 20 minute calibration procedure through the iMotions Attention Tool (iMotions, Inc., USA). This establishes the EEG baseline, which is used to generate scale-normalized EEG metrics for individuals.

Following setup and calibration, participants either performed a warm-up activity (lines and circles & art activities) or no warm-up. The examples of the warm-up activity participants from the lines and circles and art activities groups did are shown in Figure 2. After the warm-up, subjects in the lines and circles and art activities groups took a survey TLX questions and a



(a) (b) (c)

FIGURE 2: Examples from the lines and circles and art activities warm-ups: (a) sketching lines and circles; (b) drawing a bicycle (the third art activity); (c) drawing mountains upside down (the fourth art activity).

FIGURE 3: A participant wearing the EEG headset at the workstation used for conducting the study

few open-answer questions about their opinions of the warm-up. All groups then took a two minute break before starting the next portion.

Following the break, we asked all groups to generate as many ideas as possible for devices that would make it easier for student athletes with leg injuries to get around on campus. Subjects were given 15 minutes to generate ideas. Following the ideation task, participants then took a final survey consisting of TLX questions, demographic questions, attitudes toward sketching, and opinions about the experience in general (Table 2).

Since the art activities group were required to use multiple media for the warm-up, we left the supplies at the workstation (Figure 3) for participants to see and instructed all groups that they could use any of the art supplies they wished. The types of media provided were pencils, pens, crayons, markers, and finger paints.

Measurements

EEG and GSR signals were recorded as a log of cognitive states and mental stress when participants did a short design task.

TABLE 1: Sketch inhibition-reducing activities performed by the art activities group, all times approximate

Activity	Media	Purpose	Time
Draw an animal with eyes closed	Sharpies	Introduce an uncomfortable task	60 s
Draw a flower with opposite hand	Pencils	Brain hemisphere reversal	60 s
Draw a bicycle	Crayons	Introduce non-technical, imprecise tools	45 s
Draw mountains upside down	Finger-paints	Hemisphere reversal, unexpected materials	90 s
Draw a house without lifting the pencil	Pencil	Dealing with limitations and strategizing	90 s
Draw a person 3 times	Sharpie	Reduce concern about details, emphasize speed	60 s, 30 s, 10 s

TABLE 2: Survey questions used for the ideation task.

NASA-TLX Questions (scale from -10 to 10)	Examples of Demographic Questions
Mental Demand	What year in school are you?
Physical Demand	What is your gender?
Temporal Demand	What is your major?
Performance	**Examples of Questions for Attitudes toward Sketching**
Effort	How much do you agree with the following statements? - I am proud of my sketches
Frustration	How much do you agree with the following statements? - I think sketching is fun

A 10-channel wireless EEG headset system B-Alert X10 (Advanced Brain Monitoring, Inc., USA) was utilized to measure brain waves from 9 balanced sites on the scalp including Fz, F3, F4, Cz, C3, C4, POz, P3, and P4 with 256 Hz sampling rate. Foam sensors with highly conductive electrode cream were attached to these sensor sites for providing electrically conductive interfaces between the headset and the scalp. A pair of reference electrodes were placed behind the ears just above the mastoid process on the temporal bone. The collected data was wirelessly transmitted to a laptop with Windows 7 operating system through a Bluetooth - USB dongle. The data transmission range is up to 10 meters, so participants were able to move their heads freely.

EEG signals are typically divided into four bands, but the system we use, the B-Alert X10, converts the raw waves measured from the 9 sensor sites into four related measures. These measures are mental workload, distraction, drowsy, and engagement. According to the developer Advanced Brain Monitoring, EEG-workload involves the amount of working memory load, which increases during problem-solving, integration of information and analytical reasoning, and EEG-engagement reflects information-gathering, visual scanning and sustained attention [45].

GSR was measured by Shimmer3 GSR+ Unit (Shimmer, USA) in unit of micro-Siemens (μS). The sampling frequency was set at 52 Hz. Disposable Ag/AgCl electrodes (Lafayette Instrument Co., USA) were placed on the palmar surface of the index and middle fingers over the proximal phalanx of the non-dominant hand. These were linked to the shimmer sensor for data enhancing and recording.

The data recorded from EEG and GSR sensors were synchronized via the software iMotions Attention Tool. Moreover, the room temperature was set at $72-74°F$ to reduce possible effects of heat and environmental temperature change.

We consider mental workload, distraction, engagement, and stress when determining if the activities reduced inhibition. One study found that mental workload is associated with user discomfort [41]. Other researchers have assumed that workload is positively related to creativity [34], but some psychologists would argue that creativity is a degeneration of inhibition [36]. Low distraction and stress are also an important measures of creativity [36]. We assume engagement to be a measure of interest in the task, and low engagement to indicate aversion or inhibition.

