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Original Article

Discrepant changes in structure–function coupling in dancers and musicians

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Dance and music are well known to improve sensorimotor skills and cognitive functions. To reveal the underlying mechanism, previous studies focus on the brain plastic structural and functional effects of dance and music training. However, the discrepancy training effects on brain structure–function relationship are still blurred. Thus, proficient dancers, musicians, and controls were recruited in this study. The graph signal processing framework was employed to quantify the region-level and network-level relationship between brain function and structure. The results showed the increased coupling strength of the right ventromedial putamen in the dance and music groups. Distinctly, enhanced coupling strength of the ventral attention network, increased coupling strength of the right inferior frontal gyrus opercular area, and increased function connectivity of coupling function signal between the right and left middle frontal gyrus were only found in the dance group. Besides, the dance group indicated enhanced coupling function connectivity between the left inferior parietal lobule caudal area and the left superior parietal lobule intraparietal area compared with the music groups. The results might illustrate dance and music training's discrepant effect on the structure–function relationship of the subcortical and cortical attention networks. Furthermore, dance training seemed to have a greater impact on these networks.

Key words: structure–function coupling; dance training; music training; attention network.

Introduction

Dance and music are important sensorimotor activities and expressive art forms. Dance is a whole-body coordinated movement including highly visual–auditory–motor integrations, spatial patterns, and synchronization to external stimuli and internal feelings (Brown et al. 2006; Kattenstroth et al. 2010; Ono et al. 2014; Rehfeld et al. 2018). Comparatively, music focuses on fine-grained perceptions and control of specific parts of the body, such as finger and hand (Herholz and Zatorre 2012), and auditory–motor integrations. Particularly, the two arts require great involvement of the sensory and motor systems (Lu et al. 2018; Wen et al. 2021). Meanwhile, higher-order attentional processes are intensively recruited (Ho et al. 2003; Mireille et al. 2011). It was reported that once a week for 6 months dance intervention increased the attention ability of the elderly person (Coubard et al. 2011; Balazova et al. 2021).

Attention system is required for motor performance (Rinne et al. 2018). It is engaged in motor planning and imagery, mental rotation, and spatial working memory (Ptak et al. 2017). Numerous neuroimaging studies have proven that extensive dance and music training results in functional and structural adaptations of regions in the attention network (Brown et al. 2006; Li et al. 2015; Schlaug 2015; Elst et al. 2023). Professional dancers like ballroom dancers and Chinese classical dancers were found with increased amplitude of low-frequency fluctuation (ALFF) of bilateral inferior frontal gyrus and left middle frontal gyrus (Lu et al. 2018; Wen et al. 2021), which are core regions in the attention system. Seniors who underwent a 6-month dance intervention had increased function connectivity between the dorsal attention network and the anterior default mode network (Lu et al. 2018; Mitterová et al. 2021). Similarly, increased function connectivity between ventral attention network and salience network was found significantly correlate with changes in the attention performance of seniors after 6-month dance intervention (Balazova et al. 2021). Our previous study reported that dance and music training enhanced insular subnetwork function (Gujing et al. 2019). Several studies revealed regional anatomical changes in attention system of dancers and musicians, including superior parietal lobules, middle frontal gyrus, and inferior frontal gyrus (Abdul-Kareem et al. 2011; James et al. 2014; Gujing et al. 2018). Our previous study found that both long-term dance and music training decreased gray matter volume of middle frontal gyrus (Gujing et al. 2018). Abdul-Kareem et al. reported increased gray matter volume of left inferior frontal gyrus in male orchestral musicians that was positively correlated with the duration of musical practice (Abdul-Kareem et al. 2011). It was also reported that gray matter density of left inferior frontal gyrus increased in musicians (James et al. 2014). These functional and structural changes of regions in attention network may well reflect the acquisition of skills needed for dance and music such as attentional control (Lu et al. 2018).

Magnetic resonance imaging (MRI), as an effective noninvasive, fine spatial resolution neuroimaging technique, can provide important information related to brain structure and function. Numerous studies apply MRI to explore the brain plasticity effects of dance and music training on either functions or structures.

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However, the relationship between brain function and structure affected by intensive dance and music training is still not well understood. Therefore, exploration of brain structure–function coupling alternations induced by dance and music training will provide further insight into understanding the art effects on the brain. Earlier studies on structure–function coupling computed correlations between structure connectome (SC) and function connectivity (FC), which is simple and direct but provides limited insight into the mechanisms that support structure–function coupling (Hagmann et al. 2008; Damoiseaux and Greicius 2009; Honey et al. 2009). Other researchers built biophysical models to simulate functional signals from SC, requiring high computational costs and exhaustive searches of parameter spaces (Damoiseaux and Greicius 2009; Honey et al. 2009; Griffa et al. 2022). Recently, graph signal processing (GSP) has been proposed as a novel framework to analyze how brain function couples with structure and captures cognitive relevance (Huang et al. 2018; Medaglia et al. 2018; Preti and Van De Ville 2019; Griffa et al. 2022). It employs structural connectivity to represent the brain as a graph and identify function signals as graph signals, then exploits the graph Fourier transform (GFT), the corresponding notions of graph frequency components, and graph filters to analyze graph signals. It provides a measurement, structural-decoupling index (SDI), to quantify the relationship between functional signals and underlying structure. It was reported that averaged SDI in healthy subjects has revealed cortical organization from lower-level sensory areas to high-level cognitive areas (Preti and Van De Ville 2019).

