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EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Midyear Conferences

75th Midyear Conference – January, 2023, Raleigh, NC

Site Chair – Kevin Sutton (kgsutton@ncsu.edu)

Program Chair – Nolan Fahrer (nefahrer@ncsu.edu)

Future ASEE Annual Conferences

Year	Dates	Location	Program Chair	
2022	June 26 - 29	Minneapolis, Minnesota	Brooke Morin	morin.29@osu.edu
			Abayomi Ajayi-Majebi	ajayi-majebi@centralstate.edu
2023	June 25 - 28	Baltimore, Maryland		
2024	June 23 - 26	Portland Oregon		

If you're interested in serving as the Division's program chair for any of the future ASEE annual conferences, please contact the Director of Programs, Brooke Morin (morin.29@osu.edu).

Message from the Editor

Nancy E. Study, *EDGJ* Editor
Penn State Behrend

These times of Covid-19 have been difficult for most of us in academia. I went from having a relatively normal semester in Spring of 2020 to having everything come to a screeching halt with students unable to return to campus after spring break, and a switch to completely remote instruction. In the beginning of remote instruction, faculty on our campus were allowed to teach from our offices as long as we were in there by ourselves and kept the door shut, but then we too were forced to go home. For me, this was the hardest part because home has always been my sanctuary away from work and a place of very little technology aside from a dodgy old tablet computer I used to pay bills, do my taxes, and send personal emails. But, thanks to our IT staff who set me up with a laptop, temporarily poached high-speed internet from a kind neighbor (until I could get my own ordered and hooked up), and hauling books, papers, and a truckload of equipment home, I made it work. We all made it work, the best we could. And we got by with sharing and helping and working together.

Working together is something I often discuss with my students, especially first-year students. I try to impress upon them the fine line that often occurs between working together and cheating. Helping classmates with classwork and homework is great. But going beyond answering questions or helping with specific problems, to doing the work for another student, or turning in someone else's work as your own? Not good. Recently I was informed by an author of one of our previous articles that she had found her article had been plagiarized, almost in its entirety including graphics, and published in another journal. The only reason the original author found out was she was preparing a promotion document and did an internet search to find some of her work because she did not have the original reference immediately at hand. I, along with a previous editor of the EDG Journal, then began a months-long process of contacting the publisher of the journal, the editors of the journal, and the authors. The authors never responded. The publishers and editors passed blame back and forth. A retraction was eventually made. That said, the process took entirely too long and was very frustrating. Similarly, a colleague found entire sections of his dissertation were used in a textbook without citation, and without his permission. Again, even with the help of intellectual property lawyers, it took him a couple of years to get the issue resolved. For him, it was not about the money made from the textbook, it was the principle of the matter, especially since one of the authors was a former colleague of his.

Using the intellectual property of others to support our own work is something we all do regularly, but giving our colleagues proper credit is part of what

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Message from the Editor

maintains our credibility as researchers and authors. Editorial staff and reviewers can go a long way in preventing the theft of intellectual property, but unfortunately in these days where so much is available online, it is entirely too easy for people to steal work and present it as their own. We all must be vigilant, researchers, authors, and journal staff alike. In the instance of the plagiarized EDGJ content, it was an international journal with international authors. Different countries have different rules and even different social acceptance of what is cheating and what is not. Working together, even if we cannot prevent the theft of intellectual property, at least we can do our best to report it and make sure stolen content is either removed, or the articles updated to properly cite the original research.

At the time of writing this, the 2022 ASEE Annual Conference is still on schedule to be in person, after being remote in 2020 and 2021. I do hope to see some of you in Minneapolis. My thanks to Bob Chin for his continued help, especially on the technical side of things, and Judy Birchman for her excellent work in copy editing. And thank you all for reading, and please consider submitting your work to the *Engineering Design Graphics Journal*.