In addition to EEG, we also employed the NASA-TLX survey, just as the prior study on sketch inhibition did [46]. The indices include perceived mental demand, physical demand, temporal demand, level of performance, effort, and level of frustration, on a scale from negative 10 to positive 10. We also asked the participants who had a warm-up activity if they thought the activity was useful for preparing them for concept generation.

We recorded demographic information including gender of the participant, major, if they had suffered a leg injury before (i.e. were familiar with the problem statement), and year in school. We used these to characterize our sample as well as to test for covariate effects.

Finally, we measured aspects of the design documents, such as the number of ideas generated, the number of ideas written but not sketched, the ratio of sketching to writing, the percent of the page filled, and the number of media used.

EEG and GSR RESULTS

For the analysis, we used treatment group (3 levels, 7 participants each) as the main factor, but also included covariates. The covariates include year in school, gender, major, and whether the subject had had an injured limb before. Response variables were derived from Attention Tool, and included workload, engagement, distraction, and stress (GSR). To simplify the data, we averaged the values for each metric over the 2 minute rest and the 15 minute ideation periods. We then subtracted the average values for each period to get the net change. The response variables used in the statistical model were the changes in workload, engagement, distraction, and stress. Conditions for ANOVA were met. The model was analyzed with type III sum of squares ANOVA in Minitab 17 (Minitab Inc., USA) at an alpha level of 0.5.

Our primary interest is the effect of the treatment group on the relative change in cognitive states between the rest and ideation periods. In our ANOVA (Table 3), we found that the change in mental workload for each group was statistically significant ($p = 0.024$), but not for other metrics. However, in a Tukey and Bonferroni pairwise post-hoc analysis, we found no distinction between the treatment groups. Therefore, there does not appear to be a significant main effect due to the treatment group.

Several covariates tested as significant (see Table 3). The change in engagement depended on major ($p = 0.004$) and prior injuries ($p = 0.007$). Those who were in mechanical majors (aerospace, civil, mechanical) rose in engagement (+3.29%) whereas electrical (−3.24%) and chemical and industrial majors (−8.85%) became less engaged. Those who had not had a prior injury were less engaged than those who had one (−7.84% vs. +0.349%). The change in distraction was significant for the year in school ($p = 0.015$), gender ($p = 0.025$), and prior injuries ($p = 0.005$). Years 1-3 and 4th year students increased in distraction (+3.97% and +8.86%, respectively) whereas graduate students did not change from the baseline (−0.057%). Distraction increased more for women than men (+9.00% vs. +0.242%). Those who did had experienced prior injuries saw an average increase in distraction (+8.66%), and those who had not had an injury did not increase (−0.113%). The average change in stress was significant for those with prior injuries ($p = 0.011$). The change in stress was significantly higher for those with prior injuries (+73.4% vs. +2.75%). It is possible that there is trauma associated with the injuries, contributing to these results.

When we examine the interactions, however, the story becomes much more interesting. For the change in engagement, there was a significant interaction between year in school and treatment group ($F = 12.52, p = 0.007$). The interaction plot (Figure 4) shows that young students benefit more from the art

TABLE 3: p-values (F-values) for treatment group and covariates in the ANOVA for change in workload, engagement, distraction, and stress (GSR).

	Work.	Engag.	Distr.	Stress
Treatment	0.024*	0.087	0.813	0.521
	(7.33)	(4.67)	(0.21)	(0.73)
Year in School	0.237	0.074	0.015*	0.135
	(1.72)	(4.67)	(11.37)	(2.97)
Gender	0.068	0.628	0.025*	0.084
	(4.94)	(0.26)	(8.90)	(4.26)
Major	0.846	0.004*	0.949	0.283
	(0.04)	(21.34)	(0.00)	(1.39)
Prior Injury	0.986	0.007*	0.005*	0.011*
	(0.00)	(15.69)	(18.71)	(13.03)

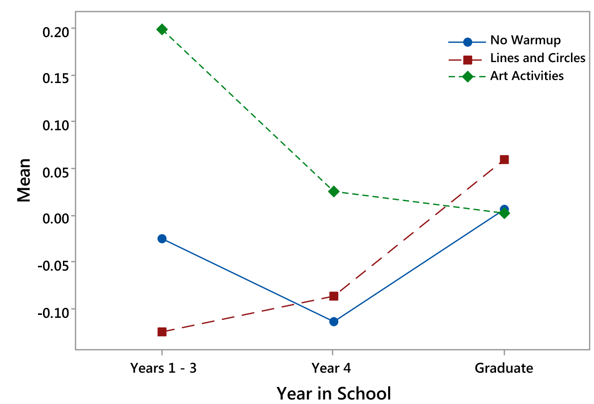


FIGURE 4: The interaction plot for the change in engagement shows that the art activities help younger students more than older ones.