In this study, we recruited subjects with professional dance and music training experience and matched control group to examine and compare the effects of dance and music on the brain structure–function relationship. Firstly, we applied GSP to investigate region-level and network-level coupling between function and structure. Secondly, we investigated the function connectivity of the coupled and decoupled components of function signal. Finally, we examine whether these measurements are associated with training experience. We hypothesized that dance training and music training will affect the relationship between structure and function of attention network and regions in attention network.

Materials and methods

Participants

In total, 36 dancers, 33 musicians, and 27 controls were recruited in this study. The participants in the expert groups consisted of college students majoring in modern dance and string instruments from the Southwest Minzu University and the University of Electronic Science and Technology of China (UESTC). All subjects in the expert group were assessed by senior dancers and musicians. The mean training years of both two groups were >7 years. Subjects, who were qualified according to the admission requirements for a professional dance student or string music student, were defined as dancers or musicians. Exclusion criteria excluded individuals with (1) professional and regular training less than 2 years, (2) claustrophobia, (3) neurological or psychiatric illness, (4) alcohol or substance abuse, (5) chronic diseases such as hypertension and cardiovascular disease, and (6) body mass index >28. The data of the control group were obtained from the UESTC Imaging Center. All the participants were aged between 18 and 25 years, and were right-handed according to the Edinburgh Inventory (Oldfield 1971).

The study was registered in the Chinese Clinical Trials Register (ChiCTR2200059526) and approved by the local ethics committee of UESTC. All participants provided written informed consent and the study was performed following the 1964 Declaration of Helsinki.[26]

Data acquisition and image preprocessing

Imaging acquisition was conducted on a 3-T MRI scanner (GE DISCOVERY MR750). During scanning, foam padding and earplugs were used to reduce head motion and scanner noise, respectively. Resting-state functional MRI data were acquired by gradient-echo echo-planar imaging sequences (repetition time (TR) = 2000 ms, echo time (TE) = 30 ms, flip angle (FA) = 90°, matrix = 64×64, field of view (FOV) = 240×240 mm^2, slice thickness/gap = 4 mm/0.4 mm), with an eight-channel phased-array head coil. All subjects underwent a 510-s resting-state scan to yield 255 volumes. During resting-state fMRI, all subjects were instructed to have their eyes closed without falling asleep. T1-weighted anatomical images were collected using a three-dimensional fast spoiled gradient-echo (3D FSPGR) sequence, and the scanning parameters were as follows: slices = 152; TR = 6.008 ms; TE = 1.984 ms; FOV = 256×256 mm^2; FA = 9°; matrix = 256×256; slice thickness = 1 mm (no gap). Diffusion tensor images (DTI) were acquired using diffusion-weighted spin-echo planar imaging sequence (TR = 6100 ms; TE = 85.3 ms; voxel size = $0.94 \times 0.94 \times 3$ mm^3; FOV = 240×240 mm; slices = 50; diffusion direction = 30; $b = 1000$ s/mm^2).

Functional images were preprocessed by DPABI (http://rfmri.org/dpabi) (Yan et al. 2016) according to a standard pipeline and briefly described here. The first five time points of the time series were deleted for signal equilibrium and to allow the participants to adapt to the scanning noise. Then, slice timing, realigning, and normalization ($3 \times 3 \times 3$ mm^3) into the EPI template were then performed. Next, function signal was smoothed by full width at half maximum 6-mm Gaussian kernel. Then nuisance signal was regressed, including the Friston-24 motion parameter (Friston et al. 1996), white matter signal, cerebrospinal fluid signal, and linear trend. Besides, each "bad" time point with framewise displacement (FD, calculated by Jenkinson method (Jenkinson et al. 2002)) >0.2 was also defined as a separate regressor. The global mean signal was not regressed out. Finally, temporal filtering was performed at bandpass 0.01 to 0.1 Hz.

All DTI imaging data were processed by FSL (https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/). The quality of all images had been visually inspected. First, motion (Jenkinson et al. 2002) and eddy current corrections were performed for each subject's diffusion MRI data. Then, a diffusion tensor mode was applied to reconstruct the FA map by the DTIFIT tool. Finally, a Markov Chain Monte Carlo sampling was used to build up distributions on the diffusion parameters at each voxel by the BedpostX tool. T1 imaging data were estimated by FreeSurfer's recon_all structural workflows (https://surfer.nmr.mgh.harvard.edu/fswiki/recon-all).

