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RESEARCH ARTICLE

Alteration of perceived emotion and brain functional connectivity by changing the musical rhythmic pattern

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Abstract

The arrangement of musical notes and their time intervals, also known as musical rhythm is one of the core elements of music. Nevertheless, the cognitive process and neural mechanism of the human brain that underlay the perception of musical rhythm are poorly understood. In this study, we hypothesized that changes in musical rhythmic patterns alter the emotional content expressed by music and the way it is perceived, that assumably causes specific changes in the brain functional connectome. Therefore, 18 male children aged 10–14 years old were recruited and exposed to 12 musical excerpts while their brain's electrical activity was recorded using a 32-channel EEG recorder. The musical rhythmic patterns were changed by manipulating only note values in beats while keeping time signature and other elements in a fixed state. The experienced emotions were assessed using a 2-dimensional self-assessment manikin questionnaire. The behavioral data showed that an increase in the complexity of musical rhythmic patterns significantly enhances perceived valence and arousal levels. In addition, the pattern of brain functional connectivity was also estimated using the weighted phase lag index and their association with behavioral changes was calculated. Interestingly, the behavioral changes were mainly associated with alteration of brain functional connectivity at the alpha band in the fronto-central connections. These results emphasize the important role of the motor cortical site-fronto-central connections, in the perception of musical rhythmic pattern. These findings may improve conception of the underlying brain mechanism involved in the perception of musical rhythm.

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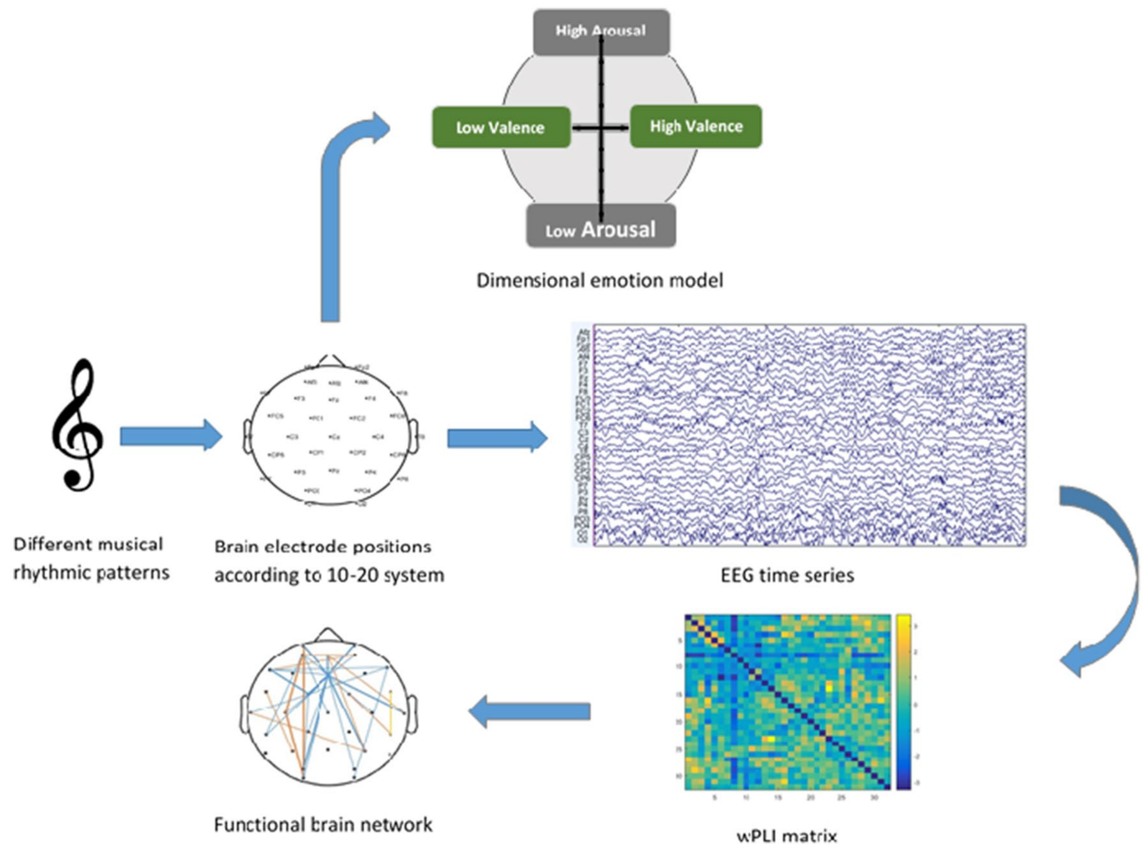
Graphic abstract



Keywords Musical rhythmic pattern · Perceived emotion · EEG · Functional connectivity · Weighted phase lag index

Introduction

The brain is one of the most complex natural systems in the world. One of the principles of natural systems is their network organization consists of many interacting units (Bornholdt and Schuster 2006). Regarding the brain as a complex network of interacting subsystems has resulted in a shift from confined locally activated functional patches toward a connectionist approach for task-related functional networks (Stam et al. 2007). In addition, using methodologies to assess connectivity among different brain regions has provided additional information on electrical activity analysis at individual parts of the brain (Rawal 2011).

The complexity and architecture of brain network are task-dependent (Hasson et al. 2009) and music, like any other higher cognitive phenomena, activates different parts of the brain and is able to change brain connectivity patterns. Brain areas that are involved in music perception have been inspected in many studies (Lotze et al. 2003; Platel et al. 1997) and also the pattern of brain functional connectivity when listening to music has been investigated in healthy individuals (Khosrowabadi et al. 2009; Wu et al. 2012, 2013) and both in musicians and non-musicians (Palomar-García et al. 2016).