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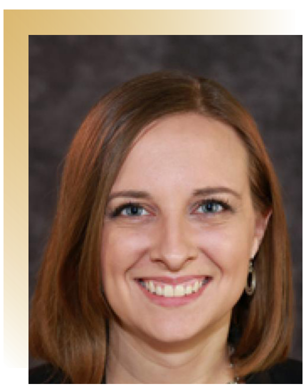
Election Results

According to the Division by-laws (available at: http://edgd.asee.org/aboutus/index.htm), the chair of the Elections Committee shall transmit the results of the election to the Chair of the Division. The Chair shall inform each candidate (including those not elected) of the results of the election for his office and shall transmit the names of the newly-elected officers to the Editor of the *Journal* for publication in the Spring issue of the *Journal*. The chair of the Elections Committee shall report the results of the election to the Division at the annual business meeting. The results for the most recent election are as follows:

Vice-Chair: Josh Gargac

Associate Professor of Mechanical Engineering

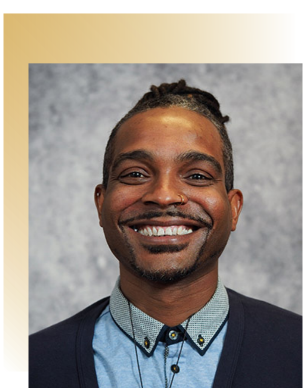
Ohio Northern University



Director of Programs: Brooke Morin

Senior Lecturer, Engineering Education

The Ohio State University



Director of Membership: Cameron Denson

Associate Professor of STEM Education and Graduate Coordinator

North Carolina State

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Neural Efficiency and Spatial Task Difficulty: A Road Forward to Mapping Students' Neural Engagement in Spatial Cognition

Ariel W. Snowden, Christopher M. Warren, Wade H. Goodridge and Ning Fang
Utah State University

Abstract

The current study examined the neural correlates of spatial rotation in eight engineering undergraduates. Mastering engineering graphics requires students to mentally visualize in 3D and mentally rotate parts when developing 2D drawings. Students' spatial rotation skills play a significant role in learning and mastering engineering graphics. Traditionally, the assessment of students' spatial skills involves no measurements of neural activity during student performance of spatial rotation tasks. We used electroencephalography (EEG) to record neural activity while students performed the Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R). The two main objectives were to 1) determine whether high versus low performers on the Revised PSVT:R show differences in EEG oscillations and 2) identify EEG oscillatory frequency bands sensitive to item difficulty on the Revised PSVT:R.

Overall performance on the Revised PSVT:R determined whether participants were considered high or low performers: students scoring 90% or higher were considered high performers (5 students), whereas students scoring under 90% were considered low performers (3 students). Time-frequency analysis of the EEG data quantified power in several oscillatory frequency bands (alpha, beta, theta, gamma, delta) for comparison between low and high performers, as well as between difficulty levels of the spatial rotation problems.

Although we did not find any significant effects of performance type (high, low) on EEG power, we observed a trend in reduced absolute delta and gamma power for hard problems relative to easier problems. Decreases in delta power have been reported elsewhere for difficult relative to easy arithmetic calculations, and attributed to greater external attention (e.g., attention to the stimuli/numbers), and consequently, reduced internal attention (e.g., mentally performing the calculation). In the current task, a total of three spatial objects are presented. An example rotation stimulus is presented, showing a spatial object before and after rotation. A target stimulus, or spatial object before rotation is then displayed. Students must choose one of five stimuli (multiple choice options) that indicates the correct representation of the object after rotation. Reduced delta power in the current task implies that students showed greater attention to the example and target stimuli for the hard problem, relative to the moderate and easy problems. Therefore, preliminary findings suggest that students are less efficient at encoding the target stimuli (external attention) prior to mental rotation (internal attention) when task difficulty increases.

Our findings indicate that delta power may be used to identify spatial rotation items that are especially challenging for students. We may then determine the efficacy of spatial rotation interventions among engineering education students, using delta power as an index for increases in internal attention (e.g., increased delta power). Further, in future work, we will also use eye-tracking to assess whether our intervention decreases eye fixation (e.g., time spent viewing) toward the target stimulus on the Revised PSVT:R. By simultaneously using EEG and eye-tracking, we may identify changes in internal attention and encoding of the target stimuli that are predictive of improvements in spatial rotation skills among engineering education students.