Structure–function couple based on graphic signal processing

Overview

The approach to quantify the coupling strength of functional signals with underlying structure was through the framework of graph signal processing (GSP) (Huang et al. 2018; Medaglia et al. 2018; Preti and Van De Ville 2019; Griffa et al. 2022). Brain structure connectome was used to construct graph Laplacian operator, to characterize the brain as a graph. The eigendecomposition of Laplacian operator then provided the harmonic components to

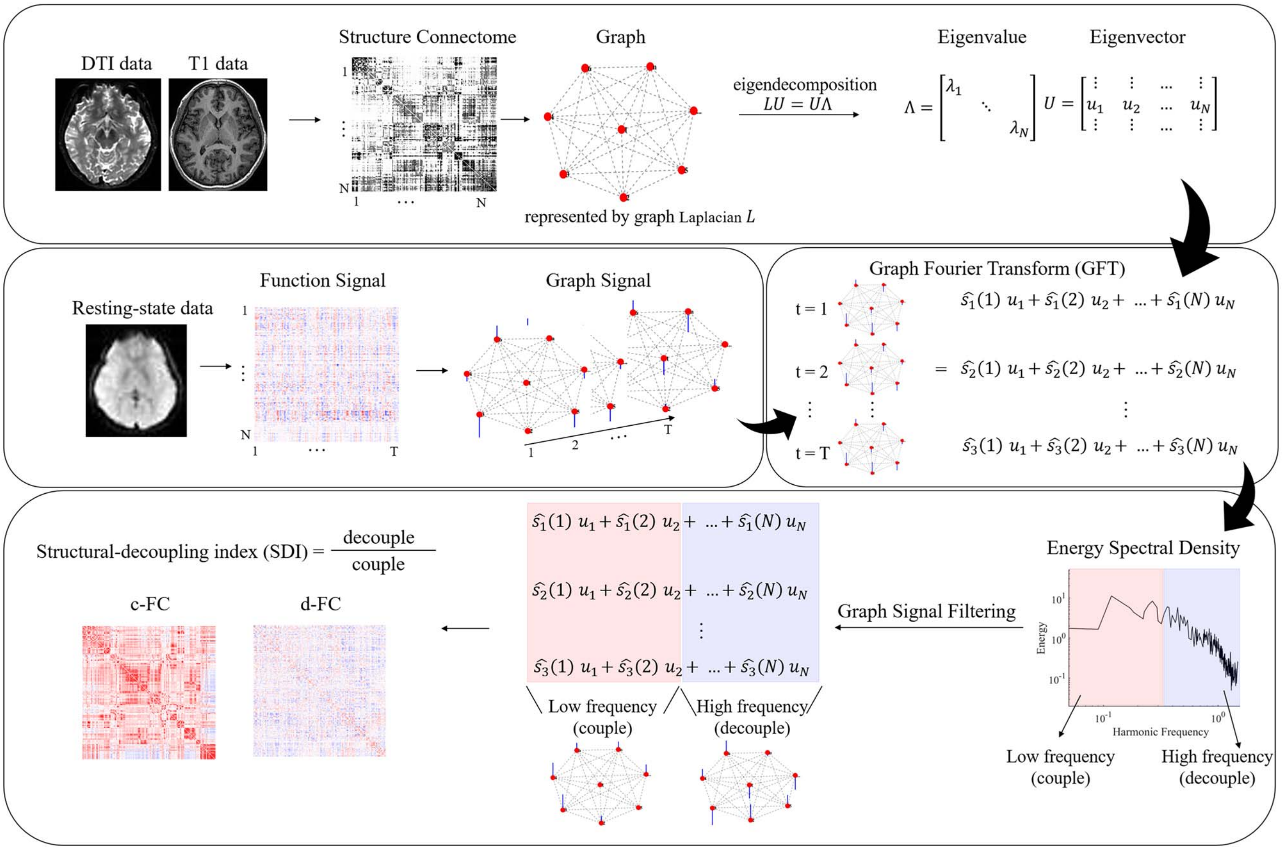

Fig. 1. Methods pipeline.

build GFT of functional signal. Low-frequency components represent signals that vary smoothly across the graph, whereas high-frequency components denote signals that vary highly across the graph at single moments in time. It means that when the frequency is higher, the functional signal is less coupled with brain structure. Finally, the coupled component and decoupled component of the functional signal are distracted by graph filtering. The ratio between the two components is determined as the SDI to quantify the relationship between brain structure and function (Fig. 1). In this study, we conducted a three-part analysis: (1) region-level SDI, (2) regional SDI network analysis, and (3) network-level SDI.

Structure connectome and functional signal

Gray matter was parcellated into 246 regions according to the human brainnetome atlas (Fan et al. 2016) and 8 predefined networks (Yeo et al. 2011) (subcortex regions were identified as subcortex network). Firstly, probabilistic streamline tractography on DTI data was applied to estimate streamlines between regions for each participant. The gray matter volume of each region was then estimated on T1 data. Thus, the $N \times N$ structure connectivity was measured by the number of streamlines connecting two regions divided by the sum of connected regions' volumes. Finally, averaged fMRI signals were extracted and stored in the $N \times T$ matrix $S = [s_t]_{t=1,\dots,T}$, where T is the number of time points. N was the number of regions for region-level SDI analysis and was the number of networks for network-level SDI analysis.

Graph Fourier transform

Adjacent matrix A was defined by structure connectome matrix. Based on it, the symmetric normalized graph Laplacian $L = I - D^{-1/2}AD^{-1/2}$ was built as a graph shift operator to capture the connectivity pattern, where the degree matrix$D$ contains the degree of each node on its diagonal and I is an identity matrix.