On the other hand, music has always had a considerable effect on our emotions (Juslin and Västfjäll 2008; Scherer and Zentner 2001) so that some investigators would call music, the language of emotions (Cooke 1959) and subsequently it has extensively been applied for the purpose of emotion regulation (Khosrowabadi et al. 2015; Moore 2013; Thoma et al. 2012).

Music has many elements including pitch (Brattico 2006), modality (Gerardi and Gerken 1995), melody (Wallace 1994), harmony (McDermott et al. 2016) and other elements that their effects on the brain and emotional state of listeners have inspired many studies so far. Among these elements, the temporal aspects of the music have attracted recent attention of the investigators so that the research on this area has expanded dramatically during the last decade. However, the cognitive and neural mechanisms underlying this phenomenon are poorly understood. Rhythm is the serial pattern of variable note durations in a melody (Schulkind 1999) so it can be defined as a sequence of temporal intervals. The rhythm itself consists of several components such as rhythmic pattern, meter, tempo, and timing. The rhythmic pattern which is the focus of our study is defined as "a pattern of durations that can be represented on a discrete symbolic scale" (Deutsch 2013) at Page 371, Chapter 9, Section II. In music theory the two terms of rhythm and rhythmic pattern are interchangeably used (Cooper and Meyer 1963).

Perception of rhythm includes the perception of regular emphasized beats which are classified into stronger and weaker beats. Although there are different complexity measures of musical rhythm (Shmulevich and Povel 2000), in general, rhythm complexity which is a kind of temporal complexity refers to the combination of different durations that are perceived or produced during a musical task (Janata and Grafton 2003).

Rhythm is an instinctive phenomenon so that participants can usually perceive and synchronize to simple and complicated rhythmic patterns without a prior music training (Large et al. 2002). Studies in this area have shown that even infants of 7–9 months (who do not yet understand the syntax and semantics of words and sentences) possess the ability to discriminate between different sequences of rhythmic structures (Bergeson and Trehub 2006) and develop expectation for the onset of rhythmic cycles (the downbeat), even when unexpectedly the stress or other distinguishing spectral features are omitted (Winkler et al. 2009).

Most of studies on the time-related features of music and their associations with emotion have focused on the tempo (speed) of a musical piece (Kamenetsky et al. 1997; Khalfa et al. 2008; Webster and Weir 2005). Nevertheless, there are some studies on the rhythm and its relationship with emotion. For instance, a study performed on the relationship between musical rhythm and emotion has demonstrated that there are interesting relationships between note value and induced emotion (Fernández-Sotos et al. 2016). Moreover, tuning into musical rhythms (different types of rhythmic entrainment) leads to a kind of affective experience (Trost et al. 2017). Interestingly, it has been proposed that sense of enjoyment and desire to synchronize with the musical rhythm is a brain general principle for predictive coding (Vuust and Witek 2014).

The topic of rhythm has been investigated by various brain imaging modalities specifically fMRI, EEG and MEG. Studies carried out using fMRI show that listening to musical rhythm activates some areas of the brain including the cortical motor system especially in the supplementary motor area (SMA), premotor cortex (PMC) as well as some subcortical structures like the basal ganglia and cerebellum (Bengtsson et al. 2009; Chen et al. 2008a; Nozaradan et al. 2017).

There are also some other investigations (all using fMRI) carried out to study the neural connectivity of the brain while hearing musical rhythms. In a study, the effective connectivity between the putamen and the supplementary motor area (SMA), the premotor cortex (PMC), and auditory cortex was found to be greater while listening to beat-based rhythms versus non-beat control rhythms (Grahn and Rowe 2009). Another study has demonstrated that the more intensity of tones in isochronous sequences increases, the greater the functional connectivity (FC) between PMC and the auditory cortex will be (Chen et al. 2006).

Studies performed by means of EEG and MEG have shown that when participants listened to auditory patterns consisting of isochronous beats in which every second beat is stronger than others, gamma-band activity (GBA) that is in the frequency band of 20–60 Hz was greater when listening to stronger beats and this happens even when downbeats are omitted (Iversen et al. 2009; Nozaradan et al. 2011, 2012; Snyder and Large 2005). Another study has shown that beta activity can be linked to the rates in which isochronous rhythmic patterns are played (Fujioka et al. 2012).

The aim of the study was to investigate the functional connectivity of the brain using EEG while listening to different groups of sound durations or note values in musical stimuli. In music notation, a note value (durational value) is the relative duration of each note played.

We hypothesized that manipulating rhythmic pattern of musical excerpts changes the brain functional connections in a frequency-specific manner. Considering the role of motor and premotor areas in processing the rhythm, alteration of functional connectivity between central areas to other brain regions was expected. So, channel-to-channel functional connectivity analysis was performed on the selected frequency bands for 32 channels placed according to the international 10–20 system on the head. Another factor of our interest was whether a change in the rhythmic pattern of musical stimuli can influence participants' perceived emotion. This factor was assessed by measuring the valence and arousal levels. We hypothesized that by the increase of rhythmic complexity of musical pieces, perceived emotion will be more pleasant and the participants will be more aroused.

While most of the studies on the temporal aspects of music have been generally focused on beat perception or synchronization (Fujii and Schlaug 2013; McAuley et al. 2006; Repp and Su 2013), rhythmic pattern or note value of tones in a piece of music has received little attention. Likewise studies in this field have generally been focused on adults than children (Jacoby and McDermott 2017; Lewis et al. 2004) and although there have been studies on the emotional effects of music on children (Boone and Cunningham 2001; Gregory et al. 1996; Kratus 1993), as far as our knowledge there is no research aimed to study the emotional effects of different rhythmic patterns on children. So, in this study, for the first time, we investigated the effects of changes in note value or rhythmic pattern of musical excerpts on emotion and also on the functional connectivity of the brain in children using EEG.

