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Does Music Induce Interbrain Synchronization between a Non-Speaking Youth with Cerebral Palsy (CP), a Parent, and a Neurologic Music Therapist? A Brief Report

Kyurim Kang[a,b,c*], Silvia Orlandi[b,d] , Nicole Lorenzen[e], Tom Chau[b],[f] Michael H. Thaut[a, g]

[a] *Music and Health Science Research Collaboratory (MaHRC), Faculty of Music, University of Toronto, Toronto, Canada;* [b] *Holland Bloorview Kids Rehabilitation Hospital, Toronto, Canada;* [c] *Center for Music and Medicine, Department of Neurology, Johns Hopkins School of Medicine, Baltimore, USA**;* [d]*Department of Electrical, Electronic, and Information Engineering "Guglielmo Marconi"- DEI, University of Bologna, Bologna, Italy**;* [e]*School of Engineering, University of Guelph, Guelph, Canada;* [f] *Institute of Biomedical Engineering, University of Toronto, Toronto, Canada;* [g] *Faculty of Medicine, Institute of Medical Science and Rehabilitation Research Institute, University of Toronto, Toronto, Canada*

*Corresponding authors

Kyurim Kang: kkang19@jhmi.edu

** Current affiliation

Does Music Induce Interbrain Synchronization between a Non-Speaking Youth with Cerebral Palsy (CP), a Parent, and a Neurologic Music Therapist? A Brief Report

Shared emotional experiences during musical activities among musicians can be coupled with brainwave synchronization. For non-speaking individuals with CP, verbal communication may be limited in expressing mutual empathy. Therefore, this case study explored interbrain synchronization among a non-speaking CP (female, 18yrs), her parent, and a music therapist by measuring their brainwaves simultaneously during music and storytelling sessions. In only the youth-parent dyad, we observed a significantly higher level of interbrain synchronization during music rather than story-telling sessions. However, in both the youth-parent and youth-therapist dyads, regardless of session type, significant interbrain synchronization emerged in frontal and temporal lobes in the low-frequency bands, which are associated with socio-emotional responses. Although interbrain synchronization may have been induced by multiple factors (e.g., external stimuli, shared empathetic experiences, and internal physiological rhythms), the music activity setting deserves further study as a potential facilitator of neurophysiological synchrony between youth with CP and caregivers/healthcare providers.

Keywords: music, hyperscanning, interbrain synchronization, electroencephalography (EEG), empathy and social interaction, non-speaking Cerebral Palsy (CP)

Introduction

Social interaction can elicit different types of interbrain synchronization that manifest in a diversity of behaviours, such as the unconscious matching of walking cadence with that of another [1] and spontaneous rhythmic alignment of clapping.[2] The phenomenon of interbrain synchronization has also been observed in the neural correlates of empathy and social communication during musical activities. Music plays a significant role in enhancing social bonds, and this enhanced state of music-induced social-emotional empathy may be reflected in a shared neural mechanism between social interaction and music listening, especially to familiar music.[3,4] Music has been used as a therapeutic medium to accomplish individualized goals in motor, cognitive, and emotion based on clinical and scientific evidence (i.e. music therapy). [5] [6] Formal studies of music have shifted from social science to neuroscience as advanced technology allows for the investigation of the underlying neural mechanisms of music perception and production. Besides, the discovery of neural processes in music perception and production that transfer to non-musical functions has led to the establishment of neurologic music therapy (NMT).[7] However, despite strong associations between music and brain activities, their shared neural mechanisms in social interaction have been less studied.

Hyperscanning, which refers to the simultaneous measurement of brain activity in multiple subjects, has allowed researchers to investigate how social-emotional empathy is coupled with neural activities among multiple individuals during musical activities, including guitar duets, [8,9] saxophone quartets, [10] and piano duets. [11] In particular, there is one study that investigated interbrain synchronization between the client and music therapist during a music therapy session. [12] They reported stronger interbrain synchronization when the client and music therapy simultaneously experienced moments of emotional exchange. This finding suggests that interbrain synchronization may serve as a measurement of socio-emotional experiences during therapy sessions. However, the neural mechanisms of emotional experiences in therapeutic relations involving children with disabilities are less known. Non-speaking children with cerebral palsy (CP) often experience difficulties with expressive communication, which may lead to social isolation.[13,14] Communication difficulties limit our understanding of how non-speaking children with CP experience empathy and build social connections, which are critical to psychosocial health. To promote the psychosocial well-being of both children and their parents, accurate assessments of their emotional processing are required.[15]