Then, the GFT was utilized to analyze brain function signals. That was defined by eigendecomposition $LU = U\Lambda$ of the graph Laplacian L, where Λ was a diagonal matrix containing the eigenvalues λ_k and $U = [u_k]_{k=1,\dots,N}$ contained eigenvectors. The eigenvalues can be interpreted as frequencies and the eigenvectors as frequency components, referred to as structural connectome harmonics. Therefore, u_k with low λ_k encode low frequencies and thus smooth functional signals corresponding to the structural network. The GFT used eigenvectors as base, and converted a function signal s_t into its spectral representation $\hat{s}_t$ and vice versa, as indicated in Eq. (1).

$$\hat{s}_t = U^T s_t \quad and \quad s_t = U\hat{s}_t \tag{1}$$

Structural-decoupling index

Graph signal filtering was implemented to decompose the functional signal into one part well coupled with structure (i.e. represented by low-frequency eigenmodes of the graph) and one that is less coupled (i.e. by higher-frequency eigenmodes). The cut-off frequency C was defined as the frequency that split average energy spectral density (across time) into two parts with equal energy.

The $N \times N$ matrix $U^{(\text{low})}$ included first C eigenmodes of U and N-C zero columns. Vice versa, the matrix $U^{(\text{high})}$contains the first C zero columns and the N-C last eigenmodes. Thus, filtered

Table 1. Demographics of the participants.

	Dance group	Music group	Control group	P
Gender (F/M)	20/11	14/13	15/12	0.601[a]
Age	19.3 (2.5)	19.5 (1.3)	19.9 (1.5)	0.515[b]
Education years	13.1 (2.4)[c]	13.3 (1.7)[d]	14.0 (1.1)[e]	0.175[b]
Training years	8.8 (4.7)[c]	10.4 (3.5)[f]	…	…

Indicated values are shown as mean (standard deviation). [a]Indicates the P values from the comparison analysis: chi-square test. [b]Indicates the P values from the comparison analysis: ANOVA. [c]Data of 30 participants available. [d]Data of 25 participants available. [e]Data of 21 participants available. [f]Data of 24 participants available.

signals are obtained following Eqs. (2) and (3):

$$s_t^C = U^{(\mathbf{low})} U^T s_t \tag{2}$$

$$s_t^D = U^{(\mathbf{high})} U^T s_t \tag{3}$$

As such, function signal was decomposed into pieces that represent different levels of variability. Low graph frequency components represented signals that change slowly with respect to brain structure, and high graph frequency components represented signals that change swiftly with respect to the structure. The L2 norms of $s^D$and s^C across time quantify coupling and decoupling strength for each node, and the logarithm of the ratio between the two was determined as the SDI, as indicated in Eq. (4). SDI is a measurement of the alignment of function with structure per brain area. The negative value of SDI represents the coupling strength of a region; vice versa, the positive value indicates the decoupling strength of a region. Based on different function signal and SC inputs for the analysis framework, region-level and network-level SDI were obtained respectively. In addition, mean regional SDI for each predefined network (Yeo et al. 2011) was identified for regional SDI network analysis.

$$SDI = \log_2 \frac{\| s_t^D \|}{\| s_t^C \|} \tag{4}$$

Pairwise Pearson's correlations of s^C and s^Dtime courses were computed to obtain coupled function connectivity (c-FC) and decoupled function connectivity (d-FC) matrices, respectively.

Statistical analysis

First, one-way ANOVA was performed to determine differences in node-level SDI, network-level SDI, and regional SDI network analysis among three groups, respectively. The multiple compare corrects of node-level SDI ANOVA took the form of false discovery rate (FDR) Bonferroni correction ($P < 0.05$). Then, repeated-measures ANOVA was performed to determine FC component × group interact effect. Finally, the correlation between the age of training beginning, training years, and training hours per week and regional SDI, c-FC, and d-FC in both dance group and music group was estimated by Spearman's rho.

Results

Participant demographic information

Five participants in the dance group and 6 in the music group were excluded because of excessive head motion. Thus, 31 subjects in the dance group and 27 subjects in the music group were included in the following analysis (Table 1).

The altered relationship between brain structure and function

Regional SDI organization across the cortex in three groups was consistent with previous finding (Vázquez-Rodríguez et al. 2019; Baum et al. 2020). As shown in Fig. 2, structure and function correspond closely in unimodal, primary sensory, and motor regions (greater negative SDI value of visual network and somatomotor network), but diverge in transmodal cortex (greater positive SDI value of frontoparietal network).

ANOVA showed that only two regions' SDI values were significantly different among 3 groups ($P_{FDR} < 0.05$), including right inferior frontal gyrus opercular area (IFGop) and right ventromedial putamen (vmPu). The decoupling strength of vmPu in both the dance and the music group had a significant decrease (Fig. 3C), as indicated lower positive SDI value. Compared with the control group, the coupling strength of IFGop in the dance group significantly increased, as indicated by a lower negative SDI value. ANOVA results show significant differences in network-level SDI of ventral attention network (VAN) among 3 groups ($F = 3.34$, $P = 0.04$, Fig. 3B). Post hoc analysis indicated that the negative SDI value of ventral attention network in dancers increased, compared with controls (Fig. 3C). However, there was no significant network-level SDI difference among three groups.

The repeated-measures ANOVA results showed significant FC component × group interactive effect (Fig. 4, $P < 0.001$), including FC between right middle frontal gyrus ventral area (MFG_ R_7_4) and left middle frontal gyrus area 46 (MFG_L_7_3), and between left inferior parietal lobule caudal area (IPL_L_6_4) and left superior parietal lobule intraparietal area (SPL_L_5_5). Compared with decoupling FC, all three groups preferred coupling FC components. Uniquely, dance group indicated significantly increased coupled FC between left and right MFG.