To address this, we changed note values (i.e., note durations) without manipulating other elements of music including temporal factors like tempo (the speed at which a musical piece is played), time signature (indicating the number of beats in each measure), and other factors such as timber (quality) of sounds, modality and even the melody of the excerpts. Since pairs of stimuli were invariant except in their rhythmic patterns, differences in experienced emotion and brain responses should be related to changes imposed on rhythmic patterns.

Materials and methods

Participants

Eighteen right-handed (specified by their hands used for writing) volunteers (all boys, age range 10–14 years, $M=11.6$, s.d $=0.9$) who generally enjoyed listening to music but were not actively engaged in making music for at least the past 5 years participated in the study; 72% of the subjects had never played a musical instrument. The subjects were listening to music (mostly Iranian pop music) between 0.5 and 3 h a day. Each subject provided a consent (written consent of National Brain Mapping Laboratory of Iran) to participate after being informed of the experimental situations and procedures. The subjects were given a gift for their participation in the experiment. None of the subjects had any history of neurological, psychiatric, audiological disorders or psychoactive drugs use and never had prior experience with EEG-based communication systems. The study was approved by the Iran Medical School review board in accordance with the Helsinki declaration (IR.IUMS.REC.1395.933091506).

Experimental design

We played a set of musical stimuli during EEG recording which included 6 natural pieces and the other 6 which were derived from the original ones, resulting in 6 pairs of music pieces. The paired versions in the same piece were similar in all musical components except in the rhythmic pattern. During each measurement, the participants were sat on a comfortable chair in a dimmed and acoustically shielded room, at a distance of about 1 m from a monitor. They were required to sit quietly, to make themselves comfortable and to look at the fixation mark on the monitor to minimize muscle and eye movement artifacts. The deliveries of these pairs were random, and the paired versions of the same piece were also randomly delivered by using two stereo loudspeakers located at 1 m before the subjects. The participants were asked to rate their experienced emotions immediately after listening to each musical excerpt. Ratings were performed on two 9° Self-Assessment Manikin (SAM) scales (Bradley and Lang 1994), reflecting valence (from unpleasant to completely pleasant) and arousal (from calm to intense) which appeared on the screen following each music excerpt. The SAM scale contained non-verbal graphical pictures, whereby rating responses were recorded on a scale of 1–9 among the depictions. We had baseline periods of 6 s (following the participant's rating) between two pieces in a pair, and 15 s (following the participant's rating) between each pair. The presentation of the stimuli as well as the recording of the behavioral responses were controlled and written in Matlab, using the psychophysics toolbox extensions (Brainard and Vision 1997; Kleiner et al. 2007; Pelli 1997). In this study, we estimated brain functional connectivity networks by taking whole EEG data instead of dividing them into segments of 2/more seconds. Previous studies have shown that music-evoked emotions could be unfolded over time (Koelsch et al. 2006; Lehne et al. 2013). The evoked emotion also could be affected by the violation or confirmation of our expectancies about the rest of the melody (Sloboda 1991). Therefore, the temporal dynamics of emotional contents of the music needs a long enough stimulus to be well established.

Stimuli

A set of six musical excerpts was selected and underwent changes in note values using Finale notation software (FINALE 2014.5), giving us 12 final excerpts. Note value is the duration of musical notes played in the excerpts. During the process of rhythm manipulation, we could either add two notes to form a longer one or divide a certain note to create two shorter notes. The musical pieces containing more notes (shorter notes) in relation to its counterpart are considered as having more complex rhythmic pattern and vice versa. In half of these stimuli the computerized natural version is more complex in the rhythmic pattern (La Vie Parisienne, Kozachok and Spanish Romance) and in the rest of them, the computerized natural version is less complex in the rhythmic pattern (Symphony No.94, Ayriliq, and Adagio). Assuming that each note is encoded as a small rhythmic unit, we can depict our changes in the rhythmic pattern as shown in Fig. 1. The values in the music pieces are supposed to be the time intervals between the onset of one note and the onset of the next which is called inter-onset intervals, or IOI (Deutsch 2013).

The musical excerpts contained no vocals and none of them were familiar to the participants. The musical pieces were monophonic without any accompanying harmony or chords and also played via the Finale software to eliminate any effects that may be caused by the live performance.

Fig. 1 A short part of one of the musical excerpts, "La Vie Parisienne". **a** The raw sheet music, **b** binary coding of the sheet music. The basic unit of time here is the eight notes which are notes connected by a single stem. An eighth note can be divided into two sixteen notes that are those connected by a double beam. Eighth notes can also add to each other, forming a quarter note which is the downbeat (first note) seen in the fourth measure of the second line in (**a**)

The sound volume level was kept at a comfortable state and consistent throughout all musical pieces presented to the participants.

The musical excerpts' length varied between 25 and 52 s but each excerpt has the same length as its rhythm-changed version because the tempo and time signature were not manipulated when changing note values. Although tempos of 6 pieces were different, they were kept fixed between paired versions of the same piece; as our goal was to study the changes between the paired versions of the same stimulus. So, we had 12 musical excerpts which were similar one by one regarding duration, modality, tempo, and other musical components except for note values or rhythmic patterns. The name and duration of music excerpts are listed in Table 1.

The presentation of excerpts was randomized and pairs of stimuli which were rhythmically connected were also played randomly following each other to ensure that there was not any relation between brain activity and the order in which music excerpts were presented. The tempos were the same inside pairs. However, they were different between the 6 pairs.

