

NEURAL MECHANISMS OF CHOREOGRAPHIC MEMORY: AN EEG STUDY ON DANCE
LEARNING AND RECALL



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NEURAL MECHANISMS OF CHOREOGRAPHIC MEMORY: AN EEG STUDY ON DANCE
LEARNING AND RECALL

A Senior Comprehensive Project

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Abstract

While dance is a fundamental aspect of human culture and communication, its neural basis remains underexplored. To address this gap, this study aims to investigate the neural mechanisms underlying dance learning and recall through electroencephalography (EEG). This study recruited participants with dance experience to view seven short video clips while wearing an EEG cap. Participants engaged in mental imagery between each clip for 30 seconds, visualizing themselves performing the choreography. After all the clips were viewed, participants attempted to physically perform the choreography from memory. EEG analysis focused on alpha, beta, theta, and gamma frequencies to compare neural activity during video observation and mental imagery. Results revealed a significant increase in alpha power during mental imagery compared to video watching, particularly in posterior regions (PO4 and P8), suggesting enhanced cognitive processes related to memory recall and motor planning. A paired samples t-test confirmed this difference ($p < .001$). Additionally, alpha power during video watching and mental imagery were strongly correlated ($p < .001$). No significant power changes were found in the theta, beta, and gamma ranges. These findings suggest that mental imagery engages neural circuits involved in memory encoding and movement planning, highlighting the potential of EEG to reveal neural processes underlying choreographic memory. Future research should explore the impact of marking, verbal rehearsal, and larger, more diverse samples to enhance our understanding of dance learning mechanisms.

Introduction

Whether you realize it or not, dance is an integral part of everybody's daily life. We all begin our journey the same way, moving instinctively from even before birth (Hackney, 1999). The interconnectedness of our human experience is established at the very start of our lives, as the rhythms of movement we share patterns that shape our existence. As Hackney (1999) explains, movement has fundamental aspects, including change, relationship/connection, and patterning body connections (Hackney, 1999). Firstly, everything is constantly changing. Life is a process; we should enjoy constant change because it all leads to something. Change is inevitable, or we can force change if we want something to happen. Secondly, we are surrounded by relationships, whether with people or ourselves. Relationships start within ourselves and our bodies, and relationships develop with others and the world. Lastly, as mentioned before, we are all connected by patterns, specifically the patterns of life. Even though we are not the same person, the way our bodies function and execute movements can be very similar from person to person (Hackney, 1999). These fundamental principles highlight the deep-seated role of movement in shaping human interaction and experience.

Beyond movement, creativity is a fundamental aspect of life that adds to our daily lives in everything we do (Daud et al., 2012). More specifically, creative intelligence is the ability to cultivate something new and to reshape something that was previously for someone's benefit (Fuster, 2013). In science, creativity is what cultivates new studies, ideas, and theories that lead to new discoveries (Daud et al., 2012; Fuster, 2013). This imaginative drive is not confined to laboratories or artistic pursuits—it is embedded in all aspects of human expression, including dance.

Dance, in particular, is included in certain aspects of our lives, such as physical behavior, culture, social behavior, political behavior, and psychological impacts (Foster et al., 2023). Most importantly, dance is a profound way to communicate with others (Foster et al., 2023). It acts as a bridge across cultures and stands as one of the most natural forms of expression, accessible to anyone regardless of background or ability. Dance is a universal language and a shared human activity that transcends cultural boundaries (Hänggi et al., 2010). Through movement, we convey emotions, stories, and connections that resonate deeply within us, fostering understanding and solidarity in an increasingly complex world (Foster et al., 2023).

Despite its universal nature, dance has not been extensively studied in the neuroscience field due to its complexity. As of 2023, there remains a significant gap in research combining neuroscience and dance; nine articles have been published on the neuroscience of dance performance, ten on the neuroscience of auditory processing directly relevant to dance, and only 61 studies have been published on the neuroscience of dance training (Foster et al., 2023). This reveals a rich area for future exploration in this specific field.

Some research connects aerobic movement and dance with neuroscience, highlighting its potential to benefit various physical and mental health aspects as people age. For instance, dance has been shown to improve cognition and memory when practiced as little as once a week for 60 minutes over an extended period of time (Ayari et al., 2023). Another study found that engaging in structured dance practice for at least six weeks can significantly enhance psychological and cognitive health, potentially outperforming other forms of physical activity in improving emotional well-being, depression, motivation, social cognition, and specific aspects of memory (Yan et al., 2024). Additionally, maintaining dance practice throughout life or accumulating

multi-year experience can prevent the decline of motor functions, cognition, and perceptual abilities, potentially delaying age-related deterioration (Kattenstroth et al., 2010).

Furthermore, a 6-month study involving aerobic exercise (dance and walking) demonstrated positive changes in brain white matter regions, which are associated with cognitive impairment and Alzheimer's disease (Mendez-Colmenares et al., 2021). These findings suggest that dance can serve as a preventative measure to combat cognitive impairments and potentially Alzheimer's disease. Dance is particularly effective because it engages attention and motivation (Cramer et al., 2011). These two major factors are required for neuroplasticity to occur, or the brain's way of adapting, organizing, and changing its neurochemical structure, which can ultimately lead to memory and cognition improvements (Cramer et al., 2011).

Dance Processes

Consider the complexity of human behavior we experience daily, thinking about how we communicate with each other using all of our senses, processing what someone has said in our memory, and using previous knowledge to create a response to give to the person in a matter of seconds. Dance itself involves many complex processes and behaviors, including but not limited to sensory, motor, cognition, emotional, social, rhythmic, and creativity (Basso et al., 2021), which all also occur in a matter of seconds or less (Bläsing et al., 2012). More specifically, dance is linked to many cognitive functions, such as imagery, attention, short and long-term memory, problem-solving, and declarative and procedural memory (Basso et al., 2021). This study will examine various types of memory processing involved in learning choreography, emphasizing the role of music as well.

For instance, spatial cognition and auditory processing are essential for dancers (Ladda et al., 2020). First, there is a very high level of spatial cognition in dance to make sure each limb is

placed in the correct spot at the proper time in a piece of music, which stems from the proprioceptive information being sent from the body's muscle sensory organs (Ladda et al., 2020). Proprioception is the ability to perceive the location and movements of our body parts (Blum et al., 2024). It has been found that dancers have an enhanced ability to combine proprioceptive information from multiple joints, which ultimately allows them to develop a more precise and complete sense of their limbs' position in space than non-dancers (Jola et al., 2011).

Visuospatial memory further supports dance learning by enabling dancers to recall spatial relationships and movement sequences (Bläsing et al., 2012). This capacity helps them visualize body positions and movement patterns, facilitating performance accuracy. Within spatial cognition, dancers also rely on spatial perception to ensure proper positioning within choreographed group formations (Ladda et al., 2020).

Additionally, visuomotor imagery—the mental simulation of movement—plays a key role in spatial transformation and memory retention, reinforcing both short- and long-term memory processes (Bläsing et al., 2012). For example, dancers often use visuomotor imagery to create a mental image while cultivating new choreography or to repeat steps in their head to improve their memory of choreography and imagine a mental image of themselves doing the steps (Cross et al., 2009). It simultaneously engages the cortical neural networks similar to those associated with the actual movement (Bläsing et al., 2012) and visual areas such as V1 and/or V2 (Sewards, 2011). Studies demonstrate that mental imagery can improve motor performance when paired with physical practice (Bläsing et al., 2012). For example, a study analyzed spatial navigation while doing a pirouette, and dancers were more inclined to use kinesthetic and mixed imagery styles to facilitate their preparation for the pirouette (Golomer et al., 2008). In this current study, visuomotor imagery will be used during mental rehearsal when the participants

visualize themselves performing the movements. They will engage their long-term memory as they recall and combine all the video clips they will view into a cohesive sequence (Bläsing et al., 2012). Immediate procedural memory will also operate in conjunction with short-term memory to assist in translating the viewed dance movements into physical action.

Dance is also unique due to its intricate auditory processing of music while synchronizing coordinated movements of each limb and muscle simultaneously. When there is music, the dancer uses their auditory processing to make sure they move their body accurately to the correct tempo or rhythm (Ladda et al., 2020). To have accurate rhythmic coordination, three cognitive-motor skills are required: adaptation, anticipation, and attention (Bläsing et al., 2012; Ladda et al., 2020). In dance, these skills contribute to the temporal processing that can happen in a tenth of a second, which is the speed at which it needs to occur to appeal to the audience and perform with the music (Keller et al., 2014). Temporally dictated movements are referred to as representations that dictate when and how specific movements are executed to be sure there is a correct flow within the rhythm or choreography (Ladda et al., 2020). These processes occur in the ventral premotor cortex and Broca's area, a brain structure that facilitates speech fluidity (Ladda et al., 2020).