The relationship between brain structure–function coupling and training intensity

A significant correlation between regional SDI and training intensity was found in one region in the dance group. There was a significant negative correlation in the dance group between the SDI of IFGop and training hours each week (Fig. 5, $r = -0.401$, $P = 0.028$). It implied that the higher IFGop structure–function coupling degree in dancers was associated with more training hours per week.

Discussion

This study first provided evidence of the changes in region-level and network-level structure–function relationships induced by dance and music training. Firstly, dance and music groups indicated increased coupling strength of function to structure of region in subcortical attention network. Secondly, the

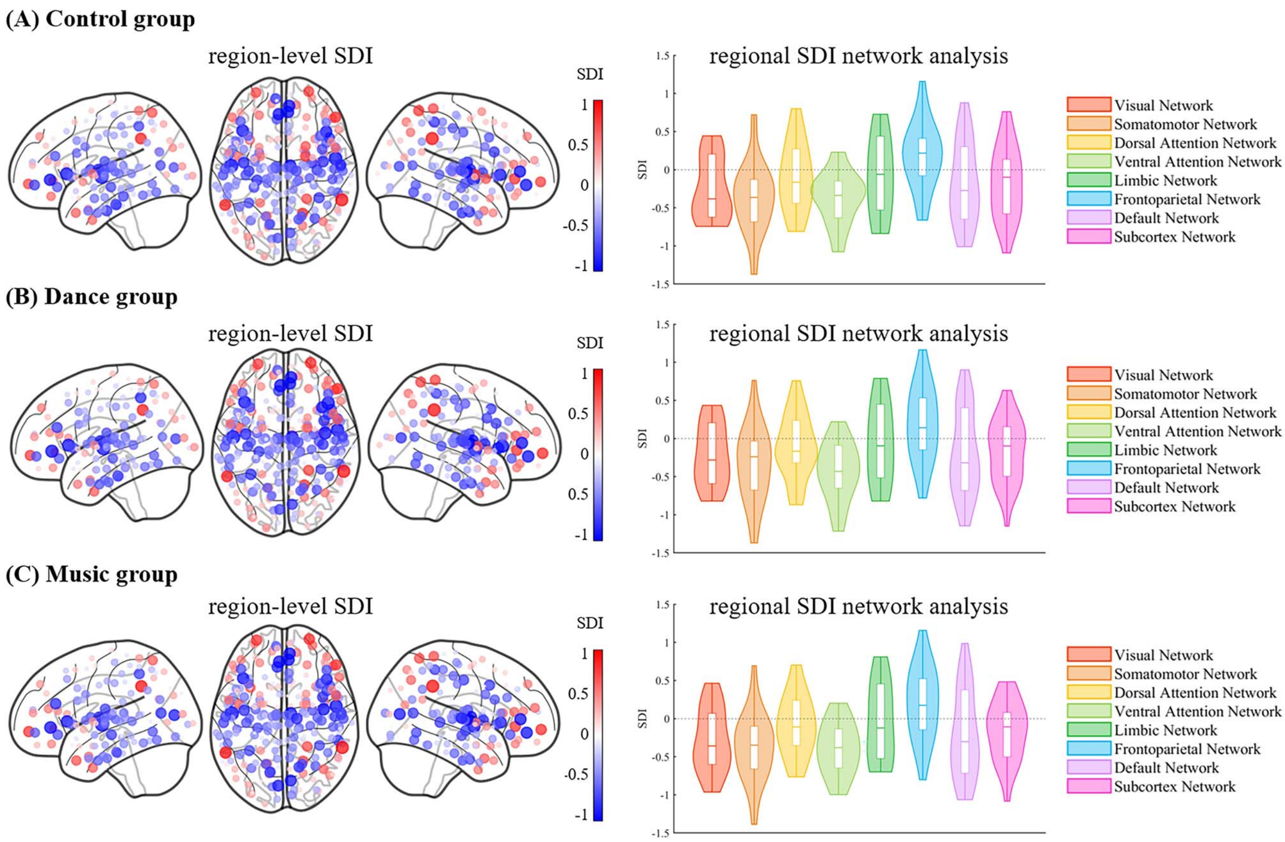

Fig. 2. Structural-decoupling index (SDI) group mean map. Node color represents its SDI value and its size is proportional to the SDI absolute value. The negative value of SDI represents the coupling feature of a region; vice versa, the positive value indicates the decoupling feature of a region.

structure–function coupling degree of ventral attention network increased only in dancers, compared with controls. Compared with control group, the regional coupling strength between structure and function of the right IFGop increased only in dancers, which is part of the ventral attention network. Thirdly, compared with the control group, the c-FC between MFG_ R_7_4 and MFG_L_7_3 increased in the dance group. Compared with music group, dance group indicated increased coupling FC between IPL_L_6_4 and SPL_L_5_5. The alternation is located in dorsal and ventral attention network. Finally, the altered coupling degree of IFGop, which is part of the ventral attention network, was associated with dance training intensity.

