# EEG Coherence Within Tutoring Dyads: A Novel Approach for Pedagogical Efficiency

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**Abstract.** The current study examined EEG coherence across Coach-Learner dyads on a spatial reasoning video game, Tetris®, using an event-locked psychophysiological synching platform. We hypothesized that (1) an intra-individual increase in Theta and a decrease in high Alpha (10-12 Hz) fronto-temporal coherence would occur across increasing difficulty levels, and (2) inter-individual fronto-temporal coherence in high Alpha would increase among lower skilled players. A sample of n = 5 healthy dyads completed the protocol with each learner playing 3 rounds of Tetris®. Across all participants (low-skilled and high-skilled), the intra-individual preliminary results presented herein indicate significant elevation in fronto-parietal coherence. Moreover, the low-skilled players experienced an increase in Theta coherence and high Alpha coherence–the latter not as expected from literature. The high-skilled players had significant reductions in fronto-parietal high Alpha coherence and small increases in Theta. The inter-individual (coach-learner) dyadic coherence results for the low-skilled player showed increased Theta coherence for Coach-Frontal: Learner-Parietal (CF:LP), with no significant change in high Alpha. Meanwhile, an increase in high Alpha coherence was observed in the Coach-Parietal: Learner-Frontal (CP:LF). The high-skilled player experienced decreased Theta coherence for CF:LP, with no significant change in high Alpha, yet a substantial increase in Theta coherence and decrease in high Alpha coherence was observed for CP:LF. These data support the application of coherence analyses for the improvement of pedagogical approaches and provide optimism that further granulated explorations of the data herein could lead to a more thorough understanding of the dynamics of dyadic learning.

**Keywords:** EEG · Coherence · Dyads · Education · STEM

## 1 Introduction

Recent pushes to enhance efficiency and efficacy of learning for those involved within Science, Technology, Engineering, and Mathematics (STEM) have encouraged more innovative approaches in teaching, including intelligent tutoring, through the integration of psychophysiology, cognitive processes, and many other factors associated with the learning process. As these approaches are explored, experimental investigations into the underlying constructs of such processes are also being utilized to advance pedagogical research. Researchers have begun to utilize visio-spatial based video games, including Tetris®, as a platform for understanding how to effectively train


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individuals' decision-making, problem solving abilities, and increase skill acquisition speed [1, 2],. Tetris® provides an open ended platform that requires optimal attention, perceptual processing, decision making, working memory, and processing speed in order to perform at the highest levels [3].

In recent decades, these processes have been linked with neuronal coherence, a measure of synchrony that taps into both increases in power and phase locking. Neuronal coherence is typically calculated across two brain sites within an individual, using EEG [4, 5], MRI [6–8], and MEG [5]. Coherence analysis utilizing EEG signals enables high resolution of temporal changes, and is associated both with changes in phase coupling and power across regions. The cross-correlation approach of coherence utilizes pairs of signals as a function of frequency in order to provide a means for identifying and isolating frequency bands at which the EEG displays between-channel synchronization [9]. Elevated coherence in parietal Gamma (35-60 Hz) have been shown in both human and animal models to be related to attention processing and prioritization [10, 11], while over the somatosensory cortex, it appears to be related to attentional modality shifting [11, 12]. Higher executive function processes, such as the complex executive processing that occurs during working memory (e.g. encoding and retrieval), have also been associated with neuronal coherence; these are found primarily in the fronto-parietal regions, with elevations in Theta coherence and suppression of high Alpha coherence as the working memory load increases [13, 14]. These findings indicate that attention and working memory are reliant, at least in part, on neuronal coherence within an individual.

Recently, we reported that neurophysiological metrics of attention (B-Alert classifier for engagement), and working memory (workload) correlations across coach-learner dyads related to performance variation [15–17]. We were able to predict a significant amount of the variance in performance by the learner in a coach-learner dyad playing Tetris® using the cross correlations of the B-Alert Classification and Workload models [18, 19]. Taken together, these findings lead to the hypothesis that coherence across individuals may provide even more insight into the tutoring/coaching learning process, particularly in a task requiring attention and working memory.

Others have recently begun to explore cross-individual coherence, and found coherence between a listener and speaker is associated with ability of the listener to recall details from a story [20]. Participant listeners with greater coherence to the speaker had the greatest recall ability. While this study utilized MRI, EEG coherence across individuals has also been explored, and been found in both social interactions [21], and in decision making during card games [22]. Of particular interest is the fronto-parietal coherence found between card players by Astolfi and colleagues, as they found inter-individual coherence in the fronto-parietal regions to occur primarily in the Alpha and higher bandwidths. Given that inter-individual coherence in the fronto-parietal regions are associated with complex executive processing in working memory [13], we proposed to examine these relationships more fully.