A previous study confirmed the existence of synchrony between parent and child with severe disabilities and the strengthening of interbrain synchronization over the course of a music therapy session [16] However, the question remains as to whether a child with severe disabilities can also develop this synchrony with a music therapist. Therefore, the present study quantified interbrain synchronization not only in a youth-parent dyad, but also in the corresponding youth-therapist dyad. To measure interbrain synchronization, we calculated Phase Locking Value (PLV), which captures the degree of temporal alignment between two brain signals, for example, from two individuals engaged in social interaction [17] In this regard, the current study aimed at answering three research questions: Are there significant differences in the magnitude of interbrain synchronization: 1) between music and storytelling sessions (as a control condition) in two dyads (Youth-Parent [YP] and Youth-Therapist [YT]) ?; 2) across frequency bands between the two dyads? ; 3) among brain regions between the two dyads?

Materials and Methods

Participant

A non-speaking 18-year-old female participant with quadriplegia CP (Gross Motor Function Classification Level V), her mother, and a certified neurologic music therapist participated in this study. The youth used a powered wheelchair and had very limited control of her body. She was able to follow cues, and her verbal skills were limited to specific words such as “ya” and “mom”. She communicated with an augmentative and alternative communication (AAC) device and was able to express specific emotions with facial or body gestures. There was no known history of neurological or psychiatric illness and no hearing/vision impairments. All participants signed a written consent form prior to the study. The Research Ethics Boards of the hospital and the university approved the study protocol.

Study Design

Demographic data on the youth were collected before the first session. The youth participant and her mother attended four music and four storytelling sessions that were each 18-minutes long (3-minute baseline recording followed by a 15-minute session). The parent sat in a partitioned area and watched her child during the sessions via a live video feed (Figure 1). During the baseline, the youth, her parent, and the neurologic music therapist were asked to sit naturally and quietly with eyes open. During the music session, the therapist played the guitar and sang the youth's favourite songs which were determined by a pre-session questionnaire completed by the parent. The repertoire of each music session consisted of 5-6 songs. The youth's two most preferred songs were played in each session, and two other songs from the youth's favourite songs list were also presented. One or two songs were used to promote engagement (e.g., including the participant's name in the melody). For the storytelling sessions, the music therapist read the youth's favourite books that were brought to the sessions by the parent. As in the music sessions, each storytelling session was also composed of most preferred and other favourite books (or stories) as well as the story for cultivating engagement (e.g., the one that included the participant's name).

[Figure 1 near here].

EEG Data Acquisition

All participants (youth, parent, and music therapist) wore EEG caps to measure simultaneous brain activity throughout the session. Each participant was assigned a separate amplifier with its own reference and ground. All amplifiers were connected to a single computer for data acquisition. The youth and parent wore 32-channel dry EEG caps (actiCap XpressTwist, BrainProducts®, Germany). The music therapist wore a 20-channel wet and wireless EEG (B-Alert X24, Advanced Brain Monitoring, Carlsbad, CA) to allow unrestricted movement while playing the guitar. The wet and dry systems were synchronized retrospectively by temporally aligning data streams at a sync pulse. Dry EEG systems were used with the youth and her mother to reduce session preparation time and facilitate hair cleaning. A previous study compared dry electrodes to conventional gel-based electrodes and reported no significant differences between the different types of electrodes. [18] All cap electrodes were positioned according to the International 10-20 system. The left ear lobe was used as a reference electrode for the youth and her mother. For the therapist's headset, the mastoids were chosen as reference electrodes. The youth and parent signals were acquired at a sampling rate of 1,000 Hz while the therapist signals were recorded at 256 Hz, as constrained by the hardware.