Dance and music training increased coupling strength of regions in subcortical attention network

Animal and human studies have shown substantial evidence that subcortical regions play a critical role in attention, including basal ganglia and thalamus (Karnath et al. 2002; Xuan et al. 2016). Putamen, a part of the basal ganglia, receives input from almost every brain region and is associated with the attention system (Choi et al. 2012). It is involved in the interaction between different attentional functions, including bottom-up alerting, top-down orienting, and top-down executive control (Xuan et al. 2016). Particularly, putamen plays an attentional role both in the enhancement of task-relevant information processing and the inhibition of task-irrelevant processing (van Schouwenburg et al. 2015). Our result showed that both dance and music training increased the putamen coupling degree of function with structure. It was reported that a stronger regional coupling degree between function and underlying structure was associated with better complex cognition (Griffa et al. 2022). It might be attributed to more reliable and consolidated brain communication pathways, possibly expressed in stronger structure–function coupling (Finn et al. 2015; Medaglia et al. 2018; Suárez et al. 2020; Griffa et al. 2022). Changes in the coupling degree of putamen we found were identical to optimized putamen functional and structural features found in previous studies on dancers and musicians (Hänggi et al. 2010; Granert et al. 2011; Li et al. 2015; Burzynska et al. 2017). Enhanced functional connectivity density and FC were found in the bilateral dorsal anterior putamen of dancers (Li et al. 2015), and it was associated with training levels in musicians (Kita et al. 2018). Meanwhile, the optimization was shown in a way of decreased putamen gray matter volumes in dancers and musicians (Hänggi et al. 2010; Granert et al. 2011; Burzynska et al. 2017; Gujing et al. 2018). The decrease in gray matter may be due to beneficial neuronal pruning caused by long-term training, removing redundant and unrelated synapses (Luna and Sweeney 2004; Hagmann et al. 2010).

Metric movements based on rhythm and meter are the shared components in dance and music performance. Attention is necessary to perceive temporal regularity in an auditory sequence (Geiser et al. 2009; Schwartze et al. 2011) and mediate the influence of musical abilities on metric beat perception (Bouwer et al. 2016). Metric movements synchronize attention and motor behaviors with periodic rhythms in the music (London and London 2012). The putamen plays a key role in the voluntary control of metric movements (Brown et al. 2006), such as rhythmic tapping tasks (Rao et al. 1997; Penhune et al. 1998) and foot movement (Sahyoun et al. 2004). Thus, the increased

