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Neurophysiology of Reciprocal Influence of Cognition and Emotion in Pianistic Performances

Marcia K. K. Higuchi[1].Tiago A. Sanchez[2], Lucas R. Ramos[2], José E. Fornari N. Jr[3],

Dráulio B. Araújo[4], and João P. Leite[1]

1 - Neurosciences and Behavioral Sciences, University of Sao Paulo School

2 - Faculdade de Medicina - Universidade Federal do Rio de Janeiro (UFRJ)

3 - Interdisciplinary Nucleus for Sound Communication - NICS, University of Campinas

4- Brain Institute – Rio Grande do Norte Federal University

Corresponding author: Marcia Kazue Kodama Higuchi

Postal Address: Av. Dom Pedro II 2245, Santo André – São Paulo - Brazil

E-mail: higuchikodama@uol.com.br

Author Note

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Abstract

Piano performance is a complex domain that involves the integration of various skills, including motor, perceptual, cognitive, and emotional abilities. However, research in neuroscience and music cognitive psychology suggests that this integration of distinct abilities may not occur spontaneously, and there may be a mutual attenuation relationship between cognition and emotion. An investigation comparing piano performances focusing attention on cognitive or affective aspects revealed a reciprocal inhibitory influence between them. Analysis of specific musical features, performance mistakes, and comments demonstrated more expressiveness features, as well as inhibition of executive skills and motor control in the piano execution with attention focusing on emotional aspects. In contrast, attention to cognitive aspects of the performances constrained both automatism and expressiveness. In this study, we used fMRI to investigate neural systems concerning cognition and emotion reciprocal modulation in piano performances. Comparing brain activity between performances in cognitive minus affective conditions indicated greater activity in the central executive network (CEN), pre-supplementary motor area (pre-SMA), supplementary motor area (SMA), language, and visual areas. The contrast of affective minus cognitive condition demonstrated greater activity in the anterior medial prefrontal cortex and right dorsolateral prefrontal cortex (DLPFC). The results support the notion of dual meta-systems relying on explicit and implicit neural circuits, respectively, and corroborate the existence of cognitive and emotional reciprocal attenuation influence in pianistic performances.

Keywords: Music; piano performance; fMRI; cognition; emotion

Introduction

Music holds a prominent place in human experience, eliciting a variety of cognitive (Forgeard 2008; Kiss & Linell 2021; Zuk et al., 2014), physical (Blood & Zatorre, 2001; Lundqvist, Carlsson et al., 2009; Krumhansl, 1997), and emotional responses (Blood & Zatorre, 2001; Brown, Martinez et al., 2004; Levitin & Tirovolas, 2009). The emotional impact of music is potent and can be profound (Blood & Zatorre, 2001). However, not every combination of sounds has the power to evoke such reactions. Mere technical proficiency, playing the right notes at the right tempo, is insufficient. A musician must combine accurate sounds with appropriate expression, which demands the reconciliation of reason, motor skills, and emotion. Piano performance, which requires a dynamic integration of multiple highly specialized skills, represents the pinnacle of human central nervous system performance (Parsons et al., 2005). Yet, integrating these skills is challenging, as many of their components are antagonistic to each other under different.

Although cognition and emotion are closely intertwined in the brain, they have traditionally been viewed as separate entities (Pessoa 2008). Distinct brain regions such as the dorsolateral prefrontal cortex (DLPFC) and the limbic system, particularly the amygdala, have been identified as cognitive and emotional areas, respectively (Pessoa 2008). Differences in their analyses, actions, and learning have been observed. While executive function analyzes highly processed information, develops strategic plans and uses conscious and controlled mechanisms; the emotional system typically assesses rapid computation of poorly processed sensory data. Mechanisms operated by the emotional system rely on conditioned, unconscious learning, and include expressive–communicative components (Gainotti 2012). In cognitive neuroscience, studies have demonstrated the capacity of emotion to influence cognitive activity and vice versa (Blair et al., 2007; Mocaiber et al., 2011; Northoff et al., 2004; Sanchez et al., 2015). This interrelation could be complementary or inhibitory (Pessoa 2008). A previous study using a computational model that retrieved specific musical features demonstrated a mutual inhibitory between cognition and emotion in pianistic performance (Higuchi et al., 2011). The study compared pianists playing the same repertory with a focus on either cognitive aspect (consciously planning and monitoring each note they play) or affective aspects (imagining emotional stimuli). The results revealed that affective performances relied on implicit procedural memory; exhibited more expressive features, and inhibited psychomotor control, while the cognitive performances inhibited automatism and expressivity. Therefore, the mutual inhibitory relation between cognition and emotion may be intrinsically linked to the integration difficulty presented in piano performance, as both implicit procedural memory and explicit controlled psychomotor skills are essential for high-level piano execution.