Here, we expand upon our original reporting to examine a set of N = 5 dyads with both high-skilled and low-skilled learners to investigate the fronto-parietal coherence both within each learner, and across each learner-coach dyad. We predict that (1) given that intra-individual fronto-temporal coherence is related to working memory, this pattern of increased Theta and decreased high Alpha coherence, across increasing level difficulty, will be present, and (2) that due to the need for the lower skilled player(s) to rely on input from the coach (based on our reported findings [17]), inter-individual fronto-temporal coherence in the Alpha bands will be increased primarily in the lower skilled players.

# 2 Methods

## 2.1 Participants

A sample of N = 6 healthy participants (one coach and 5 learners) were enrolled after screening for the following criteria: having taken college level STEM education within 2 years of the study session, self-report of non-use of excessive stimulants, alcohol, prescription or non-prescription drugs, as well as self-report of no prior or existing medical conditions including psychological and neurological disorders that are known to systematically alter EEG signals. Additionally, participants were required to refrain from the following substances prior to their study session: alcoholic beverages 24 h prior, caffeinated beverages 12 h prior, and nicotine 1 h prior. In conjunction with these requirements, participants were also to refrain from using the aforementioned substances for the duration of their study visit (approximately 2 h). The tutor was selected based on both self-report of Tetris® expertise, regular Tetris game play (5 + hr/week), and subsequent confirmation of high levels of Tetris scoring when tested prior to the onset of the study; the tutor was able to clear more than 10 levels consistently (the maximum cleared by the most expert tutee, indicating the tutor had expertise at or above the best tutee).

The final dataset had a mean age of 22.3 yr (range: 21-23 yr); were educationally balanced (33.33 % in college, 50.00 % having received a Bachelor's degree or its equivalent, 16.67 % having received an Associate's degree); computer expertise balanced (33 % reported being Average (proficient at 3-4 applications), 50 % Intermediates (proficient at 5 + applications), and 16.67 % Experts (proficient at 10 + applications)); and ethnicity and gender diverse (66.67 % female, 33.33 % non-white).

The use of human participants was approved by an Institutional Review Board process consisting of external board members and secondary approval through the Department of Navy, prior to participant recruitment. All participants completed the approved consent form before the initiation of the testing. All participants (including the coach) received compensation ($25/hr) for taking part in the study.

## 2.2 Materials/Equipment

Psychophysiology. Simultaneous and synchronized EEG and ECG were acquired from both the tutor and tutee throughout Tetris® gaming sessions, using the B-Alert® X10 wireless sensor headset connected through the Team Neurodynamics platform shown in Fig. 1 (Advanced Brain Monitoring, Inc, Carlsbad, CA). This system had 9 referential EEG channels located according to the International 10–20 system at Fz, F3, F4, Cz, C3, C4, POz, P3, and P4 and an auxiliary channel for ECG. Linked reference electrodes were located behind each ear on the mastoid bone. ECG electrodes were placed on the right clavicle and the lower left rib. Data were sampled at 256 Hz with a high band pass at 0.1 Hz and a low band bass, fifth order filter, at 100 Hz obtained digitally with Sigma-Delta A/D converters. Data were transmitted wirelessly via Bluetooth to a host computer, where acquisition software then stored the psychophysiological data. The proprietary acquisition software also included artifact decontamination algorithms for eye blink, muscle movement, and environmental/electrical interference such as spikes and saturations.

The architecture for the Team Neurodynamics platform enabled the synchronization of EEG/ECG for each dyad. Each test subject, referred to as an individual node, was hosted on a portable Windows laptop for unobtrusive, wireless, data acquisition. The set-up, shown in Fig. 1, was used for synchronization of data between the individuals (tutor and tutee) with the task environment (Tetris®). The client-server architecture on the Tetris® platform facilitated data aggregation using a common node, the Aggregator Node. The architecture relies primarily on the passing of simultaneous, real-time markers, otherwise known as beacons, to each individual node in order to provide consistent and reliable timing accuracy for the current task. EEG was acquired at each node using an External Sync Unit (ESU). The ESU not only has a Bluetooth receiver, but also an internal timer that is used to precisely timestamp each EEG packet received from the headset. In addition, the ESU also has serial and parallel ports to accept third party events. Thus, the same timer within the ESU synchronizes both EEG and third party events, providing millisecond level accuracy in alignment. The ESUs of the tutee and the tutor were networked via a serial port network in star topology. The Aggregator node functioned as the hub. Through the star network, a custom hub program generated and transmitted periodic beacons, broadcasted to both individual nodes by the aggregator node at regular intervals, with incremental numbering and the option for manual, time synched annotations.