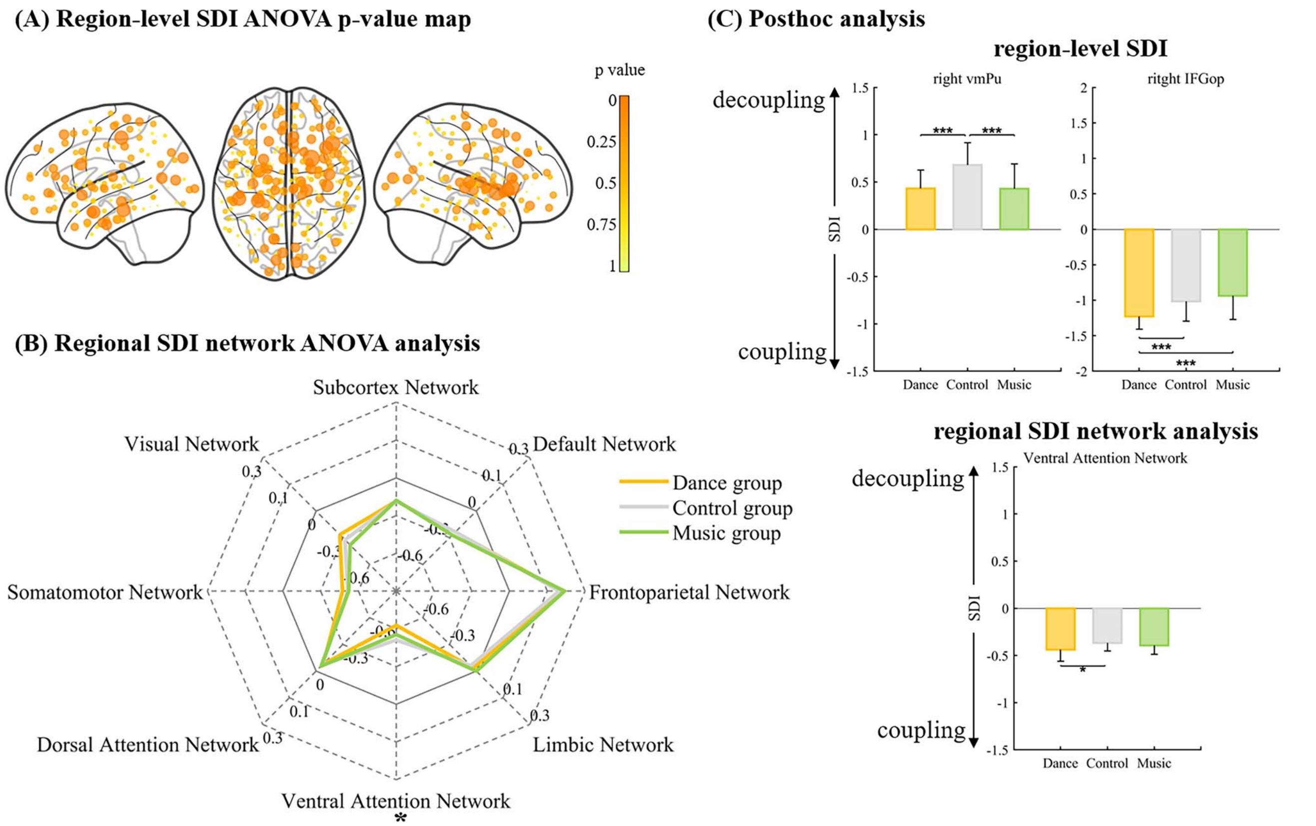

Fig. 3. Structural-decoupling index (SDI) statistic results. The negative value of SDI represents the coupling feature of a region; vice versa, the positive value indicates the decoupling feature of a region. (A) Region-level SDI ANOVA p-value map. Node color represents its *P* value and its size is proportional to *P* value. When the *P* value is closer to zero, the node size is larger. (B) Regional SDI network ANOVA analysis. (C) Post hoc analysis. IFGop: right inferior frontal gyrus opercular area; vmPu: right ventromedial putamen. **P* < 0.05, ***P* < 0.01, and ****P* < 0.001.

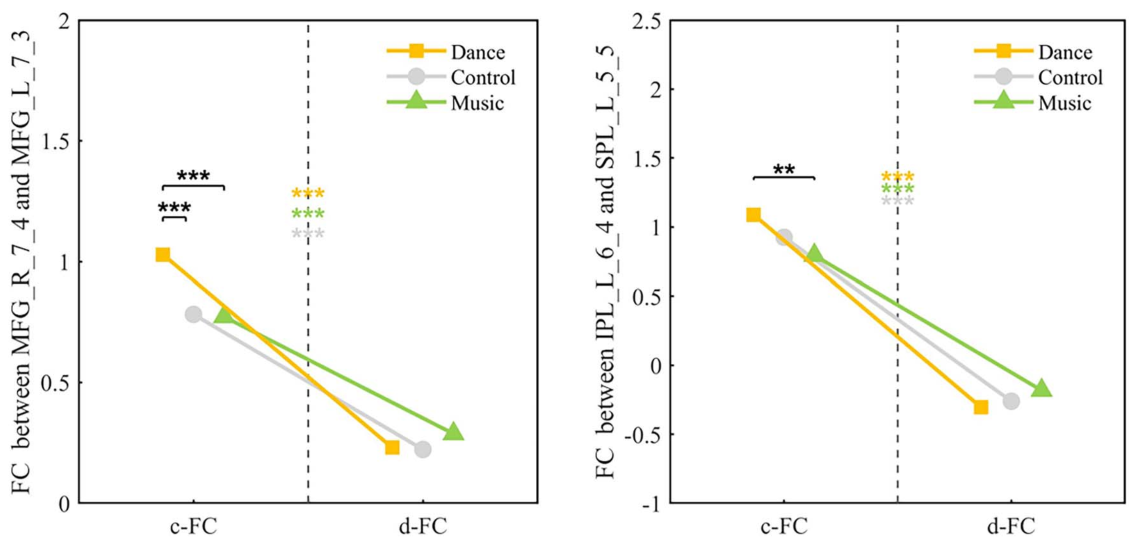

Fig. 4. The significant FC component × group interact effect. C-FC and d-FC were the functional connectivity components coupled and decoupled from the structure, respectively. The interactive effect the three graphs showed was <0.001. MFG_L_7_3: left middle frontal gyrus area 46; MFG_R_7_4: right middle frontal gyrus ventral area; IPL_L_6_4: left inferior parietal lobule caudal area; SPL_L_5_5: left superior parietal lobule intraparietal area. **P* < 0.05, ***P* < 0.01, and ****P* < 0.001.

putamen function coupling to underlying structure in dancers and musicians we found in this study might be the result of the neural correlates of highly automated synchronization movement with rhythm. Dance performance requires a rhythmic whole-body movement from head to foot. Playing instruments also needs fine hand movement to match the music's rhythm. Voluntary control of metric movements becomes more automated in professional dancers and musicians. Therefore, the increased coupling degree in putamen might facilitate the function of subcortical attention network, which represents the neural correlates of the skilled execution and sustain of metric movement in dance and music.

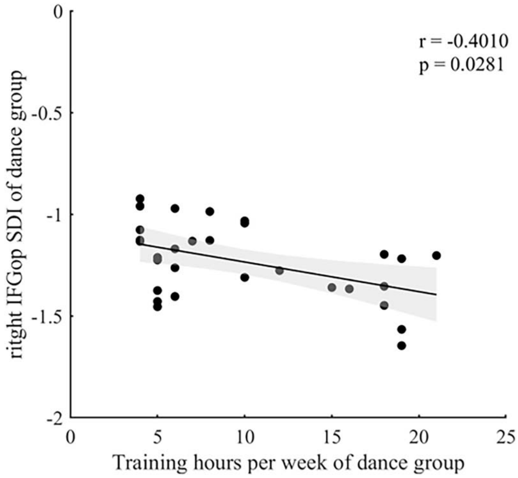

Fig. 5. The correlation between SDI and training hours per week in dance group.