The importance of emotion in musical expressivity is a topic of controversy in current music education. However, the Emotional Contagion Theory proposed by Juslin et al. (2010), provides substantial evidence suggesting that emotional expression can influence the way the musical instrument is played, impacting various performance features such as loudness, timing, articulation and interpretive inflections (Juslin 1997; Juslin 2000; Karlsson & Juslin 2008). According to this theory, the amygdala is involved in analyzing the emotional meaning of sensory stimuli and coordinating the actions of various brain systems in an associative way (Pessoa 2008), enabling an appropriate response. The amygdala can automatically activate a series of reactions that prepare the body for a specific response to each situation by sending signals to several regions of the brain. Emotion-derived reactions can influence human activities, such as cognition, body posture, gestures, and prosody, also reflecting in the way a musical instrument is played (Higuchi et al., 2011), thus affecting the musical expressiveness. Therefore, focusing on emotional aspects could decrease explicit motor control, inducing implicit procedural memory, while cognitive executions would invariably be grounded on explicit memory.

Currently, there is an understanding that different brain areas are involved in the formation, consolidation and processing of explicit and implicit memories, indicating that these two types of memories would be distinct and independent (Schacter 1992). The mechanisms of the formation of explicit memories involve several brain areas, mainly the hippocampus (Squire & Wixted 2011), while procedural memory involves mainly striatum (Albouy et al., 2013). Specific parts of the striatum influence an individual's ability to refine their motor skills, learn new procedures, develop useful strategies and adapt to a constantly changing environment (Hikosaka 2002). Piano performances require integration of several distinct natures of memories. Neuroimaging studies indicate that professional pianists activate motor areas when listening to pianistic execution and auditory areas when playing silent piano (Bangert et al., 2006), demonstrating the occurrence of such integrations. However, formal observations in pianistic learning noted that integration of explicit and implicit memories can be complex to many students (Higuchi, 2005; Higuchi & Leite 2007). This fact can be explained through studies demonstrating that infusion of anxiogenic substances in the amygdala in rats may increase striatal function (facilitating implicit memory consolidation) while preventing hippocampal function (inhibiting explicit memory) (Packard and Wingard 2004, Wingard and Packard 2008). Therefore, reconciling all the skills necessary for a more elaborate pianistic execution is challenging, as it requires integration of many brain systems that, in several circumstances, can be mutually inhibitory.

Nonetheless, many piano students spontaneously integrate diverse skills, making it difficult to identify such antagonisms (Higuchi 2004). Thus, a more detailed and profound study on the physiology of integrative and inhibiting aspects of pianistic execution can provide important data about the functioning of the brain. It can also contribute to a better understanding of the various phenomena involving learning and musical execution, as well as the interaction between cognition and emotion.

Therefore, the present study aims to use functional Magnetic Resonance Imaging (fMRI) to compare brain activity of pianists focusing their attention either on the cognitive or emotional aspects of the performance of the same piano piece. We believe that these data can provide a rich source of information regarding the multimodal integrations in the pianistic performance.

Materials and Methods

Sample Characteristics

Right-handed pianists who engage in professional or semi-professional activity related to the classical piano were recruited. This study was previously approved by Ethics Committee of USP (Process Number: 12191/2007). All participants were informed about the study protocol’s objectives, and they provided written consent.

The exclusion criteria consisted of the following: (a) left-handed; (b) history of neurological diseases; (c) magnetic resonance imaging contraindications, such as pregnancy or metal parts in the body, including cardiac pacemakers, stents, implants, etc. The inclusion criteria included: (a) age greater than 18 years; (b) graduate or undergraduate students who studied at music college or conservatory related to the classical piano; (c) started the music study after age of seven. Seventeen pianists were initially recruited, and two of them were excluded due to excessive head movement (more than 2mm or 2 degrees) during fMRI acquisition. The final sample comprised 15 pianists, with a mean age was 24.5 years (SD= 6.0; range: 18-38).

Imaging Experimental Design

The pianists performed musical tasks during an fMRI scanning in a 3.0 Tesla MRI machine (Philips – Magneto Intera Achieva). The tasks presentations were synchronized with the fMRI acquisition using a triggering circuitry. The subjects' head and forearms were restrained with foam padding. Brain functional images were acquired using a gradient-echo planar imaging sequence T2* (repetition time (TR) = 2000 ms; echo time (TE) = 40 ms; Field of View (FOV) =230mm x 120 mm x 230 mm; 64x64 matrix; flip angle = 90 degree; slice thickness = 4 mm; acquisitions = 240 scans; number of slices = 30; and interleaved acquisition method) and brain high-resolution structural images were acquired using a T1-weighted image (TR= 5.7 ms; TE = 2.6 ms; flip angle = 8 degree; 256 x 256 matrix; slice thickness = 1 mm; number of slices = 180; and FOV = 256mm).

Imaging Analysis

The hemodynamic responses based to the blood oxygenation level-dependent (BOLD) fMRI signal changes were analyzed using Brain Voyager TM 20.6 software (Brain Innovation, Maastricht, The Netherlands) by general linear model (GML) approach. The dataset was corrected for motion and slice time correction, and it was filtered in the space domain (8 mm FWHM – Full-Width Half Maximum) and filtered in the time domain (high-pass filter at 0.01 Hz). Individual functional maps were normalized into the Talairach anatomical atlas (Talairach & Tournoux, 1988).

