JOURNAL OF
EMERGING INVESTIGATORS

Article

EEG study of virtual learning demonstrates worsened learning outcomes and increased mirror neuron activation

Clara Choi[1] and Leigh-Ana Rossitto[2]
[1]Orange County School of the Arts, Santa Ana, California
[2]University of California at San Diego, San Diego, California

SUMMARY

The COVID-19 pandemic has necessitated virtual forms of schooling and learning, which has been a challenging adjustment that may continue to be required with resurgences in infection or future disease outbreaks. In order to improve the effectiveness of virtual learning, we need a better understanding of any cognitive limitations associated with virtual learning formats and technologies. This study examined the differences between in-person dance learning and virtual dance learning, as measured by mirror neuron activation and learning outcomes. My hypothesis was that virtual learning induces a lower level of mirror neuron activation in the brain (as approximated by mu rhythm band power) than in-person learning, which I expected to coincide with worse learning outcomes. In this study, the electroencephalography (EEG) brain waves of eight participants were recorded while the participants watched and learned two dances: one over a computer screen and another via live, in-person demonstration. At the end of each demonstration, participants were asked to perform the routine from memory and were scored on a 5-point rubric. As hypothesized, participants scored lower on the performance rubric when learning virtually versus in-person. However, contrary to expectations, the EEG data showed that participants actually had higher mirror neuron activation when learning virtually versus in-person. This study demonstrated a statistically significant suppression of mu rhythm power, which is a proxy for heightened mirror neuron activity, for virtual learning compared to in-person learning. This illustrates that, while virtual dance learning is harder than in-person dance learning, when participants are asked to try to learn new movements over a screen, their mirror neurons are more highly engaged than when learning in-person. These findings have broader implications for both the effectiveness and mental exertion or cognitive load of virtual learning.

INTRODUCTION

As a result of the global COVID-19 pandemic, many local, state, and national governments around the world have required quarantines, stay-at-home orders, business closures, and social distancing to limit the spread of the virus. As schools have transitioned from in-person to virtual learning, many extracurricular activities (e.g. sports, dance, music) have also experimented with virtual learning through online platforms like Zoom or Skype. This shift to virtual learning may continue for a long time even beyond the current pandemic, especially if it is demonstrated to be an effective way to learn (1).

To make virtual learning more effective, we have to first determine if there are any cognitive limitations of learning on a digital platform. Virtual learning has inherent social limitations—it can be isolating, prone to distractions, boring, and audio-visually challenging. As a result, virtual learning may have a negative impact on attention, processing, retention, and motivation compared to the standard in-person learning environment (2). The current study focused on the cognitive differences in the learning process, specifically looking at mirror neuron activation in both virtual and in-person learning.

A neuron is a nerve cell in the brain that is responsible for sending and receiving information to and from the brain. About thirty years ago, a group of neuroscientists discovered the mirror neuron system in primates (3, 4). When the researchers put electrodes on the motor cortex of a monkey's brain, they observed that certain neurons were triggered when the monkey performed an action (grabbing food) and also when the monkey watched the same action performed by a person (someone else grabbing food) (3-5). These primate studies led to the discovery of the human mirror neuron system (5).

In the last few decades, studies showed that humans have a mirror neuron system similar to monkeys which are triggered during both action and observation (1, 6). Mirror neurons are an integral part of child development because many behaviors and habits are processed, developed, and coded through mirror neuron activation (6). For example, when someone smiles at a baby, the baby will often smile back due to activation of mirror neurons (1). Studying the activity of mirror neurons is important for understanding how people learn new skills through observation. Studies have shown that mirror neuron activity is important in forming new neural connections and the ability to imitate, learn, and execute new movements, particularly in childhood (6).