EEG Data Processing and Analysis

EEG data processing was performed in MATLAB® using the EEGLAB toolbox[14] as well as with in-house scripts. The EEG signal was pre-processed by filtering the signal between 0.5 and 60 Hz using a Finite Impulse Response (FIR) bandpass Kaiser filter. FIR filtering is usually recommended for offline EEG analysis [19] due to its stability and low phase distortion. In fact, high phase distortions can affect the results of connectivity analysis. Previous studies supported the use of a Kaiser window for EEG preprocessing. [20,21] The 60 Hz cut-off was chosen to include the low gamma frequency bands, which are related to empathy.[16] Power line noise was suppressed using a notch filter at 60 Hz.

No re-referencing techniques were applied. The data from the youth and the parent were downsampled to 256 Hz to match the sampling frequency of the therapist's system. Data were divided into 4 sub-intervals: a first sub-interval of 3 minutes where the participants remained as still as possible (baseline) and 3 sub-intervals of 5 minutes, where music therapy or storytelling occurred. EEG data were epoched using a 10-second sliding window with 75% overlap, yielding 436 epochs each of 2.5 s in duration over each 18-minute session. Data from each 2.5 s epoch were normalized using the first 500ms of the baseline signal to facilitate the comparison of power spectrum values among participants. A 20-point Fast Fourier Transform was applied to each epoch to estimate the spectrum of the EEG signals using a 1-second window. [22]

The levels of interbrain synchronization in youth-parent (YP) and youth-therapist (YT) dyads were quantified via the phase locking value (PLV) as estimated using FieldTrip toolbox. [22]PLV values were estimated for each epoch and each electrode after applying the FFT. Briefly, the instantaneous phase of a signal at the time t was estimated from the Fourier coefficients of each 2.5 s epoch centred around t. The PLV at the time t was computed based on the instantaneous phase difference between signals from the channels of interest.[23] As such, the PLV quantifies the mean phase difference between two electrodes, and ranges from 0 to 1 with unity indicating that the channels are perfectly coupled. [23] PLV was calculated for the 32 pairs of corresponding channels between the youth and her mother, and the 20 pairs of corresponding channels between the youth and the music therapist. The electrodes were clustered into seven brain regions based on scalp location. We divided the electrodes of the YP dyad as follows: frontal left (Fp1, AF3, F3, and F7), frontal right (Fp2, AF4, F4, and F8), central left (FC5, C3, T3, CP1, CP5, and TP9), center (Fz, Cz, Pz, and POz), central right (FC6, C4, T4, CP2, CP6, and TP10), posterior left (P3, T5, PO7 and O1) and posterior right (P4, T6, PO8, and O2). Likewise, for the YT dyad the regions were: frontal left (Fp1, F3, and F7), frontal right (Fp2, F4, and F8), central left (C3, and

T3), center (Fz, Cz, Pz, and POz), central right (C4 and T4), posterior left (P3, T5, and O1) and posterior right (P4, T6, and O2). Channels were clustered as in Samadani et al. (2021) where 4 regions were identified based on the location of 14 EEG channels. As we used a larger number of electrodes, we were able to broaden the number of clusters, identifying 7 regions. Regional PLV values were obtained by averaging PLV values of the within-region electrodes. Data from one music and one storytelling session were excluded due to a software malfunction during the data collection.

Statistical Analysis

To investigate the difference in interbrain synchronization between music and storytelling sessions in two dyads (YP and YT), a two-way mixed ANOVA was conducted. A 2 (sessions) × 5 (frequency bands: delta, theta, alpha, beta, and gamma) repeated ANOVA tested differences in interbrain synchronization among EEG frequency bands. Separately, a 2 (sessions) × 7 (brain regions) repeated ANOVA assessed differences in interbrain synchronization among the brain regions. The threshold for significance was set at 0.05. Significant effects were further investigated with post-hoc paired t-tests with Bonferroni correction. Bonferroni correction is useful for a small set of planned comparisons, and it permits compound comparisons. [24] All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) 25.0 version.

Result and Discussion

Interbrain Synchronization: Music vs Storytelling Sessions

The two-way mixed ANOVA uncovered a significant interaction effect between sessions and dyads on PLV ($F\,(1,4) = 10.05$, $p = .03$, $\eta_p^2 = .72$). The post-hoc pairwise comparison identified a significantly higher PLV during music (*M* = .24, *SD* = .002) compared to storytelling (*M* = .23, *SD* =.001) sessions, but only for the YP dyad.