Introduction

Spatial reasoning skills are critical for engineering students' academic success. Improving spatial skills increases the retention rate in engineering programs (Sorby et al., 2018). In addition, college courses geared toward improving spatial skills improve engineering students' grades in graphics courses (Sorby et al., 2018). Mastering engineering graphics requires students to mentally visualize in 3D and mentally rotate parts when developing 2D drawings (Marunic & Glazar, 2013). Thus, students' spatial rotation skills play a significant role in their ability to learn and master engineering graphics (Blasko & Holliday-Darr, 2010).

Although previous work has established a clear relationship between mental rotation skills and academic success among engineering students (Sorby et al., 2018), there is limited research on the underlying neural correlates of mental rotation. Electroencephalography (EEG) is a useful tool to measure neural activation during cognitive tasks. EEG oscillatory frequencies reflect rhythmic patterns of post-synaptic activity of neurons (Olejniczak, 2006) and are linked to many cognitive processes including attention, working memory, and inhibition (Basar et al., 2001). Gamma and beta oscillations are of particular interest in the current study. Gamma oscillations (30-40 Hz) facilitate the encoding of sensory information and are linked to visual and spatial attention (Benchenane et al., 2011). In primates, increased attention toward a visual stimulus is associated with gamma synchrony between the frontal eye field and the visual cortex (Gregoriou et al., 2012). During mental rotation in humans, gamma synchrony is also observed between the posterior and frontal cortices (Bhattacharya et al., 2001). Gamma oscillations seem to increase the signal-to-noise ratio, fine-tuning the oscillatory rhythms of activation in brain regions responsible for visual (Gregoriou et al., 2012) and spatial attention (Noudoost et al., 2010).

The beta oscillatory frequency (13-30 Hz) provides a reliable index of attentional resources utilized during cognitive tasks (Cole & Ray, 1985; Kamiński et al., 2012). Beta power increases with greater cognitive load (Kornblith et al., 2016) and when individuals are particularly focused on the task at hand (Kamiński et al., 2012). In previous work (Call et al., 2016), we found group differences in beta activation based on student performance on the Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R). That is, low performers (determined by overall accuracy scores) showed higher increases in beta activation than high performers. These findings are consistent with the neural efficiency hypothesis, which holds that individuals who have more experience in a given task require fewer cognitive resources to perform the task relative to their more novice counterparts (Haier et al., 1988; Hair et al., 1992). Thus, reduced cortical activation during a cognitive task reflects more efficient neural processing.

The goal of the current work-in-progress study was to identify whether changes in EEG oscillatory frequencies are predictive of students' spatial rotation skills. Therefore, the two main objectives of the current study was to 1) determine whether high versus low performers on the Revised PSVT:R show differences in EEG oscillations and 2) identify EEG oscillatory frequency bands sensitive to item difficulty on the Revised PSVT:R. According to our previous findings (Call et al., 2016) and the neural efficiency hypothesis, we expected to observe higher power, specifically in the beta and gamma bands, in the high performers when compared to the low performers. In addition, we expected increases in EEG power in the beta and gamma bands as a function of task difficulty.

Methods

Participants

Eight male undergraduate students between the ages of 20 and 30, were recruited from engineering programs at a public land-grant research university in the Mountain West area of the U.S. All procedures detailed in the current work were approved by the Institutional Review Board at the University. Informed consent was obtained from all participants.

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Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R)

The Revised PSVT:R (Yoon, 2011) assesses the spatial visualization ability of mental rotation in participants ages 13 and older. This instrument contains two practice items and 30 test items. Thirteen of the 30 items consist of symmetrical figures of 3-D objects, whereas 17 items contain asymmetrical figures of 3-D objects. For each item, students are to study the object on the top line, which shows the orientation of an object after rotation. Students were instructed to "picture in their mind what the object shown in the middle line looks like when rotated in exactly the same manner". Students must then select which of the five options represents the correct position of the rotated item. Students were given an example PSVT:R item with the correct response. Researchers assured that all students understood the task instructions prior to the start of experimental trials. There were no time constraints on completion of each spatial rotation item. Figure 1 shows examples of spatial rotation trials on the PSVT:R. The test was presented on a monitor using E-prime 3.0 (Psychology Software Tools, Pittsburgh, PA).