After preprocessing, first-level analysis was performed on each subject using the GLM with a boxcar waveform convolved with a canonical hemodynamic response function. Furthermore, z-transform motion confounds of each subject were used as confounders in the GLM. Two regressions of interest were created for each experimental condition: (i) affective performances (ii) cognitive performances

After transformation into the Talairach anatomical atlas, fixed effects group analysis was calculated using a whole-brain analysis approach of these contrasts: (i) affective performances (ii) cognitive performances. The statistical threshold considered significant was set to $q(FDR)<.05$. Our a priori hypotheses were to demonstrate amplified sensorimotor activity spread across the fronto-parietal network, and language/visual areas, supporting explicitly motor controlled execution in cognitive condition. While in affective condition would present greater activity in limbic areas.

Procedure

Before fMRI sessions, the volunteers underwent 5 training sessions (described in Higuchi et al., 2011) where they were trained to play a repertoire (the prime part of an adaptation of a four-handed piano piece entitled Trauer, from opus 85, by R. Schumann) under two different conditions. In the first condition, called “cognitive performances”, they were instructed to play while thinking about each note they played (visualizing the score, planning the movements, or thinking in advance about the notes they would play next). In the second condition, called "affective performances”, the volunteers were induced to the emotion of sadness by watching selected photos of negative content from the International Affective Picture System (IAPS) presented with Trauer as background music.

Each volunteer also had a one-hour recording session where they were instructed to play in these two distinct manners. The best pair of recordings (one cognitive and one affective) focusing the attention on the respective task, according to volunteers' comments, was selected.

The pianist participants also went through a training session where all the procedures they should perform inside the MRI scanner machine were explained and applied.

Inside the fMRI machine, the pianist volunteers performed two distinct tasks of bimanual performances (one cognitive and one affective), with the sequences of the executions of the two tasks being made alternately so that the executions were presented evenly in all orders. Each task was performed in a specific run lasting 8 minutes. During the tasks, the volunteers listened to a 24-second fragment of the recording (from part B of the piece) selected among their own performances in the recording sessions. In both cognitive and affective conditions, each volunteer listened to their respective performance fragments and was instructed to listen and play along with the recording according to each condition.

Figure 1

Trauer's primo part score: Part that was executed by the volunteers

Note. All the tempo, dynamics and expressive indications were removed from the score in order to avoid induction of any expressive interpretation.

Study protocol

Each run starts with a 20-second rest (R), followed by a 5-second preparation (P), a 20-second execution (E), and a 1-second stop instruction (I). This entire sequence (rest, preparation, execution, stop instruction) is repeated 10 times in each run and ends with a rest of 20 seconds. Therefore, each run presents this sequence:

R – P – E – I - R – P – E – I - R – P – E – I - R – P – E – I -
R – P – E – I - R – P – E – I - R – P – E – I - R – P – E – I -
R – P – E – I - R – P – E – I – R

Data acquisition

The participants played on a custom-designed piano with an extension of two octaves from F 4 to E 6 of optical fiber MRI compatible materials (Nata Technologies). Volunteers listened to their performance within the scanner, along with recording through the Cakewalk program.

Inside the scanner, the volunteers performed the tasks with the piano leaning on the volunteer's lap, with their forearms immobilized to prevent movements of the forearms from moving the head. The eyes were also covered to prevent activation of the visual system.

Analysis of Behavioral Data

Before the fMRI sessions, the volunteers underwent five training sessions as described in Higuchi et. al. (2011). We were able to retrieve data from the pianistic executions performed within the MRI scanner by converting the Cakewalk work file (.cwf format) into a MIDI (Musical Instrument Digital Interface) file (.mid format). . With these data recordings, we quantified errors and compared specific musical features, namely articulation and pulse clarity, using two musical descriptors, as described in (Higuchi, Fornari et al, 2011). We calculated the averages of the results of errors and predictions of the descriptors of all performances. We statistically compared the means of cognitive performances with the affective ones. If the differences between the samples presented normality, we applied the paired Student t-test.

Results

Analysis of Behavioral Data

Table 1. Comparison of articulation and pulse clarity means.
a= affective performances
c= cognitive performances

Normality tests	articulation a	articulation c
D'Agostino &Perason omnibus	p=0,0002	p<0,0001
Shapiro Wilk	p<0,0001	p<0,0001
KS	p<0,0001	p<0,0001
Media	0,5044	0,5024
Mediana	0,504	0,5038
Wilcoxon	0,001	