It is common for dancers to learn a choreography sequence by observing someone else, which activates our mirror neuron network, including the inferior parietal and premotor cortices (Bläsing et al., 2012). Mirror neurons have been hypothesized to be a part of more extensive neural networks, also known as cognits (Fuster, 2013). When learning from mirroring, you are using your mirror cell network, which is simultaneously adding to the cognit(s) involved in learning choreography (Fuster, 2013). Mirror neurons also play a vital role in the perception-action cycle, a process that links sensory perception to motor actions in a continuous

feedback loop (Fuster, 2013). The perception-action cycle is crucial while dancing because it underpins the coordination between sensory input and motor output (Fuster, 2013), enabling dancers to move fluidly, respond to their surroundings, and interact with others.

Moreover, cognitive maps are extremely useful for making people aware and building their spatial environment to help form the memory of the actions they are doing while dancing (Sewards, 2011). The cognitive map becomes increasingly intricate and valuable as dancers encounter and must remember various spatial positions while performing (Gallistel, 2008). This cognitive mapping process has been found to occur in the hippocampus and medial temporal lobe areas of the brain (Sewards, 2011). The formation of cognitive maps in dance involves integrating tactile, proprioceptive, and kinesthetic information along with environmental stimuli (Palmiero et al., 2019). Research on cognitive mapping shows that dancers with early childhood training develop topographic brain maps more efficiently than non-dancers (Palmeiro et al., 2019). These dancers also demonstrated greater accuracy and speed in identifying body parts, suggesting that early dance experience enhances the development of the body's topographical map (Palmeiro et al., 2019). This heightened body awareness further contributes to dancers' movement-based creative thinking, or motor creativity, enabling them to generate more creative, unique, and varied movements faster than non-dancers (Palmeiro et al., 2019). Dancing can improve body awareness, which is a type of cognitive map that helps people integrate their bodies with their environment (Gallistel, 2008; Namboodiri & Stuber, 2021; Palmeiro et al., 2019).

Ultimately, dance relies on the seamless integration of sensory, motor, and cognitive processes. Sensorimotor control—combining sensory perception with precise motor execution—is critical to achieving technical proficiency and artistic expression in dance (Bläsing

et al., 2012). By investigating the memory processes involved in learning choreography, this study will contribute to a deeper understanding of how dance engages multiple cognitive systems, particularly in relation to music.

EEG and Dance

An electroencephalogram (EEG) is used to measure neuronal activity in signals at the scalp surface, commonly while the subject is experiencing a stimulus or completing a task (Biasiucci et al., 2019). Specifically, in dance, EEG can provide fine temporal resolution details that can supply researchers with insight into how dance training impacts the action observation system (“mirror neurons”) and simulation processes (Bläsing et al., 2012). Brain waves are rhythmic signals in the brain, each measuring only a few microvolts (Abhang et al., 2016).

There are five commonly recognized types of brain waves. First, alpha frequencies (8-12Hz) reflect visuomotor processing and mental imagery and are suppressed when participants are relaxed (Abhang et al., 2016) yet are engaged in cognitive tasks. More specifically, the alpha band can represent heightened attention and active task engagement (Perez et al., 2024). Second, beta (12-20Hz) is linked to motor control, movement execution (Khanna & Carmena, 2017), and conscious cerebellar learning (Abhang et al., 2016). The prominence of this wave is associated with high attention and anxiety, while suppression relates to poor concentration instances such as daydreaming (Abhang et al., 2016). Third, gamma (30-50Hz) is associated with higher cognitive functions and sensorimotor integration when the participant has high levels of concentration (Abhang et al., 2016; Terlouw et al., 2016). Fourth, theta (4-8Hz) is associated with memory encoding and retrieval (Perez et al., 2024), particularly working and episodic memory and cognitive effort, such as deep attention and inward focus (Abhang et al., 2016). For memory encoding and retrieval to occur, there must be neural synchrony between the

medial prefrontal cortex and the hippocampus (Basso et al., 2021). Theta, when in its optimal state, can aid creativity and intuition and make us feel more authentic (Abhang et al., 2016). Additionally, the coupling between these frequency bands indicates coordination across systems. For example, theta-gamma coupling can occur when working memory is activated (Perez et al., 2024), indicating coordination between memory systems and executive functions. Fifth, the delta wave (0.5-4 Hz) is most active when asleep (Abhang et al., 2016).

Despite these general classifications, there have been conflicting results in this field regarding what each band is involved in while dancing due to the complex amount of cognitive processes involved (Angelopoulou et al., 2023; Bazanova et al., 2008; Ermutlu et al., 2015; Nakano et al., 2021; Poikonen et al., 2018; Orgs et al., 2008). Notably, it has been shown that EEG activity in the alpha frequency band is sensitive to creativity-related actions (Bazanova et al., 2008). Specifically, it has been concluded that EEG alpha activity varies as a function of the creative demands of a task; the more innovative a task, the higher the level of alpha activity in the bilateral frontal and right posterior cortical sites (Basso et al., 2021; Fink et al., 2007). Similarly, an increase in gamma synchronization in the right anterior superior temporal gyrus has been thought to represent the “AHA moment” (intuition moment) creative thinkers have (Basso et al., 2021). Furthermore, years of dance training have been associated with more significant alpha and beta activity in the premotor and inferior parietal regions (Ermutlu et al., 2015), suggesting a relationship between dance expertise and neural oscillatory patterns (Cross et al., 2009).

Contrastingly, other studies challenge the notion that alpha power consistently increases during dance. Poikonen (2018) discovered that theta frequencies were heightened in the fronto-central electrodes of musicians and dancers while viewing a contemporary dance, while

the alpha band decreased during dynamic movements compared to still movement. Furthermore, Orgs et al. (2008) conducted a study involving contemporary dancers that showed that the alpha and beta frequencies react differently depending on the familiarity with the dance moves they watched in a video. There was a stronger desynchronization in the motor cortex in the dancers compared to non-dancers while viewing contemporary movements and daily movements (Orgs et al., 2008).

Overall, while most studies suggest an association between dance and increased alpha power, there is also significant evidence indicating that other frequency bands—such as beta, gamma, and theta—may play crucial roles in coordinating the cognitive and motor demands of dance. Evidence is more consistent regarding the alpha frequency than the beta, theta, and gamma frequencies. For example, a previous study associated familiarity with gamma, appreciation with beta, and attention with alpha, yet these are not set-in-stone representations (Nakano et al., 2021). Additionally, another study examining differences in brain activity in professional dancers while observing a dance video stimulus found that participants demonstrated a more active alpha frequency along with synchronous activity across the theta, beta, and gamma bands (Angelopoulou et al., 2023).

At the same time, the observed discrepancies in research findings may be attributed to differences in study designs and the specific tasks participants performed. For instance, studies showing alpha power increases often link it to tasks involving relaxation or mental imagery, whereas those emphasizing beta or gamma activity tend to investigate motor execution, sensorimotor coordination, or attentional processes. This variation suggests that the neural oscillatory patterns during dance may be task-dependent, with different frequency bands supporting specific cognitive and motor functions.

EEG and Music

Several EEG studies have targeted music-processing areas (Malekmohammadi et al., 2023; Mikutta et al., 2014). For example, an EEG study reveals multiple bands of activity while listening to the first movement of Ludwig van Beethoven's 5th Symphony. During high arousal, professional musicians had mid-frontal theta activity and posterior alpha, central delta, and beta rhythm activity (Mikutta et al., 2014). Another study has shown that listening to familiar music can induce inhibition of the alpha and beta frequencies, particularly in nonmusicians (Malekmohammadi et al., 2023).

Additionally, EEG studies have examined the relationship between music and dance (Nakano & Rosario, 2021; Nakano et al., 2021; Wind et al., 2020). For instance, Nakano and Rosario (2021) investigated electrocortical activity in dancers and non-dancers. They found that high alpha differences were observed in dancers compared to non-dancers while listening to three different types of music (rock, classical, and waltz) accompanied by a dance imagery stimulus. In another example, an EEG study between dancers and non-dancers showed increased activity for preferred music compared to non-preferred music in the gamma, beta, and alpha frequency bands; the initial alpha decrease and later alpha increase were more robust and more sustained in dancers than in non-dancers (Nakano et al., 2021). Further supporting this connection, a jazz dance study revealed that physically executing the dance with music and imagining the dance with music led to fewer increases in the alpha frequency; meanwhile, imagining the dance without music decreased all frequency bands (Wind et al., 2020).