EEG acquisition

The electrical activity of the participant's brain was recorded in NMBL (the National Brain Mapping Laboratory) of Iran via a g.tec g.HIamp (g.tec, Graz, Austria) with a 32-channel cap with passive electrodes made of Ag/AgCl materials located evenly on the brain according to the international 10/20 system for electrode placement (as shown in Fig. 2), with the ground electrode located on the forehead and the online reference was placed on the right earlobe. Data were recorded using a sampling frequency of 512 Hz and the impedance was kept below 10 kΩ.

Table 1 Descriptions of the musical excerpts

Composer	Excerpts	Time in second	Tempo
Offenbach J	La vie Parisienne (Parisian Life), D Major	37	100
Haydn J	Symphony No. 94 (Surprise Symphony), G Major	33	127
Ukrainian and Russian Folk Dance	Kozachok, D Major	25	120
Salimi A	Ayriliq (Separation), A Minor	52	40
Albinoni T	Adagio, G Minor	40	55
Anonymous	Spanish Romance, E Minor	27	40

Fig. 2 EEG data acquisition setup

Data processing and analyses

Behavioral data analysis

To assess the perceived emotion following listening to excerpts with different rhythmic patterns, we benefited from a non-verbal pictorial scale called Self-Assessment Manikin (SAM) scale reflecting two perpendicular dimensions of valence and arousal each of which contains 9 manikins reflecting from unpleasant to pleasant and from calm to intense emotions (Bradley and Lang 1994). Children's responses to these two scales were obtained just after listening to each piece of music. Participants' ratings for each stimulus were averaged and compared through *t* test method between two rhythmically changed music groups.

EEG data analysis

A standard preprocessing was performed on the raw EEG data. The EEG data were imported into EEGLAB v.13_6_5b (Delorme and Makeig 2004), an open source toolbox running under Matlab R2016b (The MathWorks, Natick, Massachusetts, United States). The channel location file was mapped into the data. The data underwent a band-pass filter between 1 and 40 Hz. And for each musical excerpts, segments including a 300 ms pre-stimulus period were created. After visual inspection and removing paroxysmal artifacts from data, independent component analysis (ICA) decomposition method applied to data and independent components (ICs) were obtained. To remove artifacted independent components we used a combination of experimental skills and an automatic algorithm called ADJUST that identifies artifacted ICs by combining stereotyped artifact-specific spatial and temporal features (Mognon et al. 2011). The cleaned EEG data were then re-referenced to an average reference. Finally, functional connectivity between different sites of the brain was extracted from cleaned data by the WPLI methodology. All the connectivities were calculated for five frequency bands including delta (1–4 Hz), theta (4–8 Hz), alpha (8–14 Hz), beta (14–30 Hz) and low gamma (30–40 Hz).

Functional connectivity estimation

To compute functional connectivity between all pairwise combinations of EEG electrodes, we used a measure called WPLI (Weighted Phase Lag Index). This method is derived from the Phase Lag Index (PLI). A methodology that ranges between 0 (if the distribution is random) and 1 (if phase synchrony is perfect) and estimates the asymmetric distribution of instantaneous phase differences of two electrodes (Ortiz et al. 2012). PLI was introduced by Stam et al. (2007) to address the problem of low signal-to-noise issue that is caused by muscle artifacts and volume conduction when two nearby electrodes pick up electrical activity from the same neural source causing incorrect correlations between the time series.

Vinck et al. (2011) introduced WPLI method as they claimed that in PLI both the sensitivity to noise such as volume conduction and the ability to indicate changes in phase synchronization are prevented by the discontinuity of PLI. So, WPLI makes an improvement to PLI as it is not sensitive to volume conduction, has a better signal-to-noise ratio and its statistical power to detect changes in phase synchronization is high (Khadem and Hossein-Zadeh 2014; Vinck et al. 2011).

We calculated WPLI in the following steps. First, we calculated the cross spectrum of each real-value signal pair which was Fourier transformed:

$$C(f) = X(f)Y^{*}(f) \tag{1}$$

where $X(f)$ and $Y(f)$ are two real-valued signals ($x(t)$ and $y(t)$) that are Fourier transformed and C indicates the cross spectrum of $x(t)$ and $y(t)$. Y^* denotes the complex conjugate of Y. When focusing on an interested frequency range f^*, the complex nondiagonal part of C can be considered as Z.

Then, PLI is calculated as the absolute value of the sign of the imaginary part of Z as follows:

$$\mathrm{PLI} \equiv |\mathrm{E}\{\mathrm{sgn}(J(Z))\}| \tag{2}$$

As PLI suffers from discontinuity, measuring changes in phase synchronization using PLI would be difficult (Ortiz et al. 2012). To overcome this problem, WPLI method use weighted cross spectrum according to the magnitude of the imaginary component (Vinck et al. 2011).

$$\mathrm{WPLI} = \frac{|\mathrm{E}\{J(Z)\}|}{\mathrm{E}\{J(Z)\}} = \frac{|\mathrm{E}\{|J(Z)|\mathrm{sgn}(J(Z))\}|}{\mathrm{E}\{|J(Z)|\}} \tag{3}$$

A schematic overview of the procedure from placing electrodes on the scalp until getting functional network is provided in Fig. 3.