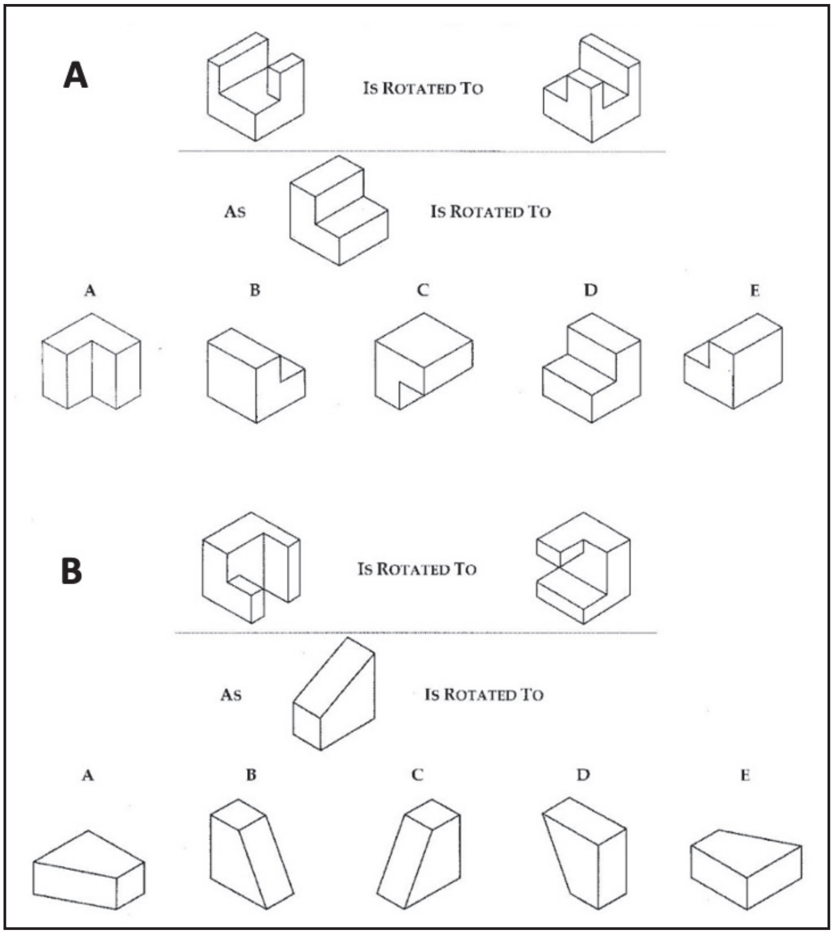

Figure 1. Revised PSVT:R Practice Items (Yoon, 2011). A) Example of an easy practice item on the Revised PSVT:R. The correct answer for this item is (d). B) Example of a more complex practice item. The correct answer for this item is (b).

EEG Recording and Preprocessing

EEG data were continuously recorded from 64 electrodes, digitized at 500 Hz, using an acti64 Champ System (Brain Products GmbH, Gilching, Germany) while participants completed the Revised PSVT:R. Impedance levels were monitored throughout the experiment, maintained at less than 10 kOhms. EEG data were preprocessed and analyzed using EEGLAB (Delorme & Makeig, 2004), and according to our previous approach (Call et al., 2016). EEG data were filtered using a high-pass filter of 0.1 Hz and a low-pass filter of 59 Hz and re-referenced to the average reference. Ocular and motor artifacts were corrected by manual visual inspection of all EEG data for each participant. After manual rejection of artifacts, independent component analysis was used to detect and remove any remaining, repetitive artifacts in the data.

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EEG Epochs

EEG data were segmented to create three epochs for each PSVT:R item difficulty condition: easy, moderate, hard. Each epoch spanned from -1.0 to +5.30 seconds. This epoch window was determined by the shortest trial response time when evaluating all participants. Using this time window for all epochs allowed for reliable power estimates across all frequencies. All epochs were baseline corrected from -200 to 0 ms.