Current Study

This study focuses on the brain processes while learning choreography. There is a lack of research in the dance and neuroscience field, specifically about how choreography is processed

in a dancer's memory. Participants with experience in dance will wear an EEG cap while watching short clips of original choreography containing 2 to 3 steps in each video. Between each video, the participants will imagine themselves repeating the steps they just watched with their eyes open for 30 seconds. This will occur for seven videos. Once the trials are finished, the EEG cap will be removed, and the participants will have two minutes to physically review (without viewing the videos again) the choreography they just learned in preparation for a physical performance test. The participants will perform what they remember and will be scored for accuracy.

Based on previous research, it is hypothesized that 1) within the alpha band, alpha increases will occur in both tasks (video watching and mental imagery), reflecting cognitive processing and visuomotor engagement; 2) the beta band, typically associated with motor-related processes, will show increased power during the video watching and mental imagery task, indicating engagement of motor areas; 3) the theta band may be engaged during the working memory processes while participants hold the movements in mind, representing memory encoding and retrieval, during the video task and mental imagery task; 4) the gamma band may be relevant when participants integrate mental rehearsal with physical execution during the mental imagery task.

Method

Participants

Fifteen participants were recruited through SONA, and email invitations were sent to campus dance organizations to invite volunteers. Data was collected in a single 1-hour session. Participants were current Allegheny College students, at least 18 years old, with a minimum of five years of recent dance experience—preferably in ballet, modern, contemporary, or jazz—or

involvement in a campus dance organization such as Orchesis Dance Company, Jazz Dance Ensemble, or the Allegheny College Dance Team. Additionally, inclusion criteria were prior familiarity with the song “Party In The U.S.A.” by Miley Cyrus and female participants only. The participants received 3 Sona credits (1 credit for every 20 minutes). They were put into a raffle for a \$15 gift card to a preferred local business as compensation for volunteering in the study. Once recruited, participants were told to show up to the study wearing clothes they were comfortable dancing in. Informed written consent was also collected from the participants, and study procedures were approved by the Institutional Review Board (IRB) before the study was conducted.

Design

This study employed a within-subjects repeated measures design to investigate how participants process and recall dance choreography through both mental imagery and physical performance. Each participant completed the same tasks individually during the time slot they signed up for, and their performance was measured at multiple stages. The independent variable was the learning process of choreography (video-viewing, mental imagery, and performance), and the dependent variables were neural activity during viewing and mental imagery and later performance accuracy. Since each participant completed all tasks in the same sequence, the study allowed for within-subject comparisons to assess how effectively participants process and retain the choreography. This repeated-measures design controlled for individual differences and provided a clear understanding of how memory and motor imagery contribute to the learning and performance of dance sequences.

Choreography

Seven original clips were choreographed, 4-8 seconds each, containing 2-3 steps. The steps were beginner from the contemporary, ballet, and jazz genres. There was a variety of videos showcasing each genre. Contemporary, ballet, and jazz dances are commonly used genres in dance education, making them highly familiar to all experienced dancers. Each participant viewed the same set of videos.

Additionally, a familiarity questionnaire informed the primary researcher what they were most proficient in to see how they reacted differently to learning the video choreography compared to someone proficient in that genre. I choreographed in a 9'x10' room to keep the space contained, as the performance area for the participants was a similar size. The choreography was set to "Party In The U.S.A." by Miley Cyrus.

Procedure

Pre-Task

The task sequence can be seen in *Figure 1*. Before starting any of the tasks, participants were guided through the Informed Consent Form to ensure they fully understood the study and their role in it (Appendix A). Also, consent was obtained to record participants' physical performance test attempts. After consent was obtained, the participants completed a familiarity test based on the framework outlined by Ivaldi et al., 2017. This 14-item questionnaire aimed to gather comprehensive information about each participant's dance experience, such as their proficiency in various dance genres and how often they engage in dance activities (Appendix B; Ivaldi et al., 2017). The results of this questionnaire were instrumental in tailoring the data analysis and identifying any variations in how participants with differing levels of expertise process choreography. While the participants completed the test, setting up the EEG equipment

began, ensuring that data collection could proceed smoothly once the tasks began. This initial assessment helped contextualize each participant's background, offering insights that could have influenced their memory retention and motor imagery during the study. After completing the pre-task questionnaire and setting up the EEG cap, a presentation went through the directions. Hence, the participant fully understood the sequence of the study (Appendix C). The PowerPoint presentation contained instruction slides for the participant to review the sequence of the study, followed by a pre-made video that included the seven dancing video clips with a 30-second mental imagery break between each clip.

Task One

The first task was to view seven short, 4-8-second videos of myself dancing. The steps were beginner-level, such as jazz square, pas de bourree, a turn, chase, etc., and varied in genre. Each video contained different steps, and occasionally, there was a step repeated throughout all seven clips to examine if they remembered the correct sequence of steps. For instance, one video contained a jazz square and a turn, the second video contained a pas de bourree and a chase, and the third video contained a pas de bourre and another pirouette (Appendix E). From the video, there were 2-3 steps to remember from each video to create a sequence by the end. The music was played with each video clip to act as a cue for the participant's memory of the physical performance. The song started from the second chorus: "My tummy's turnin', and I'm feeling kinda homesick." The participants were informed before the first task that they would need to be prepared to mimic the choreography, consistent with the typical process of learning new choreography.

Task Two

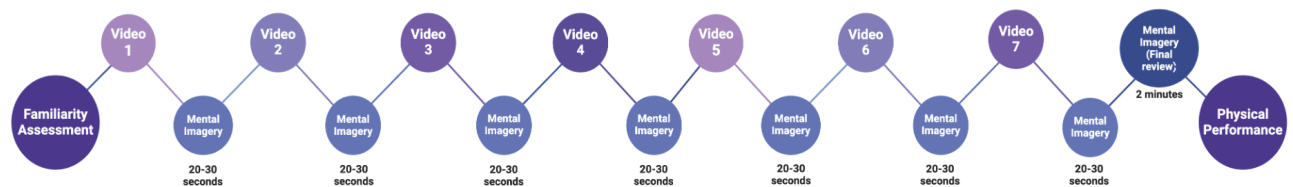
In the second task, in between each 4-8-second video, the participants were asked to keep their eyes open and create a mental image of themselves doing what they just viewed in the video, using their visuomotor imagery skills. They were asked to look at a black screen and instructed to imagine themselves rehearsing the movements in the video clip they just viewed. The participants were instructed to only follow the specific choreography from the video to reproduce it from their memory; no improvisation when imagining was allowed, and attention *only* to the choreography viewed was encouraged. Participants were told to stay as still as possible to avoid excessive motion so the EEG was not disrupted. They had 30 seconds to envision themselves performing the movements they had just watched. After 30 seconds, the following dance video clip was shown, repeating this process until all seven dance clips had been viewed and the mental imagery periods were complete. The video clips, including dancing and mental imagery periods, were presented through a cohesive video using PowerPoint.

Task Three

After completing the previous tasks, the EEG cap was removed. After the removal of the EEG cap, participants were given a two-minute opportunity to review the choreography without music prior to the physical performance test. After the two-minute review, the participants were recorded performing what they remembered. They were instructed on when to start dancing when the music was playing to ensure they started at the correct time in the song. During the physical performance test, participants were assessed on their accuracy of the choreographed steps to assess long-term memory. Assessment guidelines were based on correctness in each step, not technique. They were scored out of twenty steps. The participants performed the choreography in a 9' x 10' space outside of the testing room in Carnegie Hall at Allegheny College. After

completing the study, the participants were allowed to wash their hair due to the excess gel from the EEG cap placement. Finally, before the participants were excused to leave, they were given a Debrief Form and asked whether or not they would like to participate in the raffle drawing (Appendix D).

Figure 1



Note. Visualization of the study sequence for the participants.

EEG Acquisition

The EEG data for this study was collected using the BioSemi ActiveTwo EEG system from Cortech Solutions. The system included 32 active pin-type Ag/AgCl electrodes (BioSemi Pin Active Electrodes), which were mounted in an elastic head cap following the international 10-20 system (BioSemi Headcap). Data was collected through ActiView to ensure signal quality, with electrode impedances kept below 10 k Ω . The EEG signal was amplified online and continuously digitized at a sampling rate of 1000 Hz.

For the analysis, MATLAB (MathWorks) was used in combination with the EEGLAB toolbox (ver 2023) for data processing and analysis. EEGLAB, as detailed by Delorme and Makeig (2004), is an open-source toolbox designed for analyzing single-trial EEG dynamics (Journal of Neuroscience Methods, 134:9-21). The data, post-collection, was taken through preprocessing before analysis.