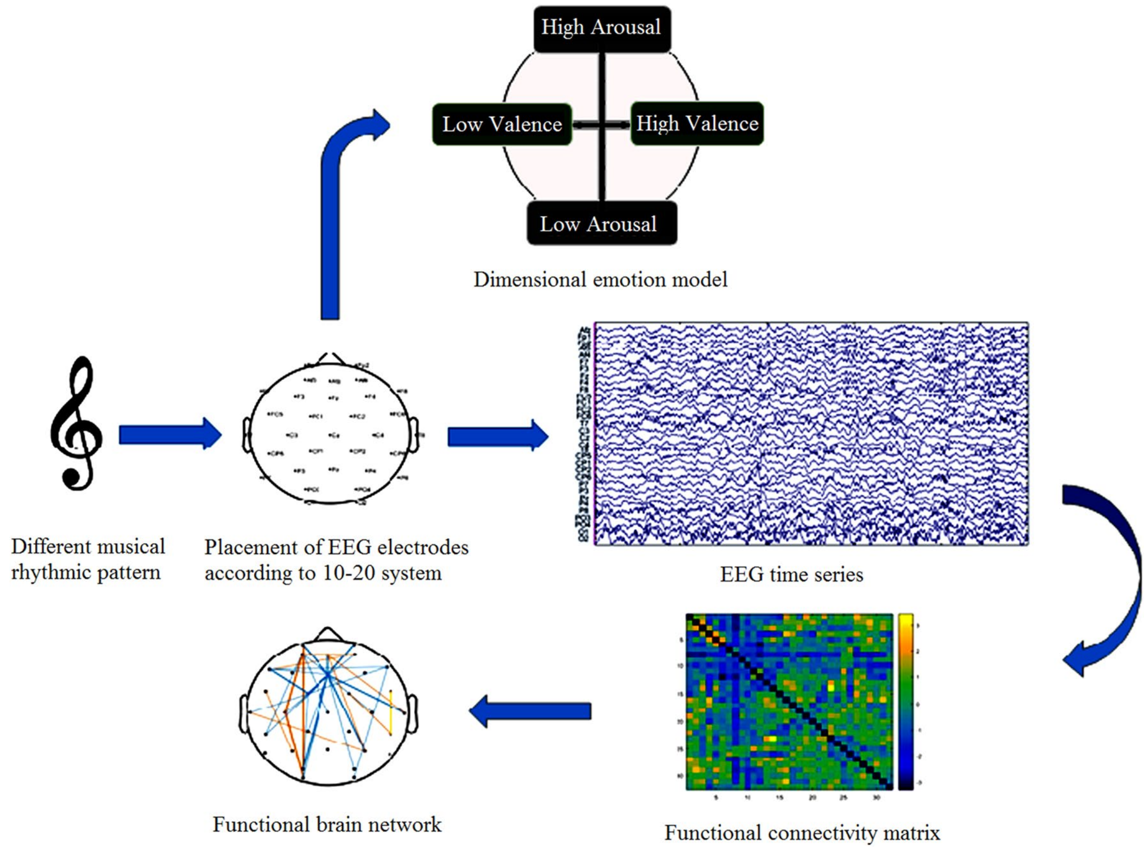


Fig. 3 Schematic design of EEG data analysis. *WPLI* Weighted Phase Lag Index

Statistical analyses

Children's responses to each musical excerpts were analyzed in terms of valence and arousal dimensions separately. The subjects' responses to each musical stimulus with more and less complicated rhythmic patterns were then statistically compared using a two-tailed paired t test. In addition, the average of all musical excerpts with the low and high complicated rhythmic pattern was also statistically compared. After that average of FCs (Functional Connectivity) related to all musical excerpts with the low complicated rhythmic pattern was statistically compared with the average of FCs related to all musical excerpts with a high complicated rhythmic pattern. A parametric method (a two-tailed paired t test) was applied for this purpose and then the results were corrected for multiple comparisons using the family-wise error correction (Bonferroni method, $P<0.05$, FWE-corrected). However, none of the changes in FCs could pass the Family-Wise Error correction criteria and the most significant result was P value of 0.0001 which was observed in the gamma band between the right frontal and parietal regions.

Results

Behavioral data

Participants rated musical stimuli on 9° valence and arousal dimensions of the SAM scale almost immediately after listening to the excerpts. In valence dimension, ratings between more complex rhythms ($M=6.35$, s.d. $=1.51$) and less complex ones ($M=4.98$, s.d. $=1.45$) differed significantly from one another [t (107) $=10.07$, $P=0.000$]. Similarly, the subjects rated the arousal dimension significantly different between more complex rhythms ($M=6.05$, s.d. $=1.39$) and less complex ones [$M=4.83$, s.d. $=1.39$; t (107) $=7.53$, $P=0.000$]. Behavioral results are presented in Fig. 4 (valence values were shifted to a range of − 4 to 4 for presentation purpose). Results reveal that excerpts with a more complex rhythmic pattern are rated both higher in valence and arousal than the less complex ones, and the same pattern is observed for all six pairs of musical pieces.

This is in line with few previous studies carried out, indicating that by changing note values in musical stimuli, we can manipulate participants' emotions so that the smaller