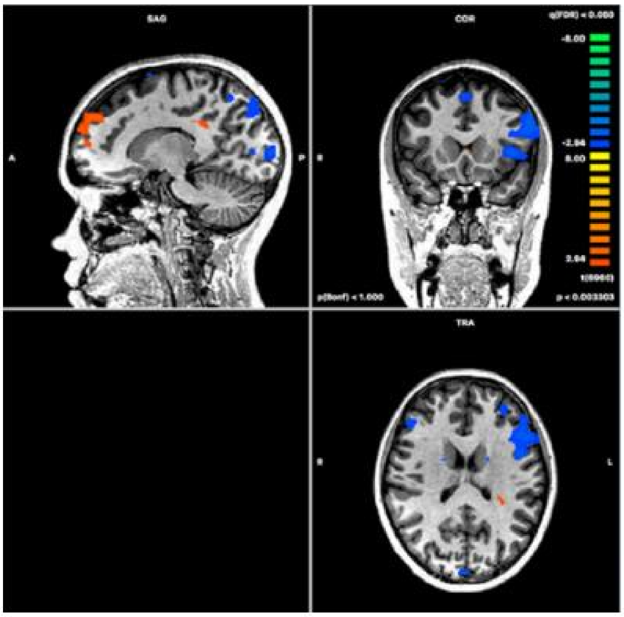
Normality tests	pulse clarity a	pulse clarity c
D'Agostino &Perason omnibus	p=0,25	p=057
Shapiro Wilk	p=0,29	p=0,48
KS	p=0,20	p=0,20
Media	4,44	4,45
SD	0,2822	0,2894
Test-t	0,35	

Note. Results demonstrated more legato in affective performances when compared to cognitive, but no statistical difference was found in pulse clarity

Analysis of fMRI Data

Data Comparing Experimental Conditions Figure 1 and Table 1/2 illustrate the results of the contrast affective – cognitive conditions

Figure 2. Contrasting brain activity between affective and cognitive conditions.



Note. Red-colored areas represent more activation in affective condition, and blue-colored areas represent more activation in the cognitive condition. Significant differences were set at q(FDR)<.05. The contrast of affective minus cognitive condition demonstrated greater activations in the anterior medial prefrontal cortex and right DLPFC. The contrast of cognitive minus affective condition greater activation in central executive network (CEN), pre-supplementary motor area (pre-SMA), supplementary motor area (SMA), language and visual areas.

Table 2

Brain areas with increased activity in affective minus cognitive performance contrast.

Gyrus	Hemispher	Voxels	X	Y	Z
Superior Frontal Gyrus	Left	58	-10,931	59,36207	23,81034
Superior Frontal Gyrus	Right	598	13,01171	56,98161	30,33278
Medial Frontal Gyrus	Left	71	-6,12676	62,49296	14,30986
Medial Frontal Gyrus	Right	97	7,649485	59,89691	18,35052

Note. The table shows brain areas with increased activity in the affective performance condition compared to the cognitive performance condition, including the hemisphere, number of significant voxels, and MNI coordinates.

Table 3

Brain areas with increased activity in cognitive minus affective performance contrast.

Gyrus	Hemispher	Voxels	X	Y	Z
Middle Temporal Gyrus	Left	329	-59,2432	-45,1884	4,866261
Postcentral Gyrus	Left	157	-50,3885	-33,5924	51,80892
Postcentral Gyrus	Right	732	43,62158	-29,4822	55,46038
Inferior Parietal Lobule	Left	2609	-44,7401	-46,5159	46,74051
Inferior Parietal Lobule	Right	2181	43,76708	-47,4897	49,29895
Supramarginal Gyrus	Left	39	-40,359	-41,8205	36,69231
Sub-Gyral	Left	209	-28,9904	-12,6507	40,49761
Sub-Gyral	Right	67	27,44776	-10,6418	53,25373
Angular Gyrus	Left	116	-34,7845	-64,0431	34,5431
Precuneus	Left	1609	-25,3785	-73,7278	39,90429
Precuneus	Right	2304	16,91146	-72,7691	41,32031
Superior Parietal Lobule	Left	1221	-33,1818	-61,9812	48,10319
Superior Parietal Lobule	Right	1311	33,61709	-60,3989	51,46682
Cuneus	Left	600	-5,86667	-91,1833	7,26
Cuneus	Right	1019	10,29342	-88,6585	14,8685
Superior Occipital Gyrus	Left	117	-33,7692	-80,5556	30,23077
Precentral Gyrus	Left	1087	-44,874	0,356946	37,79945
Precentral Gyrus	Right	968	34,14566	-18,6446	59,34917
Superior Frontal Gyrus	Left	850	-10,5	7,015294	56,14824
Superior Frontal Gyrus	Right	896	14,86272	7,733259	57,10379
Middle Frontal Gyrus	Left	2460	-43,8134	8,902439	41,57033
Middle Frontal Gyrus	Right	1007	33,70506	9,376365	50,02284
Medial Frontal Gyrus	Left	448	-5,95759	5,189732	51,5067
Medial Frontal Gyrus	Right	56	4,910714	6,446429	51,08929
Inferior Frontal Gyrus	Left	1952	-51,2485	14,77408	20,75461
Inferior Frontal Gyrus	Right	103	36,24272	24,52427	4,087379
Insula	Left	535	-39,1776	15,44112	3,966355
Insula	Right	134	33,88806	21,70149	2,574627
Lingual Gyrus	Left	317	-7,43849	-89,7256	1,952681
Lingual Gyrus	Right	149	12,89933	-90,0537	0,912752
Cingulate Gyrus	Left	43	-8,37209	6,232558	46,48837
Fusiform Gyrus	Left	285	-47,2351	-48,9825	-14,0561
Inferior Temporal Gyrus	Left	112	-51,7589	-49,125	-11,8036
Superior Temporal Gyrus	Left	51	-59,4706	-43,3922	7,019608