A 2005 study by Calvo-Merino, et al. looked at mirror neuron activity in people while they were watching dance movements (7). The experiment included 30 people: 10 ballet dancers, 10 experts in capoeira, and 10 non-dancers who served as the control group. The researchers played two videos for the subjects to watch, one with ballet movement and another

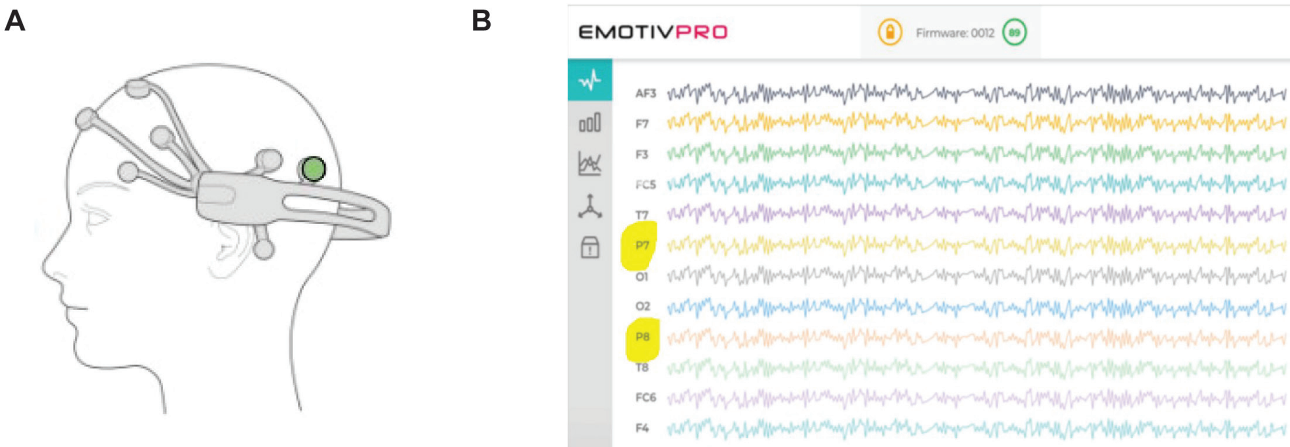

Figure 1: (A) a graphical representation of the Emotiv EEG headset worn by a participant in this study. The green dot represents Electrode P7 over the left parietal cortex. (B) A sample measurement that shows how the brain waves appear in the EEG software when the EEG headset is worn by a participant. Electrodes P7 and P8 have been highlighted in yellow.

with capoeira-based movement. The results found that mirror neuron activation in the brain as measured by functional magnetic resonance imaging (fMRI) was stronger when the person was capable of doing the observed actions. This suggests that the parietal and premotor cortex mirror neuron system does not simply respond to observations of movement but also integrates the visual observation with the person's own pre-existing motor skills (7).

One challenge of studying mirror neurons is that it often requires invasive methods of placing electrodes directly on the surface of a person's cranium (8). Therefore, most studies have been done through brain imaging devices such as non-invasive fMRI or electroencephalography (EEG) technology. EEG is an electrophysiological measurement of the electrical activity in the brain, allowing scientists to study brain activity underlying cognitive processes and human behavior. EEG brain waves can provide an indirect measurement of mirror neuron activity (4, 8).

Mirror neuron activation can be approximated using EEG by measuring the mu rhythm in the sensorimotor area of the brain (9). A mu rhythm is a brain wave that is observed most prominently when the body is at rest and is found at a frequency of about 8 to 13 Hz, which is also the range of the alpha rhythm (9). An alpha rhythm is the normal electrical activity of the brain while conscious and relaxed. When mirror neurons are activated, the mu rhythm is suppressed, attenuated, or desynchronized, and in this study, it is described as decreased mu rhythm power (5). Moving a part of the body or thinking about moving that part of the body suppresses the mu rhythm oscillations (4, 5). Despite having the same frequency, the mu and alpha rhythms are distinguishable by brain region based on topology. Alpha waves can be detected at the top of the head in the frontal-central region, whereas mirror neurons are present throughout the motor system as well as the parietal cortex (1, 10). In the current study, the mu rhythm power was detected and studied in the parietal cortex of participants (**Figure 1**, EEG electrodes P7 and P8)..