Time-frequency Analysis

Time-frequency analysis of EEG data was conducted in MatLAB 2019b (Mathworks Inc., Natick, MA). Power spectrum analysis of EEG data were decomposed using a Fast Fourier transformation. Absolute power metrics were calculated using a power-based logarithmic transform (Call et al., 2016), for all frequency bands: theta (4-8 Hz), delta (1-4 Hz), alpha (8-13 Hz), beta (13-30 Hz), gamma (30-40 Hz) and for all PSVT:R difficulty levels (easy, moderate, hard) across all 64 channels. Absolute power tables and time-frequency code can be accessed at https://osf.io/fpqy6/.

Results

Behavioral Analysis

The mean accuracy for performance on the Revised PSVT:R across all eight engineering students was 89% with a standard deviation of 31%. Table 1 shows accuracy for each student and overall mean trial response times. Table 2 shows mean accuracy and response times for the three item difficulty conditions.

Neural Analysis

A Levene's test was used to assess normality of EEG absolute power values. The Levene's test revealed a non-normal distribution of EEG data. To meet normality assumptions, a log10 transformation was used to transform absolute power values. A mixed design ANOVA was used to assess effects of factors group (high, low), band (alpha, beta, delta, theta, gamma) and difficulty (easy, moderate, hard) on absolute power values. The ANOVA showed a significant frequency band x item difficulty interaction, $F(8, 48)=2.48$, $p < .05$. Paired samples t-tests showed a trend in reduced power for the hard difficulty items for the gamma and delta bands: delta easy (M=0.15,SD=0.29) > delta hard (M=-0.02,SD=0.32), t(4.93)=, p=.001; delta moderate (M=0.10,SD=0.28) > delta hard (M=-0.02,SD=0.32), t(4.03)=, p=.001; gamma easy (M=-0.90,SD=0.40) > gamma hard (M=-1.04,SD=0.39), t(3.64)=, p=.001. Figure 2 shows the topographies for the delta and gamma powers by item difficulty after the log10 transformation. An overall trend in reduced

Table 1

Overall accuracy scores and mean response times on the Revised PSVT:R.

Student	Accuracy (%)	Mean Response Time (seconds)
1	90	22.38
2	97	31.75
3	83	32.44
4	97	21.34
5	87	24.01
6	70	32.57
7	90	20.58
8	100	26.02

Table 2

Revised PSVT:R mean scores for easy, moderate, and hard items.

Condition	Mean Accuracy (+/- s.d.)	Mean Response Time in seconds (+/- s.d.)
Easy	95% +/- 22%	16.523 +/- 10.526
Moderate	89% +/- 32%	30.894 +/- 17.911
Hard	38% +/- 52%	39.405 +/- 23.675

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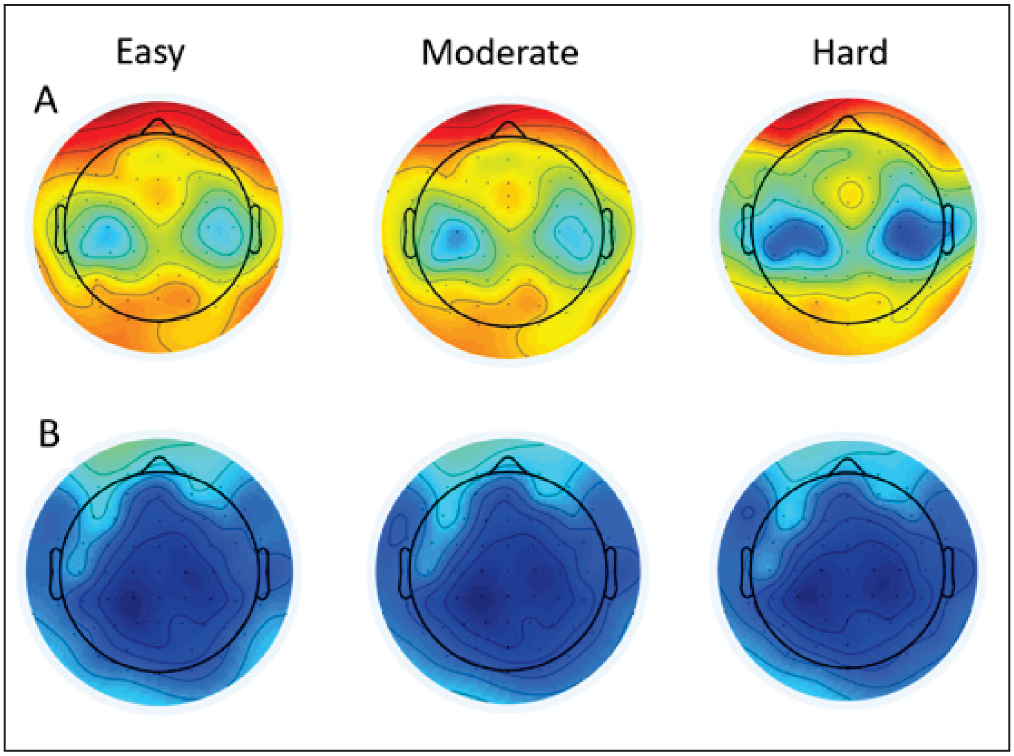