Note. The table shows brain areas with increased activity in the cognitive performance condition compared to the affective performance condition, including the hemisphere, number of significant voxels, and MNI coordinates

Correlations

The volunteers evaluated the expressiveness level of their own cognitive and affective performances. Three expert pianists analyzed the expression level of all volunteers' cognitive and affective performances. The degree of expressiveness was measured using 10 cm analog scales, with 0 representing no expressiveness and 10 maximum expressiveness.

The correlations between expressiveness level of affective/cognitive performance evaluations and both amygdales and left DLPFC were analyzed, as these areas have been respectively associated as core of emotional and cognitive regions.

The correlations between volunteers' expressiveness level of their own affective performances' evaluations and right amygdala/left DLPFC are as follows:

	right amygdala	left DLPFC
Pearson r	r -0.5300	r 0.5403
95%confidence interval	-0.8197 to -0,02418	0.03861 to 0.8244
R squared	0.2809	0.2919
P (two-tailed)	0,0421	0.0376

Note: ROI variable had two positive correlations with volunteers' own expressiveness level and left DLPFC, as well as with the right amygdala ROI, in the expressive execution task.

Pearson r	r 0.5475
95%confidence interval	0.04886 to 0,8277
R squared	0.2998
P (two-tailed)	0,0346

Note: There was a positive correlation between the expert pianists' expressiveness evaluations with right amygdala ROI in the cognitive task.

Pearson r	r 0.6707
95%confidence interval	0.2412 to 0.8805
R squared	0.4499
P (two-tailed)	0,0062

Note: There was a positive correlation with our left DLPFC cluster in the cognitive task, with the expert pianists' expressiveness evaluations.

Discussion

In this study, we aimed to investigate the neural systems involved in the reciprocal modulation of cognition and emotion during piano performances using fMRI.

Our analysis of fMRI recording during performance showed more legato in affective performances than in cognitive performances, suggesting that the tasks were executed appropriately according to the instructions. While we found no difference in pulse clarity, our comparison of brain activation between performance in cognitive minus affective conditions revealed increased activity in bilateral frontal, parietal, and occipital areas, as well as in the left temporal lobe. These regions area involved in the central executive network (CEN), the pre-supplementary motor area (pre-SMA), supplementary motor area (SMA), language, and visual areas, suggesting increased activity in areas related to explicit motor control that supports automatism inhibition. On the other hand, the contrast of affective minus cognitive condition demonstrated increased activity in the anterior medial prefrontal cortex and right DLPFC, which may be related to expressiveness and intuition in musical performance. Our results suggest that directing focus on cognitive or emotional aspects may activate distinct executive meta-systems that, while independent, may have reciprocal interactions.

The dualism and integration between the cognition and emotion (Blair et al., 2007; Damasio 1994; Pessoa 2008) has fascinated psychologists and neuroscientists over the past few decades. Both emotional (Juslin, Karlson et al., 2006; Sloboda & Davidson 2003), and cognitive (Bharucha et al., 2006; Naude et al., 2021; Palmer 1997; Palmer & Drake 1997; Palmer & Meyer 2000) aspects of music performances have been extensively studied. One study identified reciprocal inhibitory influence between cognition and emotions in pianistic performances (Higuchi et al 2011), detecting automatism inhibition and inexpressiveness in the cognitive condition and motor control inhibition and expressiveness in affective condition.

In this work, we compared neural systems concerning the piano performances from memory of the same repertory, with attention focused on cognitive or emotional aspects using fMRI. As different tasks required execution of the same succession of notes obeying same time proportion, the sequence of movements between both conditions should be similar. However, the comparison revealed increased activity in bilateral DLPFC, in primary motor area, pre-SMA, and SMA in cognitive condition. Volunteers were asked to think about each note they played, controlling the movements to avoid errors and trying to keep the strict tempo. Therefore, our current data identified greater explicit motor control and consequently automatism inhibition.