This study sought to determine whether there was a difference in mu rhythm power during in-person dance learning as compared to virtual dance learning. I hypothesized that virtual dance learning would result in worse learning outcomes as well as lower mirror neuron activation (as measured by higher mu rhythm power) compared to in-person learning. This was based on my expectation that mirror neuron activation should improve learning outcomes. My results showed that while participants scored lower on the performance rubric when learning virtually versus in-person, they actually had higher mirror neuron activation when learning virtually versus in-person. The overall significance of this study is a brain-based understanding of differences in learning outcomes and cognitive processes involved in virtual learning formats, as well as a better understanding of the function of mirror neurons in how the brain learns motor skills. Lastly, it may help educators to adapt their expectations

Table 1: The 5-point dance scoring rubric used to grade each participant's ability to repeat the dance choreography taught in both the in-person and virtual dance lessons.

Dancing Proficiency	Definition
5- Expert	Showed great understanding of the choreography and made no mistakes. Timing was on point and all 10 steps were included in the routine.
4- Advanced	Showed understanding of the choreography and timing was on point or off by one count on 1–2 steps. At least 8 out of the 10 steps were performed well.
3- Intermediate	Showed understanding of the choreography and timing was slightly off on 2–3 steps. At least 7 out of the 10 steps were performed accurately.
2- Beginner	Showed below average understanding of the choreography and timing was off for the majority of the routine. At least 4–10 steps were performed well enough that the experiment administrator could figure out the moves.
1- Deficient	Showed no understanding of the choreography and timing was off for the whole dance. Little to no steps were performed well enough to the extent that the experiment administrator could decipher between steps.

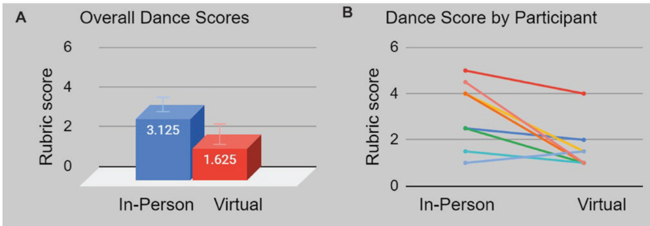

Figure 2: (A) Average dance performance scores based on a 5-point scoring rubric in the in-person and the virtual phases (*p=0.018 in a two-tailed, paired sample t-test). (B) Depicts dance scores but plots the individual scores of each of the participants to be able to show how their individual scores improved or worsened between the in-person and virtual phases.

and tools for virtual learning, providing the foundation for an evidence-based evaluation of future virtual teaching methods.

RESULTS

Participants in this study were evaluated using a 5-point rubric, with 1 reflecting no proficiency and 5 reflecting expert proficiency. The average dance score achieved by participants for the in-person phase was 3.125 with a standard error of 0.515, and the average dance score for the virtual phase was 1.625 with a standard error of 0.363 (**Figure 2A**). Participants scored significantly higher when learning in-person than learning virtually (n = 7, p = 0.018). With the exception of one participant, scores for each participant were lower in the virtual phase than the in-person phase (**Figure 2B**).

Given that the mu rhythm is associated with mirror neuron activity, this study measured the mu rhythm power in the parietal cortex, which is divided into two sides, left and right cortices. The average mu rhythm power in the left parietal cortex for the in-person phase was 4.68 uV^2/Hz with a standard error of 1.67 uV^2/Hz, and the average mu rhythm power in the left parietal cortex for the virtual phase was 2.10 uV^2/Hz with a standard error of 0.84 uV^2/Hz (**Figure 3A**). Although the mu rhythm power in the in-person phase was higher on average than in the virtual phase, there was no statistically significant difference between these two groups (n = 7, p = 0.21).

The average mu rhythm power in the right parietal cortex for the in-person phase was 11.87 uV^2/Hz with a standard error of 3.26 uV^2/Hz, and the average mu rhythm power in the right parietal cortex for the virtual phase was 5.02 uV^2/Hz with a standard error of 1.56 uV^2/Hz (**Figure 3B**). We found that participants had a significantly higher mu rhythm power when learning in-person than they did when learning virtually for the right parietal cortex (n = 7, p = 0.034).

With the exception of one participant, mu rhythm power in the left and right parietal cortices for each participant was higher in the in-person phase than in the virtual phase. As mu rhythm power is inversely related to mirror neuron activation, the results showed that mirror neuron activation was higher in virtual learning.