The higher PLV during music rather than storytelling sessions is perhaps unsurprising. For many decades, researchers have shown that music can evoke both positive and negative emotions, putatively through various psychological mechanisms (e.g. triggering episodic memory) and at varying rates of induction. [22]The finding that music sessions yielded a significantly higher PLV only in the YP dyad may be surprising given that the parent only observed the youth in a partitioned area, whereas the youth was not able to see the parent. However, note that interbrain synchronization can emerge without direct social interactions. For example, guitar duet hyper-scanning studies have reported that interbrain synchronization manifested not only when players were performing music together but also when one was simply listening to a partner's solo play. [8,9] Moreover, interbrain synchronization has been observed between performers and passive audiences.[23]

The higher PLV in the YP dyad may also be, in part, attributable to the predictability of the familiar music and the induced emotional response. In this experiment, the parent was asked to provide a list of songs and to bring books which were familiar to her child. This familiarity may have predisposed the parent to anticipate the youth's response to music. Dikker et al.[25]reported that highly predictive linguistic contexts (i.e., when a listener can anticipate the words of the speaker) strengthens brain-to-brain synchrony. Given the syntactical structure that exists between musical structures, listening to familiar music may have had a similar brain synchrony-enhancing effect between youth and parent. Further, Novembre et al. [26] contended that the capacity to anticipate the actions of others in a music-making context can promote greater interpersonal coordination. Given the unique youth-parent bond, the parent likely possessed greater cognitive empathy for the youth, that is, the predictive ability to understand the youth's thoughts and feelings, [27] which may have also contributed to higher interbrain synchronization. To specifically explore the contribution of the one-sided observation (e.g., parent observing youth) to interpersonal synchronization, the directionality of the interbrain synchronization ought to be quantified in future work. A directionality analysis would shed light on the strength of influence from youth to parent and from parent to youth.

Differences in Responses within Frequency Bands: Music vs Storytelling Sessions

In the YP dyad, there was a significant main effect of frequency bands on PLV values (F(4,8) = 48.01, p <.001, η_p^2 = .96), with the highest PLV in the delta band (*M* =.25, *SD* =.003), exceeding that in all other frequency bands, such as theta (*M* = .23, *SD* = .005), alpha (*M* =.23, *SD* = .003), beta (*M* = .23, *SD* = .003), and gamma (*M* = .23, *SD* = .003) (all, p <.001) (Figure 2a).

In the YT dyad, there was a significant interaction effect of session and frequency band on PLV values (F (4,8) = 5.54, p =.02, η_p^2 = .74) (Figure 2b). Post-hoc pairwise comparisons revealed that in music sessions, beta (*M* =.15, *SD* =.001) and gamma bands (*M* =.14, *SD* =.001) yielded a significantly lower PLV compared to lower frequency bands (e.g., delta (*M* =.21, *SD* =.01), theta (*M* =.22, *SD* =.003), and alpha (*M* =.23, *SD* =.001), all p <.001). Further, PLV values in the alpha band were significantly higher than those of the delta band (p = .04). Similarly, in storytelling sessions, beta (*M* =.15, *SD* =.001) and gamma (*M* = .015, *SD* =.002) bands exhibited significantly lower PLV compared to delta (*M* =.22, *SD* =.007), theta (*M* =.22, *SD* = .001), and alpha (*M* = .23, *SD* =.003) bands (p <.001).

While different frequency bands emerged between dyads, in general, a significantly higher PLV was found in the lower frequency bands in both dyads (delta band for YP dyad and delta, theta and alpha for YT dyad). Oscillations in low frequency, such as delta and theta bands are associated with motivational behaviour and attention.[27] Furthermore, research has found that the delta band is associated with selective attention to rhythmic auditory stimuli. [28] Previous hyperscanning studies in music ensembles also showed a higher interbrain synchronization at delta and theta frequencies when musicians started playing a short melody together.[8,9]

In contrast to the YP dyad, the highest PLV manifested in alpha frequency bands in the YT dyad. Alpha frequency bands are associated with various cognitive processes, such as working memory and sustained attention. [29,30] The therapist may have performed primarily on a cognitive level in leading the sessions while the parent may have responded more deeply on an emotional level, anticipating the youth's enjoyment. These distinctive cognitive and emotional approaches toward the youth may have attributed to the different spectral patterns of synchronization between dyads.