This structure provides a reliable method for managing synchronization, especially if an individual's node falls out of sync. With ongoing, continuous syncing, all data prior to and after a given node could be salvaged if de-synchronization of individual nodes occur. Beacons were broadcast in ASCII code and each subject node received an individual log that could be altered for offline analysis. Manually annotated, time locked events were also output in ASCII format allowing for individualized commentary pertaining to specific session details and/or errors. In addition, the aggregator node uses the beacon intervals to align and decode the EEG with the Tetris® game logging file data from the subject nodes for offline analysis.

**Tetris® Game: Objective and Scoring.** Programmed in Python by Rensselear Polytechnic Institute (RPI), the Tetris® software used in this preliminary study was designed to replicate the classic 1980 s arcade game [23]. The game is played using seven different geometrically shaped "zoids" composed of four square blocks (see Fig. 2). The objective of Tetris is to manipulate each zoid by moving them left and right and, if necessary, rotating 90 degrees in order to create a horizontal line of 10 blocks without any gaps. As each horizontal line is created, it will disappear, which constitutes as a "cleared line". As the game progresses, the levels increase in speed, ultimately ending when the zoids stack all the way to the top of the playing field. Levels were

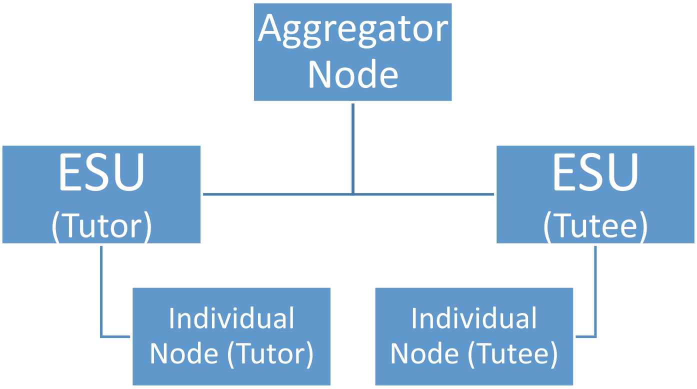


**Fig. 1.** Team NeuroDynamics architecture

automatically advanced as soon as a player met a certain criteria (lines cleared and/or points obtained). To this end, all players started at Level 0 and continued playing until (1) they reached “Game Over” or (2) they ran out of the pre-set 20 min timeframe. Points are earned based on the number of lines cleared at once and the speed at which a block was placed (“soft drop” versus “hard drop”). For maximum point value, a player should aim to obtain a “tetris” which occurs when four lines are cleared in one simultaneous move.

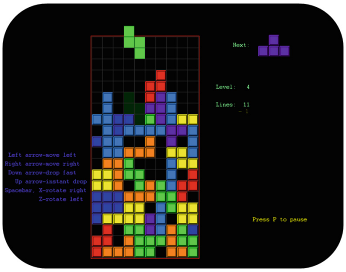


**Fig. 2.** Tetris (R) game screen shot

## 2.3 Protocol

EEG and ECG were acquired throughout the testing session, using the B-Alert® X10 wireless sensor headset (Advanced Brain Monitoring, Inc, Carlsbad, CA). Each dyad was positioned in front of one laptop, where the player was coached on the game of Tetris® for 3 games lasting approximately 15 min (or until the player lost nearest to that goal time). The coach gave advice to increase the player’s skill. Psychophsyiological data was recorded using ABM’s Team NeuroDynamics platform, which synchronized the EEG and ECG with time locked events across each dyad.

### 2.4 Coherence Calculations

Coherence between dyads was computed on a scale of 0 to 1, with 0 being no coherence and 1 being maximum coherence. Due to the variance in skill level and length of game-time between dyads, each player's first two levels of data were averaged and used as the initial starting point which was then compared to the averaged data from their last two levels (ending point). Coherence was then computed by channel to create a one-dimensional array of one average coherence value per channel (in this case, a $1 \times 9$ array). The array was then plotted on a surface map template of the channels on an idealized human head. Coherence was calculated and assessed for intra-individual fronto-temporal Theta and high Alpha using channel pairings: Fz-POz, F3-P3, and F4-P4. For inter-individual fronto-temporal coherence, Alpha was examined across the following parings: Coach Fz-Learner POz, Coach F3- Learner P3, Coach F4-Learner P4, Coach POz-Learner Fz, Coach P3-Learner F3, Coach P4-Learner F4.