EEG data were filtered with a lower edge set to 1 Hz to remove low-frequency noise and re-referenced to enhance signal clarity. The data was then resampled to 128 Hz to reduce file size and computational load while retaining relevant frequency information. Non-data channels were removed to focus the analysis on the relevant channels (channels 1-32). The data was epoched into 6-second intervals (0 to 6 seconds) to ensure consistent durations across trial types (viewing and imagining). Artifacts were identified and removed using independent component analysis (ICA), following the guidelines of Lopez-Calderon and Luck (2014). ICA was performed to isolate and eliminate components related to eye blinks, saccades, and other noise sources. After ICA, epochs and channels with excessive noise were manually inspected and rejected to ensure clean data for further analysis. The range of trials removed was 0-2, and the average amount removed was one. The range of channels removed was 0-1, and only two participants had channels removed due to excessive noise.

Data Analysis

Time-frequency analysis (TFR) was used to measure the task-evoked event-related synchronization (ERS) across test phases to analyze the EEG data (Nakano et al., 2021). Task-specific segments included EEG data during the viewing of each 4-8-second video and EEG data during the 30-second mental imagery period. The TFR was applied to analyze changes in EEG frequency bands while participants observed the dance movements and focused on how the brain activity differs when participants mentally rehearse the movements they just observed. The average frequency band power across the epoch was examined in each channel and plotted topographically. Significant channels ($p < 0.05$) were then examined using event-related spectral perturbations (ERSPs) to identify how power changes across all frequency bands (2-30 Hz) over

the first 3 seconds of the epoch. Frequency bands were defined as: alpha (8-12 Hz), theta (2-7 Hz), beta (15-30 Hz), and gamma (30-50 Hz).

Additionally, a within-subjects paired samples t-test was performed to examine the difference between the dancers while viewing the video and mentally performing compared to at rest. A correlation analysis was performed to investigate whether there is a relationship between EEG patterns during mental rehearsal and participants' subsequent performance accuracy. A separate correlation analysis was conducted to examine the relationship between EEG activity during video watching and EEG activity during mental imagery. Lastly, a regression analysis was conducted to determine whether differences in EEG activity predict performance accuracy, and a simple regression analysis was used to assess whether prior dance experience predicts performance accuracy.

Results

EEGLAB Analysis

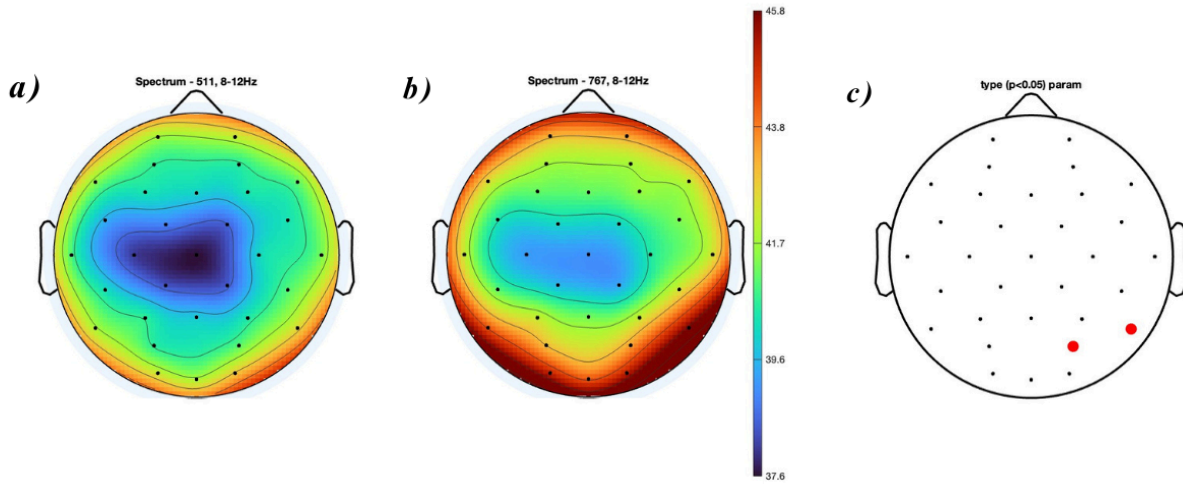
Although 15 participants completed the study, one participant had to be excluded due to insufficient data collected. To examine differences in brain activity between video observation and mental imagery, a spectral analysis of EEG data was first conducted in all frequency bands ($n=14$). After thorough analysis, the results did not fully support each hypothesis that was made. No significant power change was found in the theta, beta, and gamma ranges.

However, one hypothesis was supported regarding the alpha band. In posterior electrodes, there was a statistically significant difference in alpha power (8-12 Hz) when comparing the video-watching period to the mental imagery period, specifically in PO4 and P8 (Figure 2). The observed increase in alpha power during mental imagery supports the hypothesis that mental rehearsal engages cognitive networks associated with memory recall and motor planning.

In Figure 2a, we see that choreography viewing shows weaker alpha power centrally and posteriorly, represented by the dark blue/black in the center, suggesting overall lower activation. This alpha desynchronization (reduction in power) suggests greater external attentional engagement (Klatt et al., 2022) as participants visually processed the dance sequences.

Figure 2b illustrates higher alpha power across the scalp during mental imagery, represented by the warmer colors, particularly an increase in the peripheral regions, including the parietal and occipital regions. Increased alpha synchronization suggests a shift toward internally focused cognitive processes (Benedek et al., 2014; Ivaldi et al., 2017), consistent with mental rehearsal and movement visualization.

In Figure 2c, the significant differences in the right posterior regions, centered over the parietal-occipital areas, suggest that mental imagery engages these regions differently than passive video observation. The parietal cortex is heavily involved in visuospatial processing and movement planning (Andersen & Cui, 2009), which could indicate increased engagement during mental imagery. This aligns with the role of the parietal cortex in motor planning and working memory (Andersen & Cui, 2009), supporting the idea that mental imagery recruits brain networks involved in actual movement execution.

Figure 2

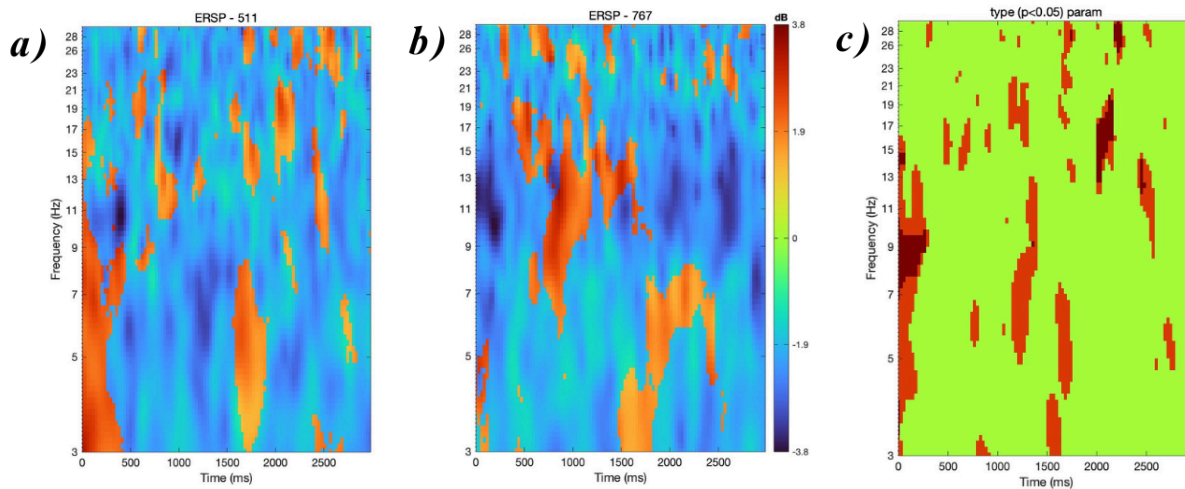
Note. Topological maps of mean alpha power during **a)** video watching and **b)** mental imagery conditions. **c)** The plot highlights electrodes with significant differences ($p < 0.05$) between conditions (PO4 and P8).

In the Event-Related Spectral Perturbation (ERSP) plots (Figure 3), power differences were analyzed across the same conditions in the significant channels from the spectral plots (PO4 and P8) ($n = 14$). The ERSP results in significant channels reveal key neural activity differences between video watching and mental imagery during dance sequence learning. In video watching (Figure 3a), significant alpha (8-12 Hz) desynchronization (blue areas) is observed, particularly around 9-11 Hz, which can indicate heightened attentional engagement and sensory processing as participants visually perceive choreography.