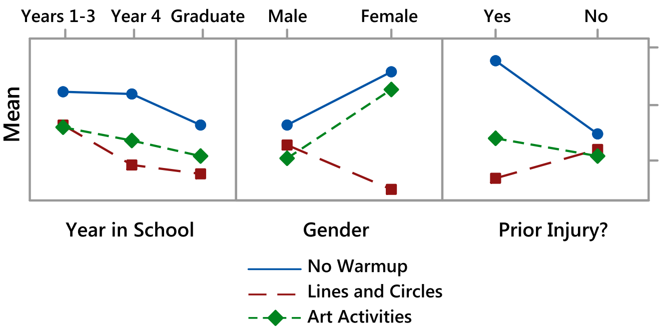


FIGURE 5: The interaction plot for the change in stress.

activities than the 4th year or graduate students. We also found that the change in stress (GSR) had significant interactions between year in school and treatment group ($F = 5.93, p = 0.038$), gender and treatment group ($F = 8.14, p = 0.020$), and having a prior injury and group ($F = 8.57, p = 0.017$). In the interaction plot (Figure 5), we see that the warm-ups reduce stress in general. We also see that the lines and circles warm-up is particularly calming for females. Finally, for participants who had a prior limb injury, the warm-ups help reduce stress.

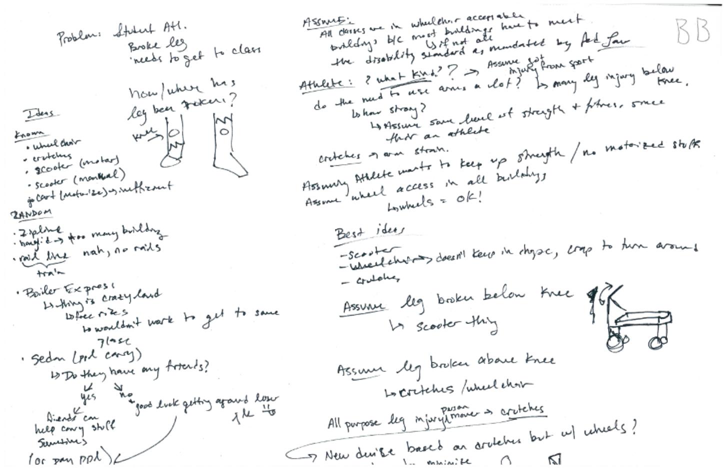
There is some evidence that warm-ups reduce cognitive load (Table 3) and stress (Figure 5), but the certainty of this evidence is low due to the wide spread in the data. To be certain about this conclusion, we need to collect more data. If it is a real difference, though, it may mean that warm-ups enhance creativity.

TLX SURVEY AND DESIGN ARTIFACT RESULTS

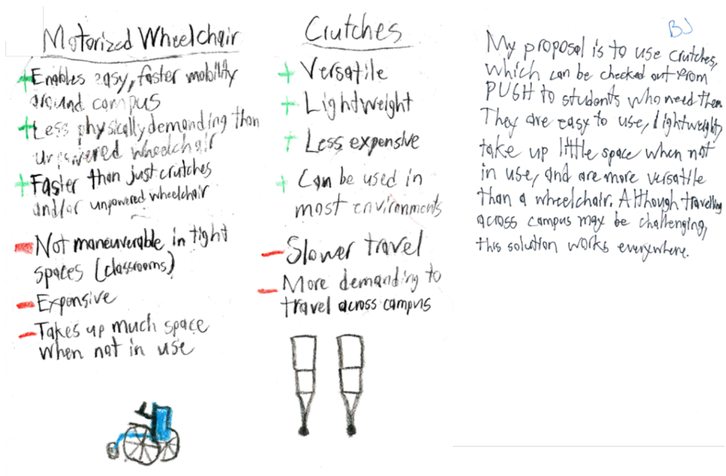
We collected survey data and analyzed the design artifacts in order to support the EEG and GSR data. Some examples of the design artifacts can be found in Figure 6. We used the NASA-TLX to measure mental workload, stress, and perceived performance. We found that in general, the average normalized values for the TLX matched the EEG values, but that there was much more variance, since these variables were self-reported. We used surveys to measure demographic data and the design artifacts to measure the number of ideas, the number of ideas written but not sketched, the ratio of sketching to writing, and the percent of the page filled during ideation.