Responses in Brain Regions between Music vs Storytelling Sessions

In the YP dyad, there was a significant main effect of regions (F (6,12) = 6.78, p <.01, η_p^2 = .77). In particular, frontal left (M =.24 , SD = .004) and frontal right regions (M =.24 , SD =.003) showed a significantly higher PLV compared to central (M = .23, SD = .007, both p = .01), central right (M = .23, SD = .006, p = .001, p = .003) and posterior left (M =.23 , SD = .007, p=.006, p = .01) and right (M =.23, SD =.008, both p <.001) regions. Further, the central left region (M = .24, SD =.002) exhibited a significantly higher PLV than the posterior right region (p = .01). In sum, frontal regions and left temporal lobe had significantly higher PLV than other brain areas, such as parietal, right temporal, and occipital lobes (Figure 2c).

In the YT dyad, there was only a significant main effect of regions (F (6, 12) = 4.36, p = .02, η_p^2 = 0.69), with the frontal left (M = .20, SD =.002), frontal right (M =.20 , SD =.002), and central left region (M =.20 , SD =.004) exhibiting a higher PLV compared to central region (M = .19, SD =.005), *p* = .006, *p* = .007, *p* = .007, respectively (Figure 2d). The results indicated a higher interbrain synchronization in frontal left and right regions in the YP dyad, and both frontal and central left regions in the YT dyad, which are associated with supplementary motor area (SMA), dorsolateral /anterior prefrontal cortex, Broca's area, and primary auditory cortex. These areas are known to be related to executive functions (e.g., anticipation, prediction, organization, and planning), [31] [32] empathy, [32] and social proficiency.[33] Empathy requires neural networks of observing, predicting, and understanding other's mind.[32] The dyadic coupling between frontal and temporal lobes may have reflected the parent's and therapist's empathetic engagement with the youth.

[Figure 2 near here].

In sum, this is the first study that shows the feasibility of quantitatively measuring interbrain synchronization in EEG as a potential physiological signature of empathy and social interaction responses among a parent, therapist, and non-speaking, severely impaired youth. However, a few crucial limitations of this study should be considered. First, this case report explored only a single youth's interbrain synchronization with her mother and a music therapist. Replicating this study with a larger sample size is necessary before any broader generalizations can be made. Second, the source of synchronization remains uncertain (e.g., shared empathetic responses, rhythmic auditory entrainment, physiological rhythms, and/or motor activities). Based on our analysis, we contend that music therapy (or music as an external driver of synchrony) served as a substrate for the development of synchrony rather than being the primary driver of synchrony given the emergence of brain synchrony predominantly in low frequency bands and frontal regions that are associated with empathy, social proficiency, and cognitive effort. To understand the specific source of interbrain synchronization, further study with more participants is required, including correlations with behavioural analysis (e.g., empathy traits, video analysis) and directionality of interbrain synchronization. Furthermore, future studies may consider observing the parent-therapist dyad for potential synchronization effects. Moreover, exploring intra-individual brainwave synchronization of each participant might also provide insight into the interplay between personal and inter-personal synchronization. Finally, although we speculated that ‘familiarity to stimulus’ may have contributed to higher youth-parent interbrain synchronization, our data did not allow us to determine if this familiarity translated into heighted joint attention to stimulus. In the future, controlling the level of familiarity by providing unfamiliar (but simple) music and stories to all participants and introducing an independent measure of attention would help to ascertain the degree to which familiarity and attention interact to impact interbrain synchronization.

The measurement of interbrain synchronization with EEG may offer a window for parents and therapists to better understand the brain responses of children who have limited expressive verbal capability. For example, if there is less synchrony between youth-parent and/or youth-therapist dyads, a parent or therapist may be able to alter their approach to engage and respond to the youth’s physical and emotional expressions and assess their success by monitoring changes in interbrain synchronization as a form of neural attunement to the youth’s needs. Qualified music therapists are particularly trained to facilitate and tailor individual’s goals and needs moment-by-moment, [34–36] thus, an understanding of neural synchronization processes during music therapy sessions could be a crucial and viable tool for high-quality therapy sessions.

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Declaration of Interests

The authors report no conflicts of interest.

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