In contrast, the mental imagery (Figure 3b) exhibits significant alpha synchronization (red/yellow areas), particularly in the later time frames (1000-2000 ms). This increase in alpha power suggests a shift from external stimulus processing to internalized cognitive and motor

planning mechanisms, which are critical for memory consolidation and movement rehearsal. The statistical significance map (Figure 3c) highlights the key differences between the two conditions. There are notable clusters in the alpha and low-beta (13-15 Hz) ranges. The early time window during the video watching shows strong desynchronization, reinforcing the role of sensory encoding. At the same time, the later mental imagery period exhibits synchronization, supporting its role in motor simulation and preparation. These results suggest that mental imagery engages neural circuits relevant to motor learning, with alpha synchronization potentially facilitating the consolidation of dance sequences.

Figure 3



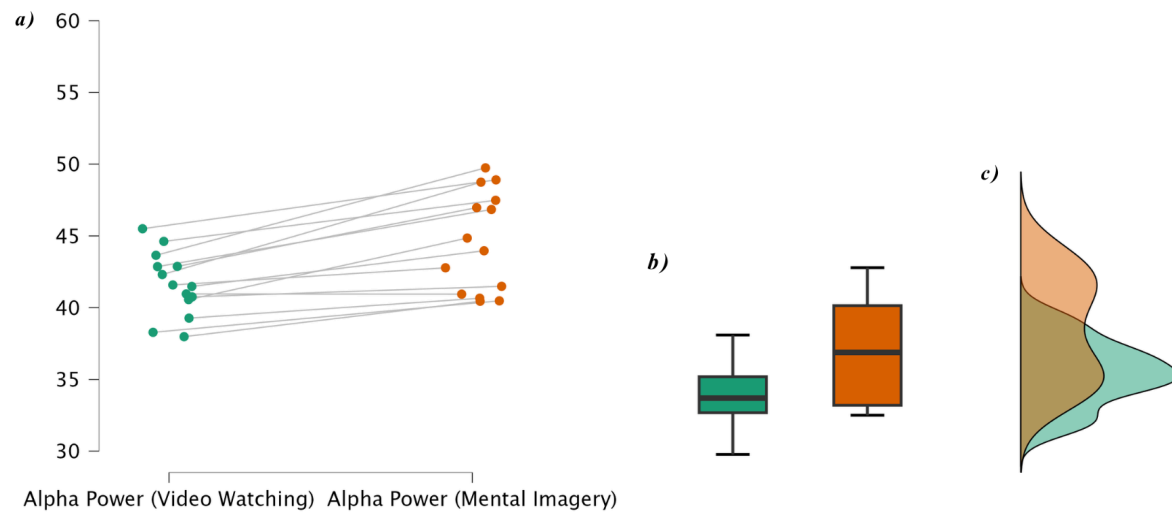
Note. Event-Related Spectral Perturbation (ERSP) plots. **a)** Left panel (ERSP-511), spectral changes during the video-watching period. **b)** Middle panel (ERSP- 767), spectral changes during the mental imagery period. **c)** Right panel (statistical differences), areas of significant differences between conditions, with red indicating frequency-time points where power differs significantly between video-watching and mental imagery.

Correlational Analysis with Behavior

To examine whether mental imagery engages different neural mechanisms compared to video watching, a paired-samples t-test was conducted on alpha power (dB) ($n=14$) (see Figure 4). Alpha power values represent the average across EEG electrodes PO4 and P8. The results

showed a significant difference between the two conditions, $t(13) = -5.87, p < .001$, and Cohen's $d = -1.57$. The t -value indicates that alpha power during mental imagery ($M = 44.59, SD = 3.48$) was significantly higher than during video watching ($M = 41.62, SD = 2.22$). The effect size (Cohen's $d = -1.57$) suggests a large effect, indicating a substantial difference in alpha power between conditions. These findings suggest that mental imagery induces significantly higher alpha power compared to passive video watching.

Figure 4



Note. Comparison of Alpha Power During Video Watching and Mental Imagery Conditions. **a)** Raincloud plot. Individual participants' alpha power values are plotted, with grey lines connecting paired values. Most lines trend upward, indicating higher alpha power during Mental Imagery. **b)** Boxplots. The median, interquartile range, and whiskers are displayed for each condition. Higher and more variable alpha power is evident during Mental Imagery. **c)** Density Plots. Overlapping distributions show a rightward shift for Mental Imagery, reflecting increased alpha power compared to Video Watching.

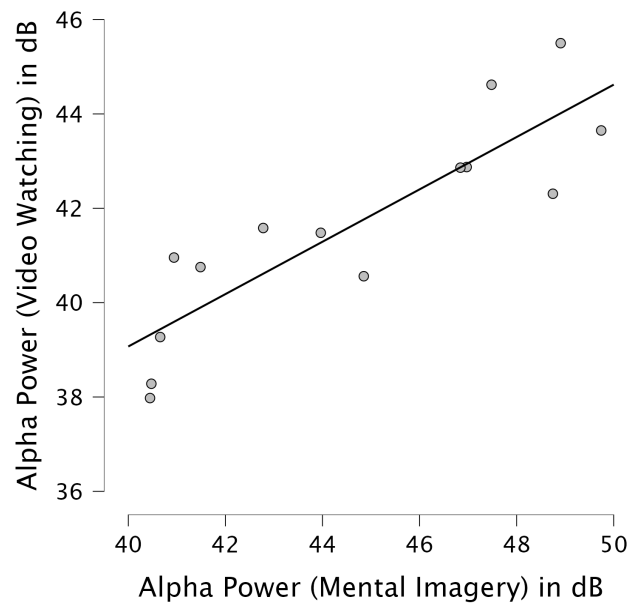
To examine whether alpha power during mental imagery was related to performance accuracy, a Pearson correlation was conducted between alpha power during mental imagery and performance accuracy ($n = 14$). On average, participants achieved 66.05% accuracy ($M = 13.21, SD = 4.12$). The results indicated no significant correlation, $r(12) = -0.07, p = .82$, suggesting

that alpha power during mental rehearsal was not associated with step accuracy. A similar correlation was conducted between alpha power during video watching and step accuracy, which also yielded a non-significant result, $r(12) = -0.14, p = .64$.

Given the significant reduction in alpha power from video watching to mental imagery, an additional regression analysis examined whether the difference in alpha power (Mental Imagery – Video Watching) was correlated with step accuracy ($n=14$). This correlation was also not significant, $r(12) = 0.04, p = .90$, suggesting that the extent of alpha power reduction did not predict performance accuracy.

A simple linear regression was conducted to examine whether dance experience (in years) predicts step accuracy ($n=14$). The overall model was not significant, $F(1,12) = 0.97, p = .34$, explaining only 7% of the variance in step accuracy ($R^2 = .07$, Adjusted $R^2 = -.00$). The regression coefficient for dance experience was not statistically significant ($\beta = 0.27, p = .34$), indicating that dance experience does not significantly predict step accuracy in this dataset.

A Pearson correlation analysis was conducted to examine the relationship between alpha power during video watching (dB) and alpha power during mental imagery (dB) ($n=14$) (see Figure 5). The results revealed a strong positive correlation, $r(12) = 0.87, p < .001$, indicating that individuals with higher alpha power during video watching also tended to have higher alpha power during mental imagery. Supplemental tables can be found in Appendix F.

Figure 5

Note. Scatterplot illustrating the correlation between Alpha Power during Mental Imagery (dB) and Alpha Power during Video Watching (dB). Each point represents an individual participant's alpha power measurements in both conditions. There is a strong positive correlation, $p < .001$.

Discussion

Current Study

This study aimed to investigate the neural mechanisms underlying the learning and retention of dance choreography, contributing to the limited research at the intersection of dance and neuroscience. Specifically, this study aimed to explore how mental imagery and video observation influence motor memory retention by analyzing changes in EEG activity during both tasks. By examining neural oscillations, particularly in the alpha frequency range (8-12 Hz), this study sought to determine how visualization and internal rehearsal contribute to choreography learning.

The results of this study revealed significant differences in alpha power between the video-watching and mental imagery conditions. During video watching, there was a pronounced alpha desynchronization (power reduction), particularly in posterior regions, indicating active

sensory processing and attentional engagement while observing the choreography. This aligns with prior research showing that alpha desynchronization reflects increased external attentional engagement and sensory processing (Bläsing et al., 2012). In contrast, mental imagery resulted in increased alpha synchronization (power enhancement), especially in the right parietal-occipital region. This pattern suggests a shift from externally focused attention to internally driven cognitive processes, supporting the role of mental rehearsal in memory encoding and movement planning.