We used the results from the TLX and design artifacts data to run an analysis parallel with the EEG analysis. The ANOVA assumptions were met, except for the number of concepts written only (i.e. no sketch). This variable is non-normal, and using ANOVA anyway carries an increased risk of a false positive [48].

The treatment group was not a significant variable for any of the tested measures, but several of the covariates were (see Table 4). Major was a significant factor for how many ideas a participant generated ($p = 0.010$). Electrical oriented majors



(a)



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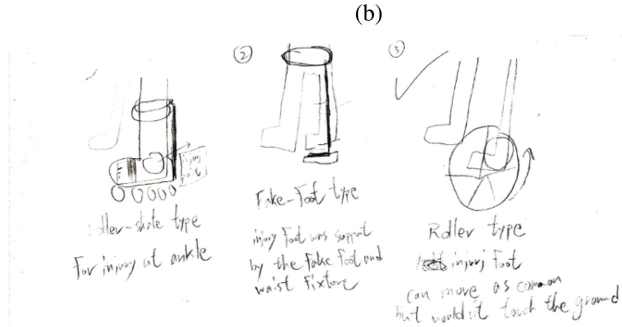

(c)

FIGURE 6: Examples from design task for all three groups: (a) no warm-up group, this example has a lot of writing; (b) lines and circles group, this example only explores two concepts; (c) art activities group, this example uses about 25% of the page

TABLE 4: p-values (F-values) for treatment group and covariates in the ANOVA for the number of ideas generated, the percent of the page filled, and the level of self-reported frustration. Other metrics did not have any significant factors.

	No. Ideas	% Page Filled	Frustration
Treatment	0.675	0.397	0.512
	(0.42)	(1.08)	(0.75)
Year in School	0.660	0.000*	0.765
	(0.21)	(49.69)	(0.10)
Gender	0.375	0.170	0.972
	(0.92)	(2.43)	(0.00)
Major	0.010*	0.155	0.044*
	(13.81)	(2.64)	(6.46)
Prior Injury	0.375	0.005*	0.812
	(0.92)	(18.38)	(0.06)

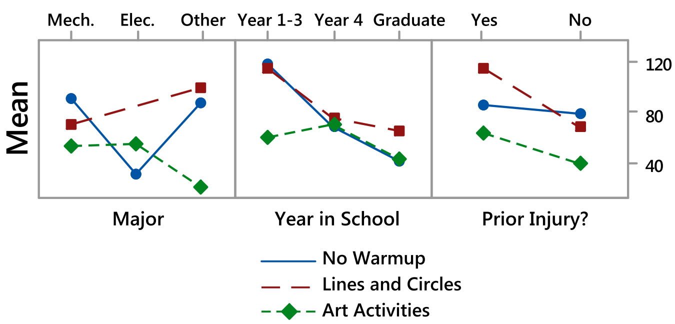

FIGURE 7: The interaction plot for the percent of the page filled with writing and sketches by participant

generated fewer concepts (4.78) than mechanical oriented majors (5.91) or other engineering majors (5.33). The year in school ($p = 0.00$) and having a prior injury ($p = 0.005$) were also significant main factors for how much of the page the participants filled. However, without the treatment group being significant, it is uncertain if there is any real meaning to this result. We also found that electrical majors reported slightly higher frustration (0.5 on a -10 to +10 scale), whereas mechanical (-0.3) and other majors (-2.7) reported lower levels of frustration on average ($p = 0.044$).

Another interesting set of interactions are those between gender and perceived pride in sketches (Figure 10) and self-reported mental demand of the design task (Figure 9). For males, there was little difference between the treatment groups. However, for females, the art activities improved a sense of pride in sketching as well as reduced the perceived mental demand. While this result does not correspond with the EEG measure of mental demand, it does suggest that the art activities may improve the self-efficacy that female engineers have in their ability to do the task.