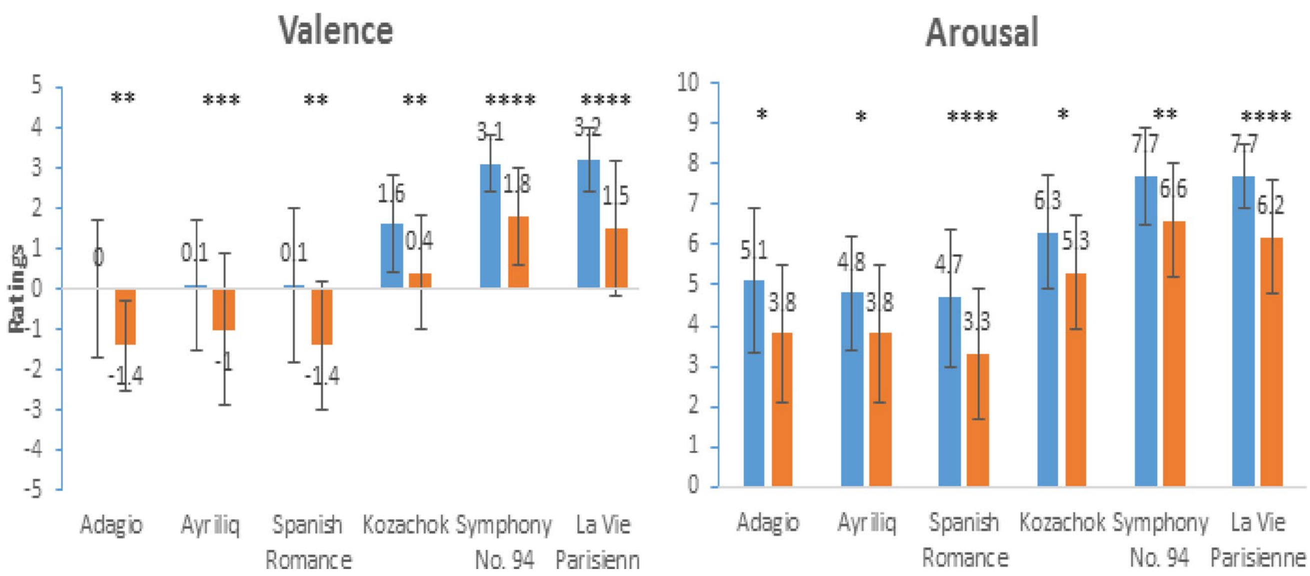


Fig. 4 Behavioral ratings of the musical excerpts (mean ± standard deviation); valence (left) and arousal (right). The more complicated rhythmic patterns are labeled in blue and less complicated ones in red. $*P<0.05$, $**P<0.01$, $***P<0.001$, and $****P<0.0001$

notes which constitute more complex rhythmic structures can be perceived more valenced and more aroused and vice versa (Fernández-Sotos et al. 2015, 2016).

As it is shown in Fig. 5, a circumplex model of emotions including two emotional dimensions of valence and arousal will exhibit the results of participants' ratings much better. It is obvious in Fig. 5 that all excerpts have been increased in both valence and arousal levels by increasing the level of rhythmic complexity.

Electrophysiological data

The synchronous activities between pairs of EEG electrodes show a functional relationship called functional connectivity (FC) between different brain regions. This study tries to identify task-related functional connectivity patterns to increase understanding of cognitive processes that occur while the rhythmic pattern of musical stimuli changes. Functional connectivity analysis was performed on the selected frequency bands using WPLI method. Then, averaged FCs of each pair (each matrix element show the connection weight between channels *i* and *j*) related to all the musical excerpts were calculated at two experimental conditions including more complicated rhythmic patterns (Fig. 6, first column) and less complicated rhythmic patterns (Fig. 6, second column). The difference between these two conditions was then calculated (Fig. 6, third column).

One of the primary observations is that the matrices related to each experimental condition have different patterns of increase and decrease (over- and under-connectivity) in different frequency ranges. The fourth column of Fig. 6 depicts the network constructions containing the most significant FCs shown in Fig. 6, third column. In the fourth column of Fig. 6, overconnectivity is presented in hot color lines and underconnectivity is presented in cold color lines. The front of the brain is placed at the top of the picture and the diameters of the lines are an indication of the significance level.

The most significant altered connections in the delta frequency band are mainly localized at the right frontal and frontoparietal parts of the brain (P value <0.01). In the theta band, the FCs alterations are mainly extended over frontal and parietal sites with the most significant connection located at the right frontal region (P value <0.01). At the alpha frequency range, the significant changes in FCs are mainly observed in the left hemisphere. A simple visual inspection easily shows that connections between fronto-central region and other parts of the brain play a key role in this frequency band. In comparison to alpha rhythm, the number of significant connections is less in the beta frequency range and again spread in the frontoparietal regions and connections are mostly overconnections and no clear hemisphere-related difference is identified. The most significant change in FC patterns (P value <0.0001), while changing the musical rhythmic pattern, is detected in the lower gamma band which was an overconnection between the right frontal and parietal regions.

Overall, the most significant alteration of FCs due to changes in rhythmic pattern of music was observed around the fronto-central and the inferior parietal parts of the brain. Looking at both behavioral and FC changes, it seems that the less-complex rhythms were less exciting to the listeners (see