Figure 2. Copographical plots of delta and gamma power averaged across all 8 students. A) Mean delta power (1-4 Hz) as a function of item difficulty across all 8 students. B) Mean gamma power (30-40 Hz) as a function of item difficulty across all 8 students. The color bar shows the range of power values depicted in the plots: dark red indicates higher power whereas dark blue indicates lower power.

power for the hard condition may indicate a decrease in engagement, or depleting mental energy when students work on the hard item relative to the moderate and easy items.

Discussions

Our study used EEG during the Revised PSVT:R to assess the neural frequencies of engineering students during mental spatial rotation. Contrary to our hypothesis and our previous work (Call et al., 2016), we did not observe any differences in absolute power between high and low performers across the five frequency bands for the Revised PSVT:R. According to the neural efficiency hypothesis, as individuals become more skilled in a cognitive task, they require less neural resources to perform the task (Haier et al., 1992; Harmony et al., 1996). Therefore, we expected that engineering students with higher accuracy scores on the Revised PSVT:R would show higher neural efficiency when performing mental rotation. In previous work (Call et al., 2016), we observed higher beta activation for low versus high performers on the PSVT:R. However, a failure to replicate these findings in the current study is likely due to differences in the assessment of EEG power. Here, we assessed group differences in EEG frequency bands using absolute power, whereas in the previous study (Call et al., 2016), we examined group differences using relative power (e.g., a percent increase in beta power relative to baseline/rest). Further studies are needed to determine the best approach for examining group differences in EEG power during spatial rotation tasks.

Interestingly, we found that the level of difficulty of spatial rotation items affected EEG frequencies.

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Specifically, we observed a decrease in absolute power in the delta and gamma frequency bands for the most challenging spatial rotation item relative to easy items on the Revised PSVT:R. A reduction in delta power has been observed with increases in task difficulty for mental arithmetic tasks (Duru & Assem, 2018; Fernández et al., 1995; Harmony et al., 1996). These studies interpret decreases in delta power as a reflection of greater external attention, specifically, attention to the stimuli involved in the task at hand. As external attention increases, consequently, internal attention decreases. In the current study, decreases in delta power for difficult spatial rotation items likely indicates greater external attention to the example and target spatial rotation stimuli with concurrent decreases in internal attention (e.g., mental rotation of the target stimulus). Increases in frontal delta power during mental tasks are associated with inhibitory processes, such as successfully inhibiting a motor response during a Go/NoGo task (Fernández et al., 2002; Harmony, 2013). Thus, a decrease in delta power may also be interpreted as a failure to inhibit external attentional processes and distractions during difficult mental rotation.