Studies implicating improvisation have provided important data to understand the neural systems involved in different forms of executions of this instrument. A study (Bengtsson et al., 2007) contrasting brain activity of classically trained pianists during the improvisation of a piece presented in a score minus the reproduction of the same improvisation found brain activity in areas similar to the cognitive condition of our experiment, such as the right DLPFC, the pre-SMA, rostral portion of the dorsal premotor cortex, and the left posterior part of the superior temporal gyrus. The authors suggest that the DLPFC is involved in attention to action, monitoring, working memory, selection of responses and suppression of stereotyped responses. The rostral part of the premotor cortex is known to be involved in cognitive aspects of actions. The SMA and pre-SMA are involved in the organization and integration of information for the execution and memorization of sequences of more complex internally generated and guided movements (Parsons et al., 2005; Zatorre et al., 2007). The SMA is also involved in the sequence of rhythmic performances, and both dorsal premotor area and SMA are interconnected with the DLPFC. The premotor areas receive a large number of inputs from the parietal lobe, and play an important role in visuo-motor control, planning, programming, initiation, sequencing and execution of spatially directed motions (Parsons et al 2005; Bengtsson et al., 2007). Therefore, these areas may be involved in tasks that require the production of relatively complex sequences contributing to motor prediction (Bengtsson *et al.*, 2007; Zatorre *et al.*, 2007). Bengtsson et al. (2007) suggest that the medial premotor area is more important for temporal processing, while the activity of the lateral premotor cortex is more related to sequencing of movements in the correct order. This is in line with our results, as we found increased activity in the cognitive performances in the bilateral dorsolateral, premotor, and SMA areas.

A possible explanation for increased activity in language areas in this condition could be consciousness. As the pianists were instructed to think about sequence of notes, they necessarily needed to evoke declarative/explicit memories, which require being described by language (Albouy et al., 2013). In our present study, volunteers played the piano blindfolded, and we found extensive increased activity in visual areas, such as the cuneus and lingual gyrus. These results may be due to the visual mental image of the music score and piano keyboard. Therefore, increased activity in cognitive performance may indicate that when our volunteers tried to play by focusing their attention on each note, they visualized the music sheet and/or their own hands playing the piano's keyboard.

In the present experiment, when the affective condition was contrasted to the cognitive condition, we found decreased activity in bilateral DLPFC, pre-SMA, SMA and in language areas, concomitantly with increased activity in bilateral anterior medial prefrontal cortex and right DLFC cortex. According to our pianists, the affective tasks were performed intuitively, and the touches were performed automatically, representing the emotion they were feeling (Higuchi et al., 2011). The decreased activity in the CEN, pre-SMA, SMA, as well as in language areas in the affective condition, enabled the interpretation of inhibition of language and motor-executive control, indicating implicit and automatic executions.

In another fMRI study that compared jazz musicians during pianistic improvisation minus reproduction of a previously memorized song, a dissociation pattern was found in the prefrontal cortex, characterized by extensive decreased activity in the prefrontal lateral cortex, accompanied by increased activity in the frontopolar part of the anterior medial prefrontal cortex. According to this study (Limb & Braun 2008), changes in prefrontal cortex underlie the spontaneous musical composition process, characterized by extensive reduced activity in the lateral part of the prefrontal cortex along with increased activity in the anterior prefrontal medial cortex. In Jazz, the idea that improvisation is performed based on a certain degree of intuition is accepted, and improvisation is considered an individual expression and part of the artist's musical identity.

Studies involving primates suggest that the anterior medial prefrontal cortex (mPFC) has connections with other high-order association cortex, particularly with the supramodal prefrontal area, anterior temporal cortex, and cingulate cortex. Therefore, the rostral prefrontal cortex may have the function of integrating information from the visual, auditory, somatic, and sensory systems of the highest level, and influencing the processing of abstract information and the integration of the results of multiple cognitive operations (Limb and Braun, 2008; Ramnani and Owen, 2004). The anterior mPFC is activated in various high-level cognitive tasks, such as episodic memory rescue, prospective memory, working memory, attention, reasoning, multitasking, rule learning, internally generated information, monitoring of external events, training and handling of task rules, decisions and processing of self-referent information (Koshino et al., 2011). In all these cases, intuition may be linked to these contexts, so we suggest that the increased activity in the anterior mPFC would be involved with intuition.

The anterior mPFC may also be related to the expressiveness resulting from focusing the attention to emotional stimulus during the affective condition. The mPFC shows anatomical projections to many regions of the limbic system, such as the amygdala, and the periaqueductal gray, and their strong interconnection can modulate each other's activity. Previous studies have reported the involvement of this region in the appraisal, representation, elaboration and expression of negative emotions (Bravo 2020; Pinho et al., 2015). MPFC regions have also been shown to integrate sensory information and predict moment-to-moment valued specific outcomes related to stimuli, choices, and actions. Their functional interconnections with striatal, limbic, and cortical regions, such as the insula and amygdala, enable the convergence of sensorimotor integration and visceromotor control in the processing of emotionally relevant information and regulation of behavior. Thus, these regions interface percepts, cognitive context, and core affect, also in relation to music (Koelsch 2010), as mPFC may support association between music, emotions, and memories (Janata 2009; Pinho 2015). Therefore, the increased activity found in the anterior mPFC in the affective condition in our current study corroborates music cognitive studies (Higuchi et al., 2011; Van Zijl & Sloboda 2011; Van Zijl et al., 2014). These studies have demonstrated that performer emotions can improve the music expressiveness, reactivating discussion concerning the importance of emotion to the music expressiveness. Thus, the anterior mPFC can be related to automatism and the expressiveness in the affective condition, as meta-analysis identified consistent increased activity in prefrontal rostral regions concerning mentalizing involving emotional materials tasks (Gibert et al., 2006).