## 3 Results

We conducted a preliminary analysis examining the 5 dyads across 3 successive games of Tetris®. These dyads represent a spectrum of skill level in relation to levels completed, total number of lines cleared, and overall score.

### 3.1 Intra-individual Coherence (Within Subject)

We examined fronto-parietal coherence in the learners, based on initial skill level, which resulted in the 2 least skilled players compared to the 3 most skilled. Skill level was driven by overall score and level obtained in game 1 for each player. Low-skilled players reached level 4–5, while high-skilled players reached levels 9–10. First we examined overall coherence differences in the two groups. Consistent with prior findings [13], both low-skilled and high-skilled players had elevated fronto-parietal coherence. However, this did not exist in the midline channels for the highly skilled players. In comparison to the most skilled players, the least skilled players had weaker coherence. In addition, we examined the coherence changes across the game playing period, and found that as play progressed, the most skilled players had large reductions in fronto-parietal high Alpha, and smaller increases in Theta. In contrast, the least skilled players had the expected increases in Theta coherence, but high Alpha coherence also increased. These findings are demonstrated in Fig. 3.

We also examined overall Theta and High Alpha changes over the course of the game play, but found no significant change ($p = .8$). Although, there was a trend in both Alpha and Theta for increased power in both bands for the least skilled players, overall ($p = .06$).

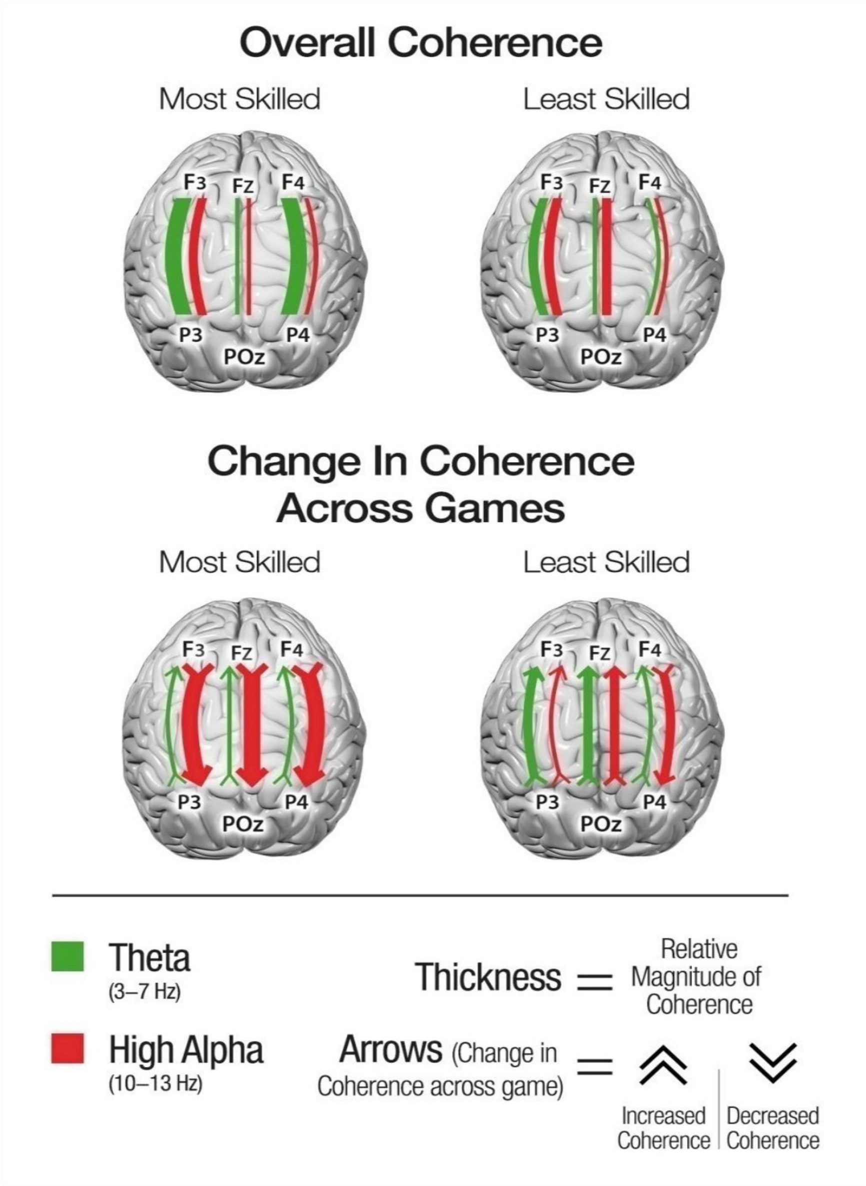


**Fig. 3.** Within individual coherence overall (top) and across game play (bottom) for most skilled player (left) and least skilled player (right).