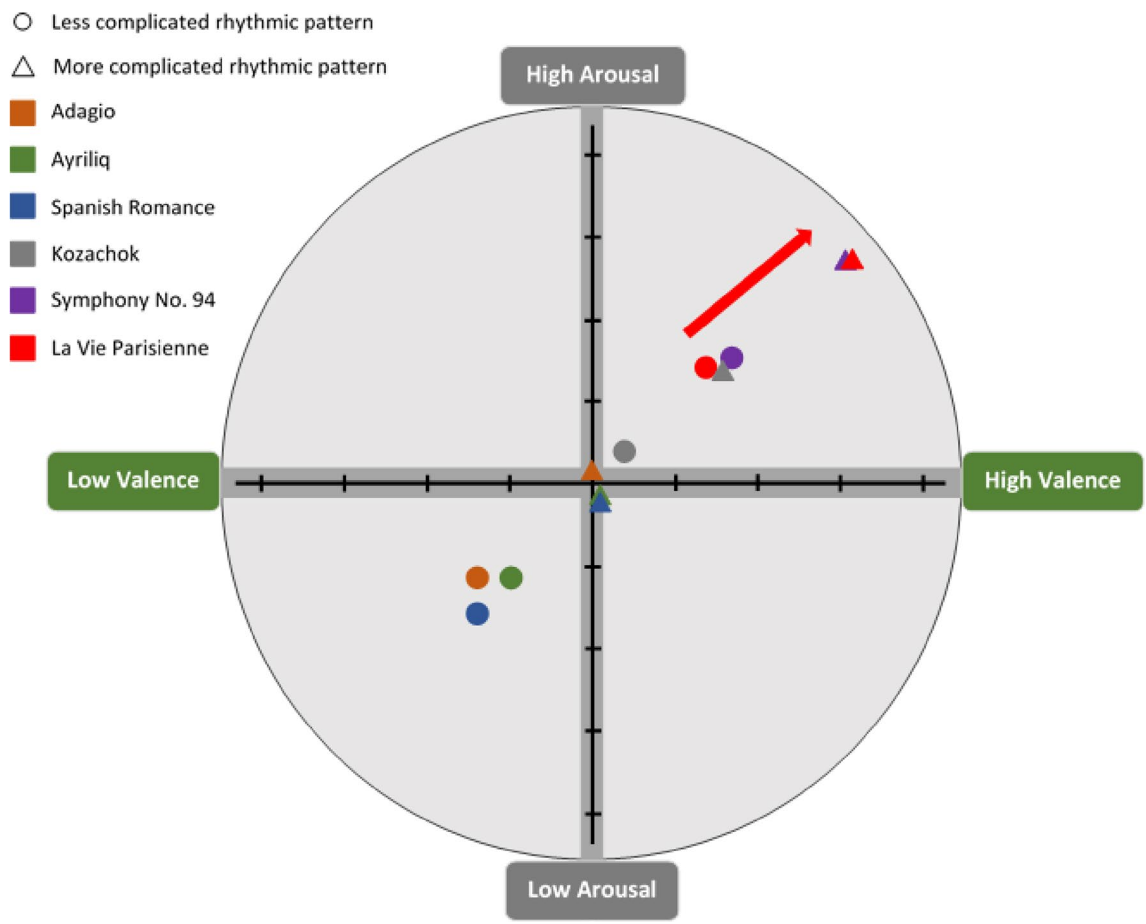


Fig. 5 Illustration of the subjects' behavioral responses in the circumplex emotional model

Fig. 5) which were significantly associated with functional synchrony (FC) between the fronto-central and the fronto-parietal regions.

Discussion

The focus of this study was to investigate changes in the functional connectivity patterns during listening to music and effect of complexity of musical rhythm on experienced emotions. We used the Self-Assessment Manikin (SAM) scale which is a two-dimensional model including 9° for valence and arousal scales to assess the experienced emotion. The SAM is an inexpensive measuring tool to easily assess emotional responses to different stimuli. It is particularly suitable for children because it is not boring and is not affected by verbal scales. In general, children can submit their answers to SAM in less than 15 s (Bradley and Lang 1994). The behavioral results of this study indicated that more complex rhythmical versions are perceived as more pleasant and more arousing. Such a finding is consistent with previous studies such as a work published by Alicia Fernández-Sotos et al. that report an association between changes in note values and listeners' mood (Fernández-Sotos et al. 2016). In addition, effect of complexity of the music rhythm on emotional perception has been indicated in study of Smith and Joyce (2004).

There are different methods to investigate task-dependent functional connectivity of different brain areas. In this study, we used a recently introduced method of studying connectivity called WPLI (Vinck et al. 2011) to assess changes in FCs while the subject is exposed to different musical rhythmic patterns. The advantage of using WPLI lies in its insensitivity to volume conduction (Khadem and Hossein-Zadeh 2014), acceptable signal-to-noise ratio, and its relatively high statistical power to discover changes in phases' synchronization (Vinck et al. 2011) which makes it more reliable to detect the true correlation between the time series.

Our results including alteration of FCs in the frontal lobe are almost consistent with many music-related EEG studies directed to the role of frontal lobe for the process of music (Altenmüller et al. 2002; Rogenmoser et al. 2016; Schmidt and Trainor 2001). It has been shown in previous studies that several frontal regions are involved in music