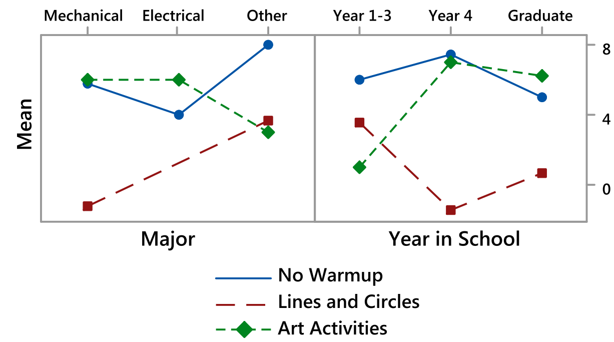

FIGURE 8: The interaction plot of the perceived performance

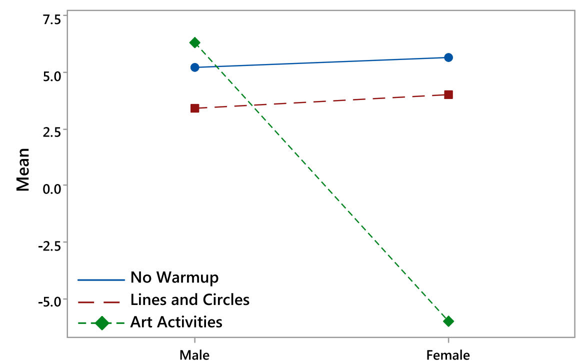

FIGURE 9: The interaction plot for the self-reported mental demand

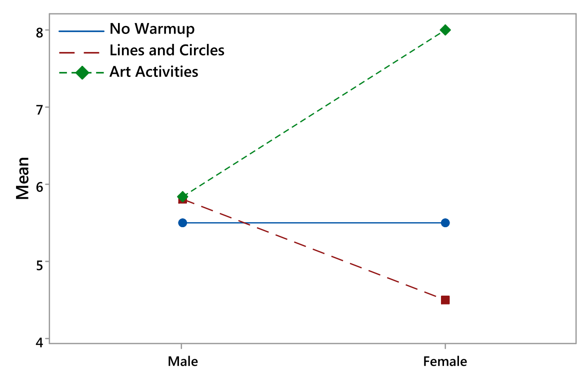

FIGURE 10: The interaction plot for the question "I am proud of my sketches", as measured on a Likert scale

There were several other significant interactions. The year in school ($F = 10.54, p = 0.011$), major ($F = 6.84, p = 0.028$), and injury ($F = 13.87, p = 0.006$) interacted with the treatment group for the percent of the page that was filled during concept generation (see Figure 7). However, these particular interactions seem spurious. We also found a significant interaction for the perceived performance between treatment group and major ($F = 5.18, p = 0.049$) and year in school ($F = 5.64, p = 0.042$). Figure 8 shows that mechanical majors perceive their performance as much lower after doing the lines and circles warm-up. It also shows that the older the student is, art activities have a more positive effect on perceived performance, and lines and circles have a more negative effect.

CONCLUSIONS

In conclusion, our data suggest that the warm-ups in general are helpful at reducing inhibition to concept generation, and that the art-based warm-ups have some additional benefits. Both warm-up activities significantly reduced stress for the engineers in the study who had previously experienced a limb injury. This suggests that warming-up helps engineers who have personally experienced a design problem be less stressed when generating ideas for it. Additionally, we found that younger students had a much higher level of engagement during the design task when using the art-based warm-up. Having a prior limb injury and major were also important factors for the level of engagement. The level of distraction was influenced by the year in school, gender, and having a prior injury.

Although the cognitive states associated with concept generation were changed as a result of the warm-up activities, the activities did not have any measured impact on the number of ideas or the amount of sketching that was used. This means that if engineers do not use the warm-ups, there will be no adverse effects to design. However, using the warm-ups improves the experience and reduces stress, so we recommend using them for this purpose. We also found that this effect was stronger for younger students, so we also recommend that these activities be used in design classes to acclimate students to the concept generation process more quickly.

In addition to these results, we also found that the art-based activities had the additional benefit of improving the self-efficacy for female engineers. Females who used the art activities were more likely to report that they were proud of their sketches. They also were more likely to report low mental load when generating ideas. This result suggests that the art-activities are an effective means for encouraging female engineers to feel more pride in their concept generation.

There are a few limitations to this study. Our participants only generated concepts for 15 minutes. The setup time took approximately 45 minutes, and this limited our ability to collect data for a long period. It is possible that a longer concept generation session would have yielded stronger or different results. We also saw that some participants did not take the task seriously. Finally, our sample size is still relatively small, despite being much larger than comparable EEG studies in design. This prevented us from doing more powerful statistical analyses to determine other possible sources of variation. Therefore, we recommend in future studies that the concept generation task last longer, and that the participants are motivated in some way to provide the best concepts possible, and that more data collection be done.

Based on our results, we recommend the use of warm-ups to improve the mood and mindset of participants. We also recommend future studies that explore the connection between right-hemisphere activation and creativity, such as the art-based activities are reported to do. Other studies have shown that mood enhancing activities, such as telling jokes or eating candy, also improve creativity, and we recommend studies evaluating the effect of these activities on brain activity. Other studies could focus on team dynamics, including the effect of building on others' ideas, team-building activities, or social inhibition effects.

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