Furthermore, we observed a widening of decreased activity in bilateral DLPFC and increased activity in the right mPFC, extending to the right DLPFC, during the affective condition. The DLPFC has been linked to central executive areas, but other studies have demonstrated that it can exert different functions (Kaller et al., 2011). While the left DLPFC assimilates and analyzes perceived information into entire comprehensible cogwheels, the right DLPFC may be associated with increased requests for integrating interdependent information with intermediate moves into a coherent order, suggesting a larger involvement to higher demands for monitoring and checking. Higuchi et al. (2011) demonstrated more variations of amplitude and pulse clarity in the affective performances, indicating more phrasing and agogic, which are two fundamental features of music expressiveness. Therefore, while the left DLPFC coordinates the execution of a sequence of notes as a single component, the right DLPFC would be involved to integrate information by previous note executions. Therefore, the touch of each note on the piano keyboard, converging sensory and visceromotor control, would influence the next ones, resulting in variations in tempo and dynamic. Hence, the differences between right and left DLPFC could explain pianistic improvisation studies demonstrating increased activity in the right but not left DLPFC (Bengtsson & Csíkszentmihályi 2007; Pinho et al., 2015). Considering the involvement of anterior mPFC in automatism and the function of right DLPFC in adapting actions according to previous moves and independent information, we could suppose the importance of integration of both areas in the procedural memory processing.

As mentioned above, we have identified results that corroborate the reciprocal attenuation of cognition and emotion in piano performances. Greater activations in central executive, language, motor control, and visual areas suggest more explicit controlled actions in cognitive condition. On the other hand, deactivations in these areas and greater BOLD signs in bilateral anterior mPFC, where the right side extends to the right DLPFC, can imply implicit and automatic execution, activations of emotional expression, integrative multitask, and intuition linked regions. Therefore, this dualistic interaction between cognition and emotion in piano performances can be related to the existence of a dual meta-system described in another fMRI investigation involving piano improvisation. Pinho et al., (2015) compared improvisation constrained to express a specific emotion minus improvisation involving determined pitch-set conditions. The fMRI signals suggested increased activity in medial orbital and dorsomedial prefrontal cortices and decreased in DLPFC, dorsal premotor area, and parietal regions, and DLPFC BOLD signal presented increased correlations with default mode regions. According to Pinho et al. (2015), pitch set conditions required the explicit executive mechanism associated with DLPFC, provoking integration of sensory, autonomic, and goal-related information to execute adaptive control. The emotional task required an implicit integrative meta-system composed of the default mode network, where basically automated processes in specialized brain systems are structured under the influence of the mPFC for the adaptable integration of exogenous and endogenous information (Pinho et al., 2015).

The hypothesis of restricted action (Wulf et al., 2001) proposes that when subjects use internal attention (focus on movements), they interfere with the automatic control process that normally regulates movements. Higuchi (2007) observed that piano students who focus their attention to internal cognitive aspects have their automatisms suppressed. The evidence that explicit memory processes mediated by the DLPFC can affect implicit recognition memory (Lee & D'Esposito 2013) supports the hypothesis of restricted action. On the other hand, students who play intuitively spread their attention on extensive areas, processing and associating a large amount of information with low resolution, guiding their performance by implicit (automatism) and auditory feedback. In the same vein, Mcnevin et al., (2003) suggested that the distance from the focus of external attention allows performance to be mediated by the process of automatic control. The indication that the distance from external attention allows performance to be mediated by automatisms may suggest that the attention spread over an extensive area is important for the automatism process.

