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Music and cortical blood flow: A functional near-infrared spectroscopy (fNIRS) study

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Abstract

The function of the prefrontal cortex (PFC) appears to be more activated in men than in women when it is conditioned to emotional situations via external stimuli. The aim of the present study was to investigate the effects of different music genres on PFC oxygenation according to gender. Eighteen healthy volunteers (10 males and 8 females), aged 20-28 years (mean: 22.25 ± 2.34 years), participated in the study. They remained in silence, and hemoglobin levels in a linear scattering were recorded (O_2Hb [oxyhemoglobin] and HHb [deoxyhemoglobin]). When this procedure was finished, music was played for 1.5 min. The results showed that different genres of music might change cortical oxygenation in several ways, and such modulation may be related to gender. We conclude that music modulated cortical oxygenation in the PFC in both the right and left hemispheres, and differences in cortical oxygenation were highly related to gender. Furthermore, preferred and motivational songs can be considered the most important for increasing blood flow in the listening process. **Keywords**: brain, activation analysis, music, motivation.

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Introduction

The hormone actions of testosterone and estrogens may alter the form and function of the central nervous system (CNS) because brain cells contain receptors for these molecules (Seney & Forger, 2009). Thus, men and women show different behavioral patterns, such as aggression, affectivity, and perceptual features (Wager & Ochsner, 2005). Furthermore, the processing of external stimuli inside the brain involves emotional factors that might be affected by the structure of the CNS (Gur, Gunning-Dixon, Bilker, & Gur, 2002; Bradley, Codispoti, Sabatinelli, & Lang, 2001).

The prefrontal cortex (PFC) appears to be more activated in men than in women when it is conditioned to emotional situations via external stimuli. To illustrate this concept, León et al. (for review, see León-Carrion et al., 2006) investigated the influence of different emotion-related films on men's and women's cerebral activation. Prefrontal cortex activity was more pronounced in men than in women during exposure to the video clip (on period) and after exposure (off period; i.e., a residual effect), demonstrating the influence of gender on perceptual and physiological responses. In an attempt to produce these effects, emotional components must be integrated in peripheral cues. Sound expression that is carried by music is a usual technique to modulate feelings and perceptions and is able to change psychophysiological responses during numerous tasks in humans (Montinaro, 2010; Razon, Basevitch, Land, Thompson, & Tenenbaum, 2009; Etzel, Johnsen, Dickerson, Tranel, & Adolphs, 2006; Szmedra & Bacharach, 1998). Some of these effects are related to indirect effects on emotional components, evoking remembrances or increasing/decreasing arousal even during physical tasks (Lucaccini & Kreit, 1972; Karageorghis & Priest, 2012a; Karageorghis & Priest, 2012b).

Some music-related components are likely able to vary the influence of music on the brain. For example, music genres are defined by particular features, such as melody and harmony composition, and considered able to induce associative memories regarding former movies or older life scenes. Importantly, music should be investigated as a "whole" because it presents inseparable components. If rhythm is separated from melody, then we would have no more music, which commonly intrigues psychologists/musicologists worldwide because exploring each musical component separately is difficult.

Eerola and Vuoskoski (2012) and Juslin (2013) demonstrated how music can act on emotional responses. They highlighted a variety of studies in this field and

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presented its complexity. Affective valence, arousal, memory, and even adherence are considered usual terms associated with psychological responses. Nevertheless, the various methodologies still need more attention in terms of accuracy. Furthermore, cerebral analyses are still necessary to support psychological hypotheses to explain underlying mechanisms of music exposure.

Functional near-infrared spectroscopy (fNIRS) is an important tool for investigating cortical phenomena that are influenced by external stimuli, such as music (Moghimi, Kushki, Guerguerian, & Chau, 2012). It is capable of demonstrating blood flow variations and cortical activation through a particular process called a chromophore (known as the color fluorescence inside hemoglobin [Hb]; Ayaz, Shewokis, Curtin, Izzetoglu, Izzetoglu, & Onaral, 2011).

The PFC highly participates in the control of feelings (i.e., inhibition) and interpretation of feelings (e.g., happiness; León-Carrión et al., 2007). Auditory stimuli can separately affect several areas related to rhythm, melody, harmony, and tone. Because of this, music might change cortical oxygenation in the PFC, and this response is presumably affected by the particular music genre and structure of the brain, which is different according to gender. Thus, the aim of the present study was to investigate the effects of different music genres on PFC oxygenation based on gender differences.

Methods

Participants

Eighteen right-handed non-musician healthy volunteers (10 males and 8 females), aged 20-28 years (mean: 22.25 ± 2.34 years), participated in the study. All of the procedures were explained before the tests. The subjects signed an informed consent form, and the study was performed according to the Helsinki Declaration and approved by the Local Ethics Committee (ethics protocol no. 212/2011, Universidade Estadual de Londrina). The adults were recruited from the Physical Education and Sports Centre of the State University of Londrina. They had no physical or intellectual problems and refrained from caffeine, alcohol, and nicotine for at least 24 h before the experiment.

Experimental design

All of the subjects were instructed that they would be in the laboratory to perform a neuroimaging test where they would hear different songs and report feelings and perceptions afterward. A fNIRS device (Biopac Systems, 16-channel forehead sensor, 10 photodetectors, four photoemitters, 2.5 mm inter optode distance) was used to detect blood flow variations before and during seven tracks of music exposure. A technician applied the fNIRS sensors in line with positions FP1-FP2 according to the International 10-20 System, designed for recording data from the PFC (Figure 1). The device was positioned on the forehead .5 cm above the eyebrows. All of the experimental procedures were performed in a dark room to avoid external light interference. This apparatus quantifies cortical oxygenation in both hemispheres of the PFC using a luminous signal that penetrates biological tissue, such as the skull and brain. The instrument was developed according to the recommendations of Chance and Leigh and is based on the modified Beer-Lambert Law. Each light source contains two light-emitting diodes with wavelengths of 730 and 850 nm, representing the fluorescence of HHb and O_2Hb, respectively (León-Carrión & León-Domínguez, 2012).

Initially, the participants were seated in a comfortable reclining chair where they remained in silence until hemoglobin values (O_2Hb and HHb) presented a linear scattering. Baseline values were then calculated during a short period of time (10 s), using white noise as background (León-Carrión et al., 2007). When this was finished, music was played for 1.5 min. After each song, the subjects completed a song appreciation scale (SAE), which classified the songs as