The ERSP analysis further confirmed these findings by demonstrating significant alpha power differences over time. The strongest alpha desynchronization occurred in the early time window (0-500 ms) of video watching, which aligns with heightened attentional engagement in processing visual movement sequences. Conversely, alpha synchronization during the later stages of mental imagery (1000-2500 ms) suggests that participants actively engaged in motor simulation and consolidation of the choreography. This finding aligns with previous studies indicating that alpha power increases are associated with internally directed attention, memory consolidation, and motor planning (Basso et al., 2021; Bläsing et al., 2012).

Interestingly, although there were significant differences in alpha power between video-watching and mental imagery, no significant differences were found in the theta, beta, or gamma ranges. This strong correlation suggests that power in other frequency bands is relatively stable across both conditions, implying that individuals may have consistent neural activity patterns regardless of whether they are watching a video or mentally rehearsing movements. However, the previously reported paired samples t-test indicated a significant overall reduction in alpha power during mental imagery, meaning that while alpha power generally decreases during mental imagery, the relative ranking of individuals remains consistent across conditions.

Additionally, the lack of significant findings in these other bands suggests that the tasks performed in this study primarily engaged cognitive processes reflected in the alpha band (Fink et al., 2009). Alternatively, it is possible that these other cognitive processes are engaged equally across both conditions, resulting in no detectable differences in power. Future research could further investigate the roles of theta, beta, and gamma bands during video-watching and mental imagery to better understand their contributions to dance learning and motor memory formation. This is particularly relevant given the hypothesis that mental imagery would engage motor-related processes (beta band) and working memory encoding and retrieval (theta band). Furthermore, future research could investigate the potential contributions of these bands by using different task designs or additional measures to capture a broader range of cognitive processes.

One possible explanation for the patterns observed in alpha power during the video-watching and mental imagery conditions is the involvement of mirror neurons. Mirror neurons, which are activated both when an individual performs an action and when they observe someone else perform that same action, might play a significant role in both action observation and mental rehearsal (Bläsing et al., 2012). The increased alpha desynchronization during video watching could reflect the activation of the mirror neuron system as participants observe the choreography. This neural system may facilitate imitation and motor learning by simulating the observed actions in the brain, even before performing them physically (Stefan et al., 2005). Similarly, during mental imagery, participants may engage mirror neurons to mentally simulate the movements, aiding in memory consolidation and motor planning. This connection suggests that the brain's motor systems, including the mirror neuron network, may be integral to both action observation and mental rehearsal in the context of dance learning (Stefan et al., 2005).

These findings have several implications for dance pedagogy and motor learning strategies. First, the results reinforce the importance of mental imagery as a tool for enhancing motor memory. Dancers and choreographers often use mental rehearsal techniques to retain and refine movement sequences, and the increased alpha power observed in this study suggests that internal visualization actively engages brain regions responsible for motor planning and memory consolidation (Cross et al., 2009; Bläsing et al., 2012). Training programs that incorporate structured mental rehearsal could improve dance retention, particularly in settings where physical practice time is limited.

A common strategy dancers use to help remember choreography in real-time is called marking—a technique in which dancers use their hands to mimic choreography while learning (Bläsing et al., 2012). Marking allows dancers to encode movement patterns without performing them at full capacity, helping to preserve energy while reinforcing muscle memory (Warburton, Wilson, Lynch, & Cuykendall, 2013). An example of this is twirling your finger to represent a turn without actually physically doing the turn with the whole body (Warburton et al., 2023). It is particularly beneficial for recalling movement sequences or specific steps as a rehearsal tool. However, to ensure participants remained as still as possible while memorizing choreography, they were explicitly instructed not to use marking during the study. This restriction was necessary to maintain a clean EEG signal, as excessive movement could introduce artifacts and disrupt data quality.

Another widely used strategy for learning choreography is verbal rehearsal, where dancers say the names of steps or describe movements aloud to reinforce memory (Bläsing et al., 2012). Although participants were not explicitly instructed to stay silent during the study, only one participant was observed whispering the names of the steps while watching the video clips.

Notably, this participant achieved a perfect step accuracy score, suggesting that verbalizing movements enhanced their ability to retain the choreography. This finding aligns with prior research indicating that verbal rehearsal aids encoding, yet this is not specific to dance learning (Bläsing et al., 2012). Specifically, labeling steps verbally or mentally engage the phonological loop, a component of working memory responsible for retaining verbal information over short periods (Papagno et al., 2017). Given that the total duration of the video viewing and mental imagery period in this study was four minutes, it is plausible that the phonological loop contributed to the short-term retention of the choreography. Additionally, the phenomenon of using the verbal system and visual system to encode memories defines the dual coding theory (Bi, Y., 2021; Cornoldi et al., 2008). Dual coding could be useful to dancers who are learning, memorizing, and performing choreography. A future direction could be to include a post-study questionnaire asking participants about their mental rehearsal strategy. For example, asking if they used verbal cues or purely visual imagery and then further analyzing whether those who naturally apply dual coding (visual and verbal) perform better would strengthen the findings.

These findings suggest that both marking and verbal rehearsal could influence how dancers encode and recall movement sequences. Future studies could investigate how these strategies interact with motor memory by comparing EEG activity in conditions where participants are allowed to mark or verbalize choreography versus when they are restricted from doing so. Such research could provide deeper insight into the cognitive mechanisms underlying dance learning and memory.

Limitations

One major limitation of this study is the small sample size. The study included 15 participants who met the inclusion criteria, requiring recent or previous dance experience and

familiarity with the song "Party in the USA" by Miley Cyrus. While all participants had dance experience, the duration of experience varied significantly, ranging from 8 to 19 years.

Additionally, the type of dance training was not standardized, as participants were only required to have at least five years of recent dance experience—preferably in ballet, modern, contemporary, or jazz—or to be actively involved in campus dance groups. This broad criterion could contribute to variability in participants' familiarity with the choreography. Notably, all but one participant had ballet experience, which may have positively influenced memory retention, as the choreography incorporated beginner-level ballet movements. This familiarity could have made the sequence easier for participants with ballet training to recall, potentially skewing the results.

Another limitation involves the physical space available for performing the choreography. The lab space, while sufficient for minimal movement, was restricted in size. A larger area would have allowed participants to perform the choreography more realistically, providing a fuller execution of movements and potentially enhancing engagement and recall. This limitation may have influenced movement quality and overall engagement with the choreography, possibly impacting their performance accuracy.

Additionally, the study exclusively included female participants (assigned female at birth), which limits the generalizability of the findings. The imbalance in gender representation reflects a common demographic trend in dance, where female dancers outnumber male dancers. In 2022, 75.4% of dancers were female, while only 24.6% were male (Data USA, 2022). However, this lack of diversity restricts the study's ability to identify potential sex-based differences in motor learning and memory. A comparative analysis between male and female dancers could provide valuable insights into whether neural mechanisms differ between genders.

during dance learning and recall. Expanding the sample to include male participants in future studies would enhance the generalizability of the findings.

Furthermore, the influence of music as a cue remains unclear. While some participants appeared to follow the music's rhythm, others did not synchronize their movements to the music. Interestingly, during the lyrics “Movin’ my hips like, yeah,” many participants swayed their hips side to side, corresponding to the last steps of the choreography—this intentional design aimed to test whether participants would associate specific lyrics with related movements. However, beyond this example, the music did not appear to serve as a cue for most participants, suggesting limited effectiveness in guiding choreography recall.

Performance accuracy was also inconsistent across participants. Only one participant accurately mimicked the choreography with correct timing throughout the sequence. Another participant demonstrated accurate timing but lacked perfect step accuracy. Most participants started with the correct timing during the first video clip but progressively sped up, resulting in a mismatch between their movements and the music. This variability in performance suggests that timing accuracy may be influenced by factors beyond neural activity, such as familiarity with the song, choreography difficulty, or personal rehearsal strategies (Bläsing et al., 2012).

These limitations should be addressed in future studies to strengthen the validity and applicability of the findings. Enhancing the standardization of participant experience, broadening demographic representation, and providing a more suitable performance environment could contribute to a more comprehensive understanding of the neural mechanisms underlying dance learning and recall.

Conclusion and Future Directions

To investigate how expertise influences neural activity during dance learning and recall, future research could benefit from increasing the sample size and including a more diverse range of dancers, from novices to experts. This approach could offer deeper insights into how dance experience impacts choreography memorization compared to individuals with less training.