The identifications of a set of three large-scale, naturally organized networks in the human brain reinforce the Higuchi et al. (2011), which demonstrated the mutual inhibition of cognition and emotion. The fronto-parietal central executive network (CEN), the cingulo-opercular salience network (SN), and the medial prefrontal-medial parietal default mode network (DMN) are considered to play important roles in cognitive and emotional information processing in humans (Chen et al., 2013). Neuroimaging studies have identified that CEN and DMN are organized intrinsically based on spontaneous correlations within each system and anticorrelations between them (Fox et al., 2005). The identification of a causal neural mechanism by which the dorsolateral prefrontal node of the CEN negatively regulates the mPFC portion of DMN and vice versa shows the existence of an antagonistic pattern of activation (Chen et al., 2013). The interaction of emotional and cognitive processes can be associated with the functional mechanism of this medial and lateral prefrontal cortex reciprocal attenuation (Northoff et al., 2004). The cooperative and antagonistic interactions among regions involving specialized large-scale brain systems are essential to generate flexibility of humans' complex behaviors (Cocchi et al., 2013; Ray et al., 2020). Functional segregation of activity within the DMN and control networks encompassing CEN and SN can be essential for successful performance of challenging cognitive tasks, as areas within the DMN can show deactivation with increases in relational complexity of the task (Hearne et al., 2015). Thus, the differences in activity between the medial and lateral prefrontal cortices during cognitive and emotional conditions could be amplified by the reciprocal influence between the two described meta-systems. The complex question introducing topics such as automatic versus controlled processing and explicit versus implicit processing in flow state is constantly associated with hypofrontality (decreased activity of certain parts of the frontal lobes). Explicit processing refers to controlled processing with involvement of working memory, focused attention, and conscious awareness of actions, which are associated with CEN activity. Implicit processing implies more automatic processing of well-learned knowledge or skills that require small guidance of conscious attention. The hypofrontality hypothesis of flow suggests that during flow, implicit or automatic processing is relied upon, where well-learned behavioral or cognitive actions smoothly follow each other, with little or no interference of conscious thinking. In music performance, where flow occurs, it indeed seems to happen (Linden et al., 2020), and the study demonstrating effortless attention in the flow state in piano performance supports this hypothesis (De Manzano et al., 2010).

Furthermore, it could be understood that the hypofrontality level may be indicative of deeper flow states (McPherson et al.,2016), as affective conditions could support automatism, intuition and expressiveness necessary to the pianistic performance flow state. However, Sloboda (2004) observed that one of the main difficulties of average pianists is that the performance sequence is dissociated from conscious control, and a piano piece can be executed automatically. In this case, any mistake can compromise the rest of execution. Furthermore, examples of expressive students who presented mind blockades during musical learning, affecting attention, concentration, motor control and explicit memory have been reported (Gainza 1988; Higuchi 2003).

On the other hand, piano students who play by explicitly decoding each note of the score, thinking about localization on the keyboard, and controlling each movement of their fingers may constrain automatism and expressiveness (Higuchi et al., 2011l). Even repeating these procedures for many years may not lead to successful performance. Therefore, the integration of cognition and emotion meta-systems in a high level of pianistic performance seems to be essential.

The participants in this current study analyzed the expressiveness level of their own performances, which were recorded and employed to draft the auditory stimuli that they listened to during the tasks inside the MRI machine. Three expert pianists also analyzed all the recordings, and both the volunteers and the experts evaluated the affective performances as more expressive than cognitive ones. The positive correlations in DLPFC and amygdala with expressivity level evaluations made by expert pianists and volunteers demonstrated the importance of both cognitive and emotional skills for expressiveness in piano performances.

In the expressive execution task, ROI variable of left DLPFC and also the right amygdala was correlated with volunteers' own expressiveness level evaluation. In cognitive tasks, the activity of the right amygdala and left DFLC were positively correlated to the perception of expressiveness by the expert pianists. A study using fMRI compared brain activation during listening to the same repertoire in an expressive and a mechanical execution (Chapin et al., 2010). In this comparison, the increased activity area included the right amygdala. Consequently, we could suggest that the right amygdala function could be related to the expressiveness. This interpretation could expose evidence that the integration of both cognitive and affective aspects in the right amygdala and left DLPFC is the basis of expressiveness in pianistic performances.

Limitations of our study include the heterogeneity of volunteers, which consisted of both amateur and professional pianists. This was due to difficulties in finding professional pianists who started their musical studies before the age of 7, as the majority of the professionals tend to start before this age. The importance of late age initiation was highlighted in several studies, which suggested that musicians who started their studies before the age of 7 tend to have differences in their brain structures compared to musicians who started their studies later and non-musicians. Specifically, these differences include greater fractional anisotropy in the genu of the corpus callosum (Schmithorst & Wilke, 2002) and increase size in the mid septal area of the corpus callosum (Schlaug, Jancke et al., 1995). These differences in corpus callosum could be interpreted as greater facilities of inter hemispheric integration, which could result in less evident attenuation between cognitive and affective aspects in early age initiation pianists,

Conclusion

In 1994, neurologist Antonio Damasio challenged the prevailing notion of reason over emotion by emphasizing the significance of emotion in reasoning (Damasio et al., 1994; Damasio 1994). The role of emotion in music performance has been debated throughout Western music history, with its importance limited to expressiveness. However, this research suggests that the activation of mPFC and right DLPFC by emotions provides essential elements for piano performances, such as intuition, automatism, multimodal integration and expressiveness. Nevertheless, the dualistic relationship between cognitive and affective meta-systems demonstrated in this study can impede their assimilation. Although some emotional and cognitive behaviors might be partly separable, true integration of emotion and cognition often occurs. In fact, every complex behavior has both cognitive and emotional components (Pessoa 2008; Gu 2013). Therefore, further investigations into this topic can be crucial in clarifying the sources of information on the multimodal integrations of the human nervous system and the influence of cognition and emotion in different human skills. A better understanding of these topics can also provide valuable tools to facilitate musical learning.

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