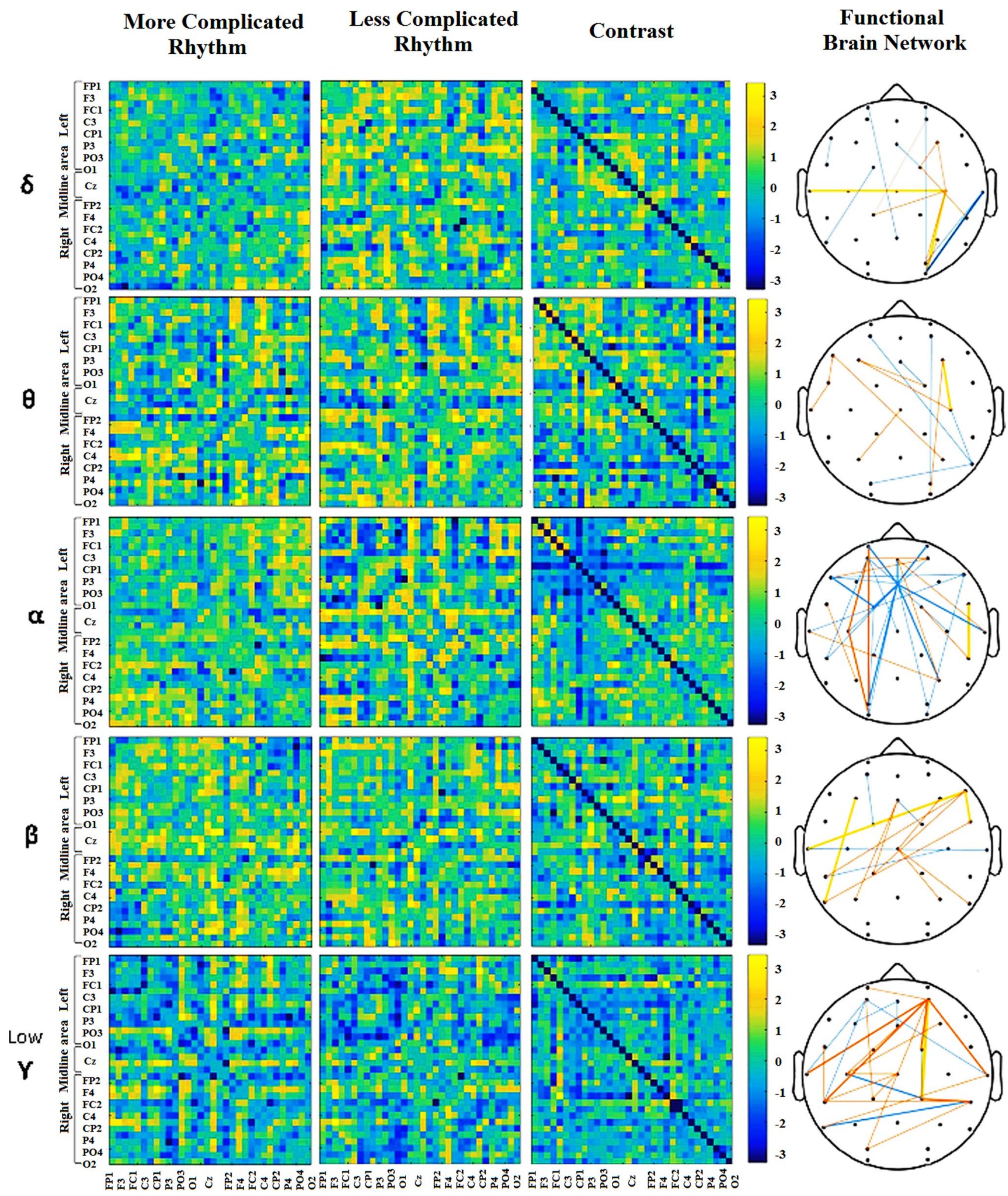


Fig. 6 Differential patterns of brain functional connectivity in the perception of musical excerpts. Color bars depict the functional connectivity values estimated by the weighted phase lag index. The diameters of the lines in the fourth column present the significance level while over-connectivity is presented in hot colors and under-connectivity in cold colors

processing including the motor and premotor cortex which are principally involved in process of rhythm (Bengtsson et al. 2009; Chen et al. 2008a; Popescu et al. 2004). Moreover, it has been shown that the middle frontal cortex plays a role in emotions derived from mode and tempo manipulation (Khalfa et al. 2005; Phan et al. 2002).

In our study, the dominant involvements of the fronto-central and premotor areas are almost observed in all frequency bands of brain activities. These findings are consistent with previous literature accenting the role of the motor area of the brain on perceiving rhythmic patterns (Lin et al. 2010, 2014). In other words, we found many phase synchronizations between areas located in the frontal and sensory-motor parts of the brain and other regions. As the main focus of this study was on effects of musical rhythmic patterns, therefore, it was not surprising to observe that synchrony between fronto-central and central areas of the brain and other brain regions alters during the changes in rhythms of music. Regarding the results related to the FCs between occipital and fronto-central regions observed in delta, theta, and alpha bands, we assumed a contribution of the cerebellum with perception of rhythm as it has been studied in previous researches (Nozaradan et al. 2017).

In terms of findings related to the frequency of EEG signal, as it is shown in Fig. 4, the most numerous paired communication among brain regions is formed in the range of alpha frequency band. Various studies have shown that the mu frequency band (8–12 Hz) has a connection with motion (Pfurtscheller et al. 2000). In addition, based on studies carried out in the field of rhythm and beat perception, we know that the brain motor system is actively involved in the perception of rhythmic patterns (Bengtsson et al. 2009; Chen et al. 2008a, b). Our findings on the alteration of FCs at the beta and gamma bands highlight the role of auditory–motor interactions. The roles of beta and gamma-band activities in beat perception and perceiving metric structure in music have been also presented in previous studies (Fujioka et al. 2009; Snyder and Large 2005).

Studies have shown that changes in musical elements could influence emotional perception. For instance, alteration of note values is linked to emotional perception (valence and arousal levels) which has been clearly shown in our results. It has been shown that valence levels of emotional stimuli are more detectable on FCs between frontal and central regions at lower EEG frequencies (theta and alpha bands) and FCs between parietal and temporal regions at higher EEG frequencies (beta and gamma bands). In addition, arousal levels of emotional stimuli mostly change the FCs between central and frontal regions at the alpha band and FCs between parietal, central and temporal regions at the beta and gamma bands (Khosrowabadi et al. 2014). These findings demonstrate an association with our results that changes in FCs may result from changes in the experienced emotion due to changes in musical rhythmic patterns.

Limitations

Because of some official barriers, we used only boys between 10 and 14 years old in our study. Therefore, it is impossible to apply our findings to girls or to anyone outside this age range. According to previous studies, however, it is anticipated that the emotional effects of changing musical rhythmic patterns are greater in girls (Altenmüller et al. 2002). We only studied emotional responses within a two-dimensional framework likewise many investigations on emotion. This does not allow capturing some aesthetic emotions like those specified by the GEMS (Zentner et al. 2008). In addition, the number of participants was small. So, the extension of the study framework with larger sample sizes could provide more robust results.

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