DISCUSSION

This study sought to determine whether there was a difference in mirror neuron activation and learning outcomes during in-person dance learning as compared to virtual dance learning. The independent variables were in-person learning and virtual learning. The dependent variables were mu rhythm power and learning outcomes. My hypothesis was that virtual dance learning would result in a lower level of mirror neuron activation (as measured by higher mu rhythm power) and worse learning outcomes compared to in-person dance learning.

The rationale for this hypothesis derives from my own experience as a student in the dance conservatory of a performing arts school, which was distance-learning from the beginning of the COVID-19 pandemic through the end of the last school year. Personal experience indicates that in online dance conservatory, it is harder to replicate intricate dance movements and our retention of the choreography is poor compared to when we are learning in-person. Given that the human mirror neuron system is responsible for motor learning, I hypothesized that the virtual learning format for dance lessons induces poorer mirror neuron activation and that poorer mirror neuron activation may be a cause for worse learning outcomes.

As I expected, participants scored worse in the virtual dance lessons than in the in-person lessons, and therefore I concluded that virtual learning was not as effective as in-

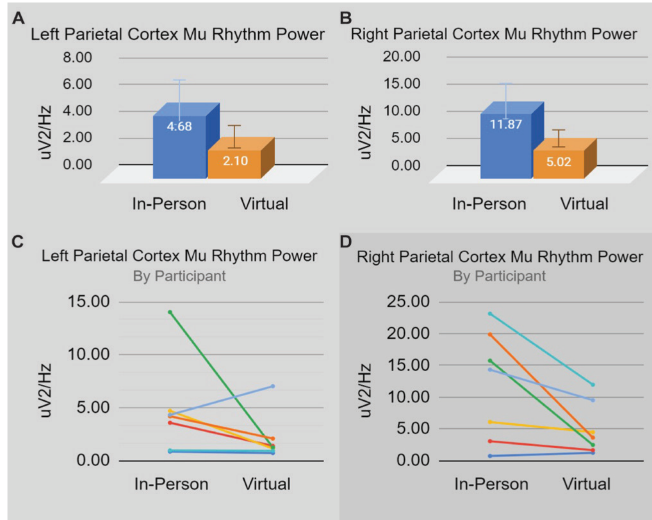

Figure 3: (A) shows the brain wave power measurements from the 8 to 12 Hz frequency (which, based on topology, are assumed to be mu rhythms) collected from electrode P7 over the left parietal cortex. This bar graph shows mu rhythm power, measured in microvolts-squared per Hz (uV^2/Hz), in participants' left parietal cortex while watching each dance (in-person and virtual). p=0.21 in a two-tailed, paired sample t-test. (B) shows the brain wave power measurements from the 8 to 12 Hz frequency (mu rhythms) collected from electrode P8 over the right parietal cortex. This bar graph shows mu rhythm power in participants' right parietal cortex while watching each dance (in-person and virtual). *p=0.034 in a two-tailed, paired sample t-test. Panels C and D depict the activation of the left and right parietal cortex but plot each of the individual participants to be able to show how their activation levels improved or worsened between the in-person and virtual phases (with mu rhythm power inversely related to mirror neuron activation).

person learning in terms of learning outcomes. However, the hypothesis regarding mirror neuron activation was not supported. The experiment demonstrated that the mu rhythm power was more suppressed (suggesting higher mirror neuron activation) in both the left and right parietal cortex in virtual dance lessons than in-person lessons. The difference was not statistically significant in the left parietal cortex, which was likely due to the small sample size (n = 7); a follow-up study with a larger sample size (n > 20) will be necessary to confirm this difference. However, in the right parietal cortex, the difference in mu rhythm power was statistically significant. While outside the scope of this study, it would be interesting to examine what functional attributes in the left and right parietal cortices may account for the differences in neuronal activity.