Additionally, expanding the use of imaging techniques could enhance our understanding of how the brain processes choreography. Complementing EEG findings with methods such as fMRI or MEG would provide greater spatial resolution of the brain regions involved in dance learning and recall, particularly areas like the motor cortex, basal ganglia, and cerebellum (Basso et al., 2021; Bläsing et al., 2012; Cross et al., 2008). Another promising avenue involves incorporating mobile EEG technology, allowing participants to perform dance sequences while wearing the EEG cap throughout the study (Foster et al., 2023; Theofanopoulou et al., 2024). This would enable researchers to capture real-time neural activity during dance execution rather than only during the memory task (Theofanopoulou et al., 2024).

Another future research topic could investigate how marking and/or verbal rehearsal influences the consolidation of choreographic memories. For example, Warburton et al. (2013) examined how marking confers processing benefits that enhance subsequent performance, finding that movement reduction supports this process. Their work suggests that marking can alleviate cognitive load, supporting more efficient encoding and consolidation (Bläsing et al., 2012). However, this has not been completely proven. To explore this further, future studies could examine the neural mechanisms underlying this process and systematically investigate how marking influences memory consolidation. While dancers in the current study were unable to mark or engage in physical movement while wearing the EEG cap, it could be interesting to

examine how marking affects choreographic memory when using a more mobile EEG system that allows for movement while maintaining a clean signal (Foster et al., 2023; Theofanopoulou et al., 2024).

Furthermore, future research could explore how music and emotion influence choreography learning and whether they benefit dancers (Foster et al., 2023). This study was not well-equipped to determine whether music acted as a cue for dance recall, suggesting an opportunity to examine how auditory and emotional cues might enhance motor memory retention (Angelopoulou et al., 2023; Basso et al., 2021; Foster et al., 2023; London et al., 2016; Toader et al., 2023).

Overall, insights from this research could advance our understanding of embodied cognition and inform strategies to improve motor learning and memory retention in dance and broader movement-based practices. While research at the intersection of dance and neuroscience is gradually gaining attention, a substantial gap exists in the literature (Foster et al., 2023). Bridging these fields is essential because understanding the neural mechanisms underlying dance learning and memory could lead to innovative developments in how movement can enhance cognitive function (Bläsing et al., 2012; Foster et al., 2023). For example, this knowledge could be applied to therapeutic strategies aimed at improving memory, motor skills, and emotional well-being in various populations, including those with neurodegenerative diseases, brain injuries, or mental health conditions (Bläsing et al., 2012; Foster et al., 2023).

Additionally, this research holds practical implications for current dancers seeking to enhance their training and performance (Foster et al., 2023). By understanding how mental imagery and marking contribute to motor memory retention, dancers can more effectively incorporate these techniques into their practice routines (Ladda et al., 2021). This could improve

efficiency in learning choreography, refining movements, and enhancing overall performance quality (Ladda et al., 2021). Moreover, applying neuroscience principles to dance training could offer dancers valuable insights into optimizing their learning processes and achieving more consistent results.

Integrating dance-based interventions with neuroscience could also enhance rehabilitation protocols and optimize motor training techniques for dancers, athletes, and patients undergoing physical therapy. Continued research in this area could ultimately contribute to developing new, evidence-based methods that harness dance's cognitive and motor benefits to improve quality of life and cognitive health across the lifespan.

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*Appendix A**Informed Consent***Informed Consent**

Neural Mechanisms of Choreographic Memory: An EEG Study on Dance Learning and Recall

Allegheny College

Department of Psychology and Neuroscience Program

Purpose of Research: The purpose of this study is to examine how the brain processes and retains choreography, adding to the limited research at the intersection of dance and neuroscience. Specifically, it aims to explore the neural mechanisms underlying the learning and memory of dance sequences by using EEG to monitor brain activity in real time. By imagining dancers performing choreography immediately after watching it and later performing it from memory, the study seeks to understand how visualization and mental rehearsal contribute to motor memory retention and recall accuracy. Insights from this research could enhance our understanding of embodied cognition and offer potential applications for improving motor learning and memory retention in dance and broader movement-based practices.

Method/Procedure: I understand that during the study, I will wear an EEG cap while watching seven short video clips (each 4-8 seconds long) of choreography, with a 20-30-second mental imagery period between each clip. Once all videos and mental imagery tasks are completed, the EEG cap will be removed. I will then have two minutes to stand up and physically practice the choreography sequence. After this, I will perform the sequence, which will be recorded for scoring purposes, using the song “Party in the USA” by Miley Cyrus. At the end of the study, I will have the option to wash my hair to remove any (non-harmful) excess gel residue from wearing the EEG cap.

Length of Participation: I understand that the study will take approximately 45 minutes to 1 hour to complete.

Risks to the Individual: I understand that there will be no more risk other than what is normally experienced in everyday life. There may be discomfort associated with the EEG cap while it is being put on, specifically while the gel is being put on, or taken off.

Benefits of the Research: I understand that this research will address the gap in understanding how the brain processes choreographed movement, particularly the cognitive and motor processes involved in dance. I can gain a better understanding of how my brain responds to learning and recalling choreography. This awareness might help identify the mental strategies that work best for my unique learning styles, potentially improving my own approach to practicing and remembering movement sequences.

Compensation: I understand that I may receive 1 Sona credit for every 20 minutes (estimated up to 3 credits) and have the choice to be put into a raffle for a \$15 gift card to a preferred local business as compensation for volunteering in the study.

Confidentiality, Recording Information, and Data Security: I understand that information provided by participants will be kept anonymous or confidential. Data will be stored on password-protected computers and Google Drive folders accessible only to the investigators and secured with two-factor authentication. Identifying information will be stored separately from any data collected. The data, including any recordings, will be stored and protected, will only be accessed by the researcher and principal investigator, and data will be destroyed (one year after the publication of results/at the end of the spring 2025 semester). Participants may receive a summary of the study's results by email from the primary researcher once the study is completed and if they are interested.

Voluntary Nature of Participation: I understand that I do NOT have to participate in this research project. Furthermore, I may choose to withdraw my participation at any time without penalty. I understand that I may skip any individual questions or tasks that I do not wish to complete, and I may choose not to participate in any part of the study without being questioned. I understand that I am 18 or older.

Results of Research Project: I understand that I am entitled to a copy of the results once this study is completed (summary available by email).

Contact Information: If I have any questions about this research project, I can contact Lily Kons at kons01@allegheny.edu or the research advisor, Dr. Warren, at kwarren@allegheny.edu. If I have questions or concerns about the treatment of research participants in this IRB-approved project, I can contact the Chair of the Allegheny Institutional Review Board (IRB) at IRB@allegheny.edu.

I understand that my signature(s) below indicate(s) that I am at least 18 years of age at the time of my participation in this study, and that I have received a copy of this informed consent form. I have carefully read and understood the information on this form and all of my questions thus far have been answered.

I agree to participate in the study.

Participant's Signature

Date

Participant's Name (print)

I agree that this interview may be recorded/transcribed

Yes

☐

No

☐

Researcher's Signature

Date

*Appendix B**Familiarity Assessment***Familiarity Assessment**

Name _____ Age _____ Grade _____

Please answer the following questions:

Do you have any dance-related experience? NO YES If yes, for how many years? NO YES

What genres of dance have you studied?

What genre do you enjoy the most?

Are you in any dance groups on campus (Orchesis, JaDE, Dance Team, etc.)? NO YES

If yes, which one(s)?

Have you attended any dance courses at Allegheny College? NO YES

If yes, which one(s)?

Do you play an instrument? NO YES

If yes, what instrument(s)?

Do you have any prior musical or non-dance training? NO YES

If yes, select all that apply from the following:

Vocals

Orchestra

Band

Cheer

Gymnastics

Color guard

Other:

What kind of music do you listen to? (genre(s))

Have you heard the song “Party In The U.S.A.” by Miley Cyrus? NO YES

Appendix C

Presentation for Participants

Welcome to my study!

1.

Instructions Overview:

1. Watch the dance video clip.
2. After the clip, a white screen will appear. You will have 30 seconds to imagine yourself dancing what you just watched. Keep your eyes OPEN when imagining!
3. After 30 seconds, the next dance clip will play.
4. This will repeat until all 7 clips are played. In each 30 second period, add the choreography that was just viewed to make a sequence with the clips previously watched.
5. After all clips are played, you should have a full choreographic sequence in your head.
6. After removal of the EEG, you will have 2 minutes to stand up and review the choreography.
7. I will then record you performing the dance with music. You will not be scored on technique, only step accuracy.
8. The end!

2.

Sequence of the study:



3.