In addition to effects of spatial rotation item difficulty on absolute delta power, we also observed decreases in absolute power in the gamma frequency band for the difficult spatial rotation item. Increases in gamma activation during mental rotation are believed to reflect encoding of visual stimuli (Nikolaev & Anokhin, 1998). In our study, decreases in gamma activation as task demands increase during spatial rotation may indicate students' difficulty to efficiently encode a mental representation of the spatial target object. In summary, our preliminary findings suggest that students are less efficient at encoding the target stimuli and may rely more on the example spatial rotation stimuli as task demands increase. Further, our findings indicate that reduced power in the delta and gamma bands may be used as a proxy for identifying challenging spatial rotation items/tasks.

Limitations of the Current Study

The current study is limited due to the constraints of the item difficulty on the Revised PSVT:R. The majority of subjects scored 90% or higher on the task, with one item that was especially challenging for engineering students, in which only 32.4% of students answered correctly (item 30 on the Revised PSVT:R). This resulted in a single trial being included in the hard condition. Therefore, our findings have limited power and future studies should include a wider range of item difficulty, with more challenging spatial rotation items. In addition, the engineering students who participated in the current study were all male. Future studies are needed to assess the neural correlates of spatial rotation in both male and female engineering students.

Future Work

Future work will identify spatial rotation items that are most challenging for engineering students and assess spatial rotation skills across a more diverse sample of engineering students. Upon identifying a set of spatial rotation items showing a wider range of difficulty, we will employ a spatial rotation intervention to assess whether changes in the absolute power of EEG frequencies (specifically in the delta and gamma bands) are predictive of improvements in mental rotation. In addition to using EEG, we will include methods to examine whether other psychophysiological markers (e.g., eye movements, pupil size) are predictive of improvements in spatial rotation performance. Our preliminary findings suggest that eye-tracking will be a valuable tool to further examine visual encoding of spatial stimuli. Collectively, this work will provide insight into alternative methods that may be used to a) identify areas of improvement and b) track progress of spatial abilities, by evaluating the cognitive demands of spatial rotation in engineering students.

Acknowledgments

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References

Acti64 Champ System (2019). Gilching, Germany: Brain Products GmbH.

Başar, E., Başar-Eroglu, C., Karakaş, S., & Schürmann, M. (2001). Gamma, alpha, delta, and theta oscillations govern cognitive processes. *International journal of psychophysiology*, 39(2-3), 241-248. https://doi.org/10.1016/S0167-8760(00)00145-8

Benchenane, K., Tiesinga, P. H., & Battaglia, F. P. (2011). Oscillations in the prefrontal cortex: a gateway to memory and attention. *Current opinion in neurobiology*, 21(3), 475-485. https://doi.org/10.1016/j.conb.2011.01.004

Bhattacharya, J., Petsche, H., Feldmann, U., & Rescher, B. (2001). EEG gamma-band phase synchronization between posterior and frontal cortex during mental rotation in humans. *Neuroscience Letters*, 311(1), 29-32. https://doi.org/10.1016/S0304-3940(01)02133-4

Blasko, D. G., & Holliday-Darr, K. A. (2010). Longitudinal analysis of spatial skills training in engineering graphics. In Proceedings of the *65th Midyear Meeting of the Engineering Design Graphics Division* (pp. 138-151).

Call, B. J., Goodridge, W., Villanueva, I., Wan, N., & Jordan, K. (2016). Utilizing electroencephalography measurements for comparison of task-specific neural efficiencies: spatial intelligence tasks. *JoVE (Journal of Visualized Experiments)*, (114), e53327.

Cole, H. W., & Ray, W. J. (1985). EEG correlates of emotional tasks related to attentional demands. International *Journal of Psychophysiology*, 3(1), 33-41. https://doi.org/10.1016/0167-8760(85)90017-0

Delorme, A., & Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of neuroscience methods*, 134(1), 9-21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Duru, A. D., & Assem, M. (2018). Investigating neural efficiency of elite karate athletes during a mental arithmetic task using EEG. *Cognitive neurodynamics*, 12(1), 95-102. https://doi-org.dist.lib.usu.edu/10.1007/s11571-017-9464-y

Fernández, T., Harmony, T., Rodríguez, M., Bernal, J., Silva, J., Reyes, A., & Marosi, E. (1995). EEG activation patterns during the performance of tasks involving different components of mental calculation. *Electroencephalography and clinical neurophysiology*, 94(3), 175-182. https://doi.org/10.1016/0013-4694(94)00262-J