The results of this study confirm that virtual learning is not as effective as in-person learning for dance. I expected that results would show that the ineffectiveness coincided with lower mirror neuron activation during virtual learning. But instead, my results showed that when participants were asked to try to learn motor skills in a virtual format, their mirror neuron system became more activated than when they were trying to learn those skills in an in-person format. This suggests that the mirror neuron system is required to be more actively engaged due to the increased mental exertion and cognitive processing challenges of learning to dance online. Furthermore, because it is easier to learn a dance through in-person observation, the mirror neuron system may be less activated. Future research could measure stress and focus of participants (either through EEG indicators or through self-reporting) when they are learning to dance virtually versus in-person to confirm whether mirror neuron activation is correlated with the intensity of cognitive processing. This would help show whether the inherent challenges of virtual learning are impacting the mirror neuron system, and specifically, whether attention and focus modulate mirror neurons.

A potential experimental bias was having only one experimenter score the dances performed by participants. Because this scoring is highly subjective, it could cause a bias toward ideal results. Future endeavors should use two dance scorers or, given permission and ethical approval, record the participants' dancing to allow multiple people to score the dances. Another potential limitation was that, although I tried to choreograph two different dances that were equivalent in difficulty, it is possible that the choreography for the in-person phase was in fact easier to learn than the one for the virtual phase, and therefore resulted in lower scores for the virtual phase. To eliminate this potential confounding variable, an additional control group could learn both dances using the same instructional method.

In addition, due to COVID-19-related health and safety restrictions, it was not possible to safely recruit and test additional participants. All eight participants were members of the same family living on the same street. A follow-up study should be conducted to study a larger sample size ($n \geq 15$) and determine if the statistical significance is enhanced and whether a correlation could be made.

In addition to improving the sample size, it would also be interesting to conduct a mu rhythm study on another type of learning besides dance, such as learning a new sport, instrument or even a foreign language. Another interesting inquiry would be whether differences in mu rhythm power when watching someone dance virtually versus in-person affects one's enjoyment of a dance performance.

In the past year, the entire world has had to experiment with virtual work and virtual schooling. Both Governor Newsom of California and President Biden have recently emphasized the importance of students returning to the classroom in person referring to the negative impact on learning outcomes when learning remotely. But we need to study whether there actually are differences in learning outcomes, and if so, what the reasons are. Could it have to do with a biological process within the brain such as mirror neurons? Is it possible that the challenges of virtual learning such as poorer attention span, human connection, internet connection or fatigue can have an impact on mirror neuron activity? This study demonstrated that mu rhythm power was significantly lower (indicating higher mirror neuron activation) in virtual versus in-person dance lessons and was related to a significantly worse learning outcome. Once we can accurately identify the problem, we can begin to come up with solutions, innovations or technologies to help address the problem because virtual learning is likely to continue. Even if the pandemic subsides, there may be future surges or new pandemics that force people to socially distance again. We may be moving to a world where it is important to improve the way we learn, communicate, and collaborate through virtual formats as effectively as we do in-person.

MATERIALS AND METHODS

The Emotiv Epoc X mobile wireless EEG headset was used in this study to measure and track mu rhythms. (11) The Emotiv Epoc X is a rotating headset positioned like a headband on top of the head with 14 electrode sensors placed over various parts of the brain.

EmotivPro (version 2.0) software was used in this study to display the EEG brain wave recordings from the Emotiv Epoc X headset (11). The EmotivPro software was installed on a Lenovo laptop (Intel Evo Platform Core) to display the EEG readings from the Emotiv Epoc X device.

The video of the dance choreography for the virtual phase of the experiment was recorded on an Apple iPhone. During the experiment, the video was played from the Lenovo laptop and projected onto a 30-inch computer monitor.

This study enrolled 8 people (with minimal or no dance training) living in Orange County, California, ranging from ages 8 to 43 years old (4 female and 4 male), with no underlying brain conditions. Each person provided informed consent to participate in the study, and for anyone who was under age 18, their parents provided informed consent. All participants were family members of the same two households that lived across the street from each other. For health and safety reasons, the headsets were sanitized with alcohol solution between each use, and the experimenter and participants wore masks.