4. Slide containing video

*Appendix D**Debrief***Research Participation Debriefing Form**

Neural Mechanisms of Choreographic Memory: An EEG Study on Dance
Learning and Recall
Department of Psychology and Neuroscience

Purpose of Research: The purpose of this study is to examine how the brain processes and retains choreography, adding to the limited research at the intersection of dance and neuroscience. Specifically, it aims to explore the neural mechanisms underlying the learning and memory of dance sequences by using EEG to monitor brain activity in real-time. By imagining dancers performing choreography immediately after watching it and later performing it from memory, the study seeks to understand how visualization and mental rehearsal contribute to motor memory retention and recall accuracy. Insights from this research could enhance our understanding of embodied cognition and offer potential applications for improving motor learning and memory retention in dance and broader movement-based practices.

Compensation: I understand that I may receive 3 Sona credits and have the choice to be put into a raffle for a \$15 gift card to a local business of choice (Cup and Spoon, French Creek Coffee and Tea Co., or Kettle Lake Kitchen) as compensation for volunteering in the study.

Confidentiality: The data you provided for this research project will be confidential and your name will never be associated with your results. Furthermore, the data will be destroyed one year after the study's conclusion.

To Learn More: For further information about this topic, please consult the following sources:

- Bläsing, B., Calvo-Merino, B., Cross, E. S., Jola, C., Honisch, J., & Stevens, C. J. (2012). Neurocognitive control in dance perception and performance. *Acta Psychologica*, 139(2), 300–308. 10.1016/j.actpsy.2011.12.005
- Foster Vander Elst, O., Foster, N. H. D., Vuust, P., Keller, P. E., & Kringelbach, M. L. (2023). The neuroscience of dance: A conceptual framework and systematic review. *Neuroscience & Biobehavioral Reviews*, 150, 105197. 10.1016/j.neubiorev.2023.105197
- Nakano, H., Rosario, M. M., & De Dios, C. (2021). Experience affects EEG event-related synchronization in dancers and non-dancers while listening to preferred music. *Frontiers in Psychology*, 1210.3389/fpsyg.2021.611355

Contact Information: If you have any questions about this research project, please consult the information below:

Experimenter: Lily Kons E-mail: kons01@allegheny.edu

Faculty Advisor: Dr. Kristen Warren E-mail: kwarren@allegheny.edu

If you would like a copy of the results of this research study, please fill this out and return it to the researcher.

I would like to receive a summary of the results of this study.

Yes ☐ No ☐

If yes, what is your Allegheny email?

If yes, what is your Box #? _____

Raffle? : Yes ☐ No ☐

*Appendix E**Sequence of Choreography with Corresponding Lyrics***Dance Steps for Each Video Clip and Corresponding Lyrics**

“My tummy’s turnin’ and I’m feelin’ kinda homesick

Too much pressure and I’m nervous”

Video 1: Jazz square starting with the right foot, and a prep and pirouette on the right side

“That’s when the DJ dropped my favorite tune

And a Britney song was on”

Video 2: Chase with a ball change to the right and chase ball change to the left

“And a Britney song was on

And a Britney song was on”

Video 3: Tombe to the right, pas de bourree to the right, and a pirouette on the right side

“So I put my hands up

They’re playin’ my song, the butterflies fly away”

Video 4: Balance to the right and pique arabesque to the left

“I’m noddin’ my head like yeah

Movin’ my hips like, yeah”

Video 5: Land in parallel second position and bend upper body to the left side and right side

“I got my hands up, they’re playin’ my song

They know I’m gonna be okay”

Video 6: Head roll and step with right foot front, and kick left foot out and step back to parallel

“Yeah, it’s a party in the U.S.A.”

Video 7: Standing with legs hip-width apart, sway hips side to side with the corresponding arm and then

take two steps and end with small jump

*Appendix F**Additional Statistical Figures***Table 1:***Descriptive Statistics For Each Condition*

	Alpha Power (Video Watching)	Alpha Power (Mental Imagery)	Step Accuracy	Dance Experience (years)
Valid	14	14	14	14
Missing	0	0	0	0
Mean	41.62	44.59	13.21	14.93
Std. Deviation	2.22	3.48	4.12	3.50
Minimum	37.98	40.45	5.00	8.00
Maximum	45.50	49.74	20.00	19.00

Table 2:*Paired Samples T-Test Between Alpha Powers*

Measure 1		Measure 2	t	df	p	Cohen's d	SE Cohen's d
Alpha Power (Video Watching)	-	Alpha Power (Mental Imagery)	-5.8 7	1 3	< .001	-1.57	0.20

Note. Student's t-test.**Table 3:**

*Linear Regression Between Step Accuracy, Alpha Powers, and Dance Experience***Model Summary - Step Accuracy**

Model	R	R ²	Adjusted R ²	RMSE	R ² Change	F Change	df1	df2	p
H ₀	0.00	0.00	0.00	4.12	0.00		0	13	
H ₁	0.35	0.13	-0.14	4.39	0.13	0.48	3	10	0.70

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
H ₁	Regression	27.61	3	9.20	0.48	0.70
	Residual	192.75	10	19.27		
	Total	220.36	13			

Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p	Collinearity Statistics	
							Tolerance	VIF
H ₀	(Intercept)	13.21	1.10		12.01	<.001		
H ₁	(Intercept)	21.78	24.98		0.87	0.40		
	Alpha Power (Video Watching)	-0.87	1.15	-0.47	-0.76	0.47	0.23	4.37

Alpha Power (Mental Imagery)	0.49	0.75	0.42	0.66	0.53	0.22	4.58
Dance Experience (years)	0.38	0.37	0.33	1.04	0.32	0.90	1.11

Collinearity Diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				(Intercept)	Alpha Power (Video Watching)	Alpha Power (Mental Imagery)	Dance Experience (years)
H ₁	1	3.96	1.00	0.00	0.00	0.00	0.00
	2	0.04	9.85	0.00	0.00	0.00	0.80
	3	2.43×10 ⁻³	40.36	0.57	0.00	0.18	0.15
	4	3.98×10 ⁻⁴	99.70	0.43	1.00	0.82	0.05

Note. The intercept model is omitted, as no meaningful information can be shown.

Table 4:

Paired Samples T-Test For Alpha Powers

Measure 1		Measure 2	t	df	p	Cohen's d	SE Cohen's d
Alpha Power (Video Watching)	-	Alpha Power (Mental Imagery)	-5.87	13	< .001	-1.57	0.20

Note. Student's t-test.

Table 5:*Linear Regression Between Step Accuracy and Dance Experience***Model Summary - Step Accuracy**

Model	R	R ²	Adjusted R ²	RMSE
H ₀	0.00	0.00	0.00	4.12
H ₁	0.27	0.07	-0.00	4.12

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
H ₁	Regression	16.50	1	16.50	0.97	0.34
	Residual	203.85	12	16.99		
	Total	220.36	13			

Note. The intercept model is omitted, as no meaningful information can be shown.

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
H ₀	(Intercept)	13.21	1.10		12.01	<.001
H ₁	(Intercept)	8.40	5.00		1.68	0.12
	Dance Experience (years)	0.32	0.33	0.27	0.99	0.34

Table 6:*Pearson's Correlations Between Alpha Power (Video Watching) & Alpha Power (Mental Imagery)*

Variable		Alpha Power (Mental Imagery)	Alpha Power (Video Watching)
1. Alpha Power (Mental Imagery)	Pearson's r	—	
	p-value	—	
2. Alpha Power (Video Watching)	Pearson's r	0.87	—
	p-value	< .001	—

Table 7:*Pearson's Correlation Between Alpha Power (Mental Imagery) & Step Accuracy*

Variable		Alpha Power (Mental Imagery)	Step Accuracy
1. Alpha Power (Mental Imagery)	Pearson's r	—	
	p-value	—	
2. Step Accuracy	Pearson's r	-0.07	—
	p-value	0.82	—

Table 8:*Pearson's Correlation Between Alpha Power (Video Watching) & Step Accuracy*

Variable		Alpha Power (Video Watching)	Step Accuracy
1. Alpha Power (Video Watching)	Pearson's r	—	
	p-value	—	

2. Step Accuracy	Pearson's r	-0.14	—
	p-value	0.64	—

Table 9:*Pearson's Correlations Between Alpha Power Difference and Step Accuracy*

Variable		Alpha Power Difference	Step Accuracy
1. Alpha Power Difference	Pearson's r	—	
	p-value	—	
2. Step Accuracy	Pearson's r	0.04	—
	p-value	0.90	—

* $p < .05$, ** $p < .01$, *** $p < .001$