The effects of dance training on cortical ventral attention networks

Ventral attention network, including IFG and MFG, detects salient and behaviorally relevant stimuli in the environment (Corbetta et al. 2008; Yeo et al. 2011). For this reason, this network has been implicated in stimulus-driven attentional control, processing bottom-up sensory information (Corbetta and Shulman 2002; Vossel et al. 2014). Right IFGop proximity to primary and secondary motor areas is the shared area of ventral attention network and motor system. It processes motor-related information (Hartwigsen et al. 2019), such as action observation (Heiser et al. 2003; Molnar-Szakacs et al. 2005; Caspers et al. 2010), execution (Ehrsson et al. 2003; Sahyoun et al. 2004; Sebastian et al. 2013; Cai et al. 2014; Zhang et al. 2017), imitation (Heiser et al. 2003; Molnar-Szakacs et al. 2005; Caspers et al. 2010), and imagination (Szameitat et al. 2007). It is also involved in the integration of the perceptual or emotional domain into motor acts, such as visuo-motor integration (Macuga and Frey 2011; Papadelis et al. 2016), auditory–motor integration (Tourville et al. 2008; Parkinson et al. 2012; Behroozmand et al. 2016), somatosensory–motor integration (Ehrsson et al. 2000), or the integration of an emotional state in speech production (Pichon and Kell 2013). Coupling strength functions with the structure of VAN and right IFGop were found to be enhanced only in dancers in this study. The enhancement of IFGop coupling degree was significantly associated with higher dance training insensitivity each week. These findings were in accordance with previous evidence on dancers. Lu et al. elucidated increased ALFF of ballroom dancers in bilateral IFG and left MFG during resting state (Lu et al. 2018). Hänggi et al. found that fractional anisotropy was lower in the white matter of the right frontal operculum in professional ballet dancers (Hänggi et al. 2010). We also found that coupling FC between left and right MFG area enhanced in dancers. Dance training intensively requires participants to integrate body motor action into visual–auditory–somatosensory information. Specifically, the involvement of the ventral attention network might help to monitor the switch between perception input and motor output and synchronize perception and action interaction between cognitive and sensory stimulation (Hartwigsen et al. 2019). Hence, the alternation of right IFGop and MFG area in dancers might be a result of more skilled complex sensory–motor integration in dance movement with lower attention load.

The effects of dance training on cortical dorsal attention networks

The dorsal attention network enables the selection of sensory stimuli based on internal goals or expectations (goal-driven attention) and links them to appropriate motor responses (Corbetta et al. 2008). It emphasizes the internal or top-down signals that guide perception through a dynamic interaction with sensory or bottom-up information (Corbetta et al. 2008). The neuroimaging study indicated that motor planning and imagery, mental rotation, and spatial working memory similarly engage the dorsal attention network (Ptak et al. 2017). Superior parietal lobules is one of the core regions of dorsal attention network (Corbetta et al. 2008) and involved in feed-forward modulation of sensory inputs (Green et al. 2011), integrating auditory and visual input to execute goal-directed spatial orienting (Bushara et al. 1999; Sarter et al. 2001; Shomstein et al. 2010). Inferior and superior parietal lobules are critical to spatial attention and spatial orientation (Bushara et al. 1999; Shomstein et al. 2010; Szczepanski et al. 2010; Vandenberghe et al. 2012). Compared with musicians, coupled FC between IPL_L_6_4 and SPL_L_5_5 increased in dancers in the present study, which is in keeping with previous evidence. Brown et al. found that the medial SPL of dancers was involved in spatial guidance of leg movements (Brown et al. 2006). A functional Near-infrared spectroscopy (fNIRS) study recording brain activity when dancers took part in a dance video game found that activity in SPL increased with increased task difficulty (Tachibana et al. 2011). Compared with non-dancers, greater activity of IPL during resting state (Gardner et al. 2015) and observation of dance (Calvo-Merino et al. 2005; Cross et al. 2006) were found in dancers. Spatial information processing is one of the main differences between music and dance performance. Dancers need to generate a representation of the body in space and organize body movements into spatial patterns, but musicians do not. Therefore, compared to musicians, the increased FC of dance between IPL_L_6_4 and SPL_L_5_5 might be a result of the skilled unique spatial characteristics of dance movement.

Limitations

Some limitations of the study should be mentioned. Cognitive performance changes in dancers and musicians are important to understand structure–function coupling changes. Cognitive function measurement in dancers and musicians should be considered in the future. Besides, longitudinal studies of dance/music training are recommended to investigate how the process of dance and music training affects the brain.

Conclusion

In summary, this study examined and compared the benefits of dance and music training from a novel perspective: the strength of brain function couples with structure. Our study deepens our understanding of the specific plasticity effect of dance and music training. These alternations in cortical and subcortical attention networks might be induced by the skilled large-scale and whole-body movement of dance training and the small-scale and delicate movement of music training. It provided possible evidence for the application of dance as a more effective way to improve attentional networks and might be a complementary intervention for some psychiatric diseases related to deficits in attentional processing such as schizophrenia (Javitt 2009) and attention deficit hyperactivity disorder (Caye et al. 2019). Furthermore, longitudinal studies are needed to offer more evidence about how the function–structure relationship is affected by dance training step by step.

Author contributions

Kexin Gao (Data curation, Formal analysis, Investigation, Software, Visualization, Writing—original draft, Writing—review & editing), Hui He (Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing—original draft), Bao Lu (Formal analysis, Software), Qiushui Xie (Investigation), Jing Lu (Investigation, Resources), Dezhong Yao (Resources, Supervision), Cheng Luo (Project administration, Resources, Supervision, Writing—review & editing), and Gujing Li (Funding acquisition, Project administration, Supervision, Writing—review & editing).

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