Fernandez, T., Harmony, T., Gersenowies, J., Silva-Pereyra, J., Fernández-Bouzas, A., Galán, L., & Díaz-Comas, L. (2002). Sources of EEG activity during a verbal working memory task in adults and children. In *Supplements to Clinical Neurophysiology*, 54, 269-283. Elsevier. https://doi.org/10.1016/S1567-424X(09)70461-1

Gregoriou, G. G., Gotts, S. J., & Desimone, R. (2012). Cell-type-specific synchronization of neural activity in FEF with V4 during attention. *Neuron*, 73(3), 581-594. https://doi.org/10.1016/j.neuron.2011.12.019

Haier, R. J., Siegel Jr, B. V., Nuechterlein, K. H., Hazlett, E., Wu, J. C., Paek, J., ... & Buchsbaum, M. S. (1988). Cortical glucose metabolic rate correlates of abstract reasoning and attention studied with positron emission tomography. *Intelligence*, 12(2), 199-217. https://doi.org/10.1016/0160-2896(88)90016-5

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Haier, R. J., Siegel, B., Tang, C., Abel, L., & Buchsbaum, M. S. (1992). Intelligence and changes in regional cerebral glucose metabolic rate following learning. *Intelligence*, 16(3-4), 415-426. https://doi.org/10.1016/0160-2896(92)90018-M

Harmony, T., Fernández, T., Silva, J., Bernal, J., Díaz-Comas, L., Reyes, A., ... & Rodríguez, M. (1996). EEG delta activity: an indicator of attention to internal processing during performance of mental tasks. International journal of psychophysiology, 24(1-2), 161-171. https://doi.org/10.1016/S0167-8760(96)00053-0

Harmony, T. (2013). The functional significance of delta oscillations in cognitive processing. *Frontiers in integrative neuroscience*, 7, 83. https://doi.org/10.3389/fnint.2013.00083

Kamiński, J., Brzezicka, A., Gola, M., & Wróbel, A. (2012). Beta band oscillations engagement in human alertness process. *International Journal of Psychophysiology*, 85(1), 125-128. https://doi.org/10.1016/j.ijpsycho.2011.11.006

Kornblith, S., Buschman, T. J., & Miller, E. K. (2016). Stimulus load and oscillatory activity in higher cortex. *Cerebral Cortex,* 26(9), 3772-3784. https://doi.org/10.1093/cercor/bhv182

Marunic, G., & Glazar, V. (2013). Spatial ability through engineering graphics education. *International Journal of Technology and Design Education*, 23(3), 703-715. https://doi-org.dist.lib.usu.edu/10.1007/s10798-012-9211-y

MATLAB. (2019). version 9.7.0.1190202 (R2019b). Natick, Massachusetts: The MathWorks Inc.

Nikolaev, A. R., & Anokhin, A. P. (1998). EEG frequency ranges during perception and mental rotation of two-and three-dimensional objects. *Neuroscience and behavioral physiology*, 28(6), 670-677. https://doi-org.dist.lib.usu.edu/10.1007/BF02462988

Noudoost, B., Chang, M. H., Steinmetz, N. A., & Moore, T. (2010). Top-down control of visual attention. *Current opinion in neurobiology*, 20(2), 183-190. https://doi.org/10.1016/j.conb.2010.02.003

Olejniczak, P. (2006). Neurophysiologic basis of EEG. *Journal of clinical neurophysiology,* 23(3), 186-189. https://doi.org/10.1097/01.wnp.0000220079.61973.6c

Psychology Software Tools, Inc. [E-Prime 3.0]. (2016). Retrieved from https://support.pstnet.com/.

Sorby, S., Veurink, N., & Streiner, S. (2018). Does spatial skills instruction improve STEM outcomes? The answer is 'yes'. Learning and *Individual Differences*, 67, 209-222. https://doi.org/10.1016/j.lindif.2018.09.001

Yoon, S. Y. (2011). Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R) [Psychometric Instrument].

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Wade H. Goodridge is an Associate Professor in the Department of Engineering Education

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