### 3.2 Dyadic Coherence (Between Coach-Learner)

In contrast to the individual findings, our dyadic coherence results are less consistent with prior findings [22]. For the least skilled players, we found that Theta coherence from the Coach Frontal to Learner Parietal regions was elevated slightly over the course of game play, but Coach Parietal to Learner Frontal was substantially decreased. High Alpha had small decreases in coherence in the latter, but no change in the former. In contrast, Theta coherence between the most skilled player and the coach decreased slightly for the Coach Frontal to Learner Parietal regions, meanwhile there was minimal change in Alpha. Theta coherence increased substantially for the Coach Parietal to Learner Frontal, and Alpha decreased substantially as well. This is in direct contrast to our hypothesis that the dyadic coherence would grow stronger in the least skilled dyads, compared to the high-skilled dyads. Table 1 summarizes these results.

**Table 1.** Percent change in coherence during game play

| | COACH Frontal to LEARNER Parietal | | COACH Parietal to LEARNER Frontal | |
|---|---|---|---|---|
| | *Theta* | *High Alpha* | *Theta* | *High Alpha* |
| Least skilled | 0.51 % | –0.01 % | –1.36 % | –0.44 % |
| Most skilled | –0.30 % | 0.07 % | 1.15 % | –1.81 % |

## 4 Discussion

Coherence analysis is a promising approach for identifying the underlying neurophysiological processes associated with tutored learning. Consistent both with our hypothesis, and prior literature on working memory and fronto-temporal coherence [13], intra-individual Theta coherence was elevated in the fronto-parietal regions. Interestingly, the highest skilled players, as compared to the lowest skilled players, demonstrated the strongest coherence across these regions, which suggests that skill levels may be associated with underlying neurophysiological factors. In contrast to our intra-individual findings, our dyadic coherence results do not support our hypothesis; as play continued, the lower skilled players had weaker fronto-temporal Theta coherence with the coach. Alpha coherence did decrease slightly. Inter-individual results specific to the highly skilled player's dyadic coherence were consistent with our hypothesis, with strong changes in the expected direction for both Theta and Alpha, primarily in the Coach Parietal to Learner Frontal regions.

The current approach examined gross level changes in synchrony, based on coherence, of initial and highest level attained parts of a coached Tetris gaming session. This approach was successful in identifying the changes and relationships of coherence between and across individuals during the gaming session, and appear to delineate highly skilled from lower skilled players. However, we have the ability to examine whether coherence changes are associated with errors by assessing more granular level changes based on time synchronized markers associated with such errors. Furthermore, future analyses may reveal differences in dyad dynamics based on time lapse and error occurrences. For instance, Lerner et al. (2011) found that synchrony of the listener usually occurred slightly behind that of the speaker [20]. The best listener would even occasionally anticipate the moments of synchrony, as if predicting what was coming next in the story [20]. That level of communication could be a marker of optimized learning, although more work is needed before such interpretations are made. Future analysis will also examine other intra- and inter- individual coherence measures associated with cognitive processes in Tetris®, including attention and attentional shifting.

It should be noted that while elevations in synchrony have been associated with increased performance, attention, and overall improved cognitive processing, synchronization comes at a cost in flexibility and adaptation resources to new information that may have long term influence on the efficacy of learning [24, 25]. As such, retention of learned information and skills that occur during the coached sessions should be examined in future studies.

The work discussed herein supports the need for additional exploration of the role of cross-neuronal synchrony, as measured by coherence in identifying effective training and tutoring approaches. If supported by additional research, these findings can be used to objectively assess new intelligent tutoring approaches, as well as drive the development thereof. Inter-individual and intra-individual neuronal synchrony may also be used to identify (1) those most likely to benefit from tutoring; (2) when a learner has maxed the benefits of the current tutor/tutoring session; and (3) at what time training modalities must be adapted to optimize cognitive processing. This study demonstrates the promise of this approach, yet shows the need for subsequent research to replicate and/or expand upon these findings with larger sample sizes.

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