The study consisted of two phases: a virtual phase and an in-person phase, conducted in randomized order. In the virtual phase, each participant was asked to sit still wearing the EEG headset and watch a pre-recorded video of a dance teacher demonstrating a simple dance routine and try to learn and memorize the movements by passive observation. The EEG sensors were placed over the sensorimotor cortex of the brain, which is the area from one ear to the other ear over the top of the head. In the in-person phase, each participant was asked to sit still wearing the EEG headset and watch a different dance routine performed in person by the same dance teacher who demonstrated the routine live and try to learn and memorize the movements by passive observation. In order to make sure that the order in which the dance routines were taught would not be a confounding variable, the order was randomized. For half the participants, the virtual phase was conducted first. For the other half of the participants, the in-person phase was conducted first. The two dance routines were choreographed to be substantially similar in level of difficulty and simple enough for a non-dancer to be able to learn and perform.

Both dance routines in the virtual phase and in-person phase were choreographed to the same popular music by the experimenter and were 30 seconds each. The routines consisted of dance moves standing in one place, mostly using the upper body and minimal use of legs. In both the virtual phase and in-person phase, the participant was instructed to simply watch the dance routine, while the EEG waves in their brains were recorded and stored for analysis. Then at the end of each phase, the EEG headset was removed and the participant was asked to perform the routine to the best of their ability from memory. Each participant's performance of the routine was scored by the experimenter on a 5-point rubric to measure how well the dance movements were learned (1 through 5, with 1 reflecting no proficiency and 5 reflecting expert proficiency) (**Table 1**). Between phase 1 and phase 2, the subjects were given a short 10-minute break to eliminate the possibility of fatigue affecting the results of the performance evaluation. After placing the EEG headset on the participant's head, the 14 electrode sensors had to be properly placed in the optimal position to be able to pick up the brain signals. When connected to the headset, the Emotiv software indicated how well the headset was connected (0–100% connection). Because the focus of this experiment was on the mu rhythms in the parietal cortex, the P7 and P8 sensors had to show 100% connection. Participants were instructed not to talk or make any movements while wearing the EEG headset because something as simple as itching or shifting in your seat could skew the brain wave readings.

The mu rhythm power of the brain was measured during the two phases of the experiment: the in-person phase and virtual phase. In **Figure 1A**, the electrode shaded green is electrode P7. Electrode P8 resides on the opposite side of the head mirroring the position of electrode P7. These are the electrodes that detected and recorded mu rhythm activity.

During the virtual and in-person experiments, the brain waves were recorded using the Emotiv software, which automatically calculated and saved the recordings onto a Microsoft Excel spreadsheet. After the experiments, the Excel data for each participant was transferred to a Google Sheet. Each participant's spreadsheet included thousands of rows of brain wave data broken up into columns by power bands for each of the 14 electrodes. I was interested in the alpha frequency in the P7 and P8 sensors, which indicated mu rhythm activity, and calculated the average alpha band power appearing in the brain waves of those sensors.

All data was organized in Google Sheets, all graphs were made in Google software, and all statistics were performed using built-in Google packages. For each experimental group, the measure of center was represented as a mean, and the variation within the group was represented as a standard error. P-values were calculated using two-tailed, paired sample t-tests. A p-value was considered statistically significant if it was less than 0.05 ($p < 0.05$).

One of the eight participants was excluded from downstream analysis as an extreme outlier (e.g., 2–3 times higher mu rhythm power during the experiment). A reason this participant may have been an outlier is that they appeared particularly distracted and fidgety during the experiment and incidentally, this person was the only left-handed participant. Therefore, it was not possible to determine whether the EEG data for this participant would accurately reflect mirror neuron activity, as opposed to another confounding variable. Accordingly, the results in **Figures 2A** & **2B** and **3A–3D** reflect a sample size of $n = 7$.

ACKNOWLEDGMENTS

I would like to thank senior mentor, Leigh-Ana Rossitto, for her guidance on this research paper and her dedication to teaching me about neuroscience. I would also like to acknowledge my school science teacher, Marissa Mares, for the passion she has inspired in me for science and all her support throughout my research project. Finally, I am grateful to the editors of the Journal of Emerging Investigators for their rigorous review and feedback in the publication of this paper.

Received: February 26, 2021
Accepted: May 9, 2021
Published: August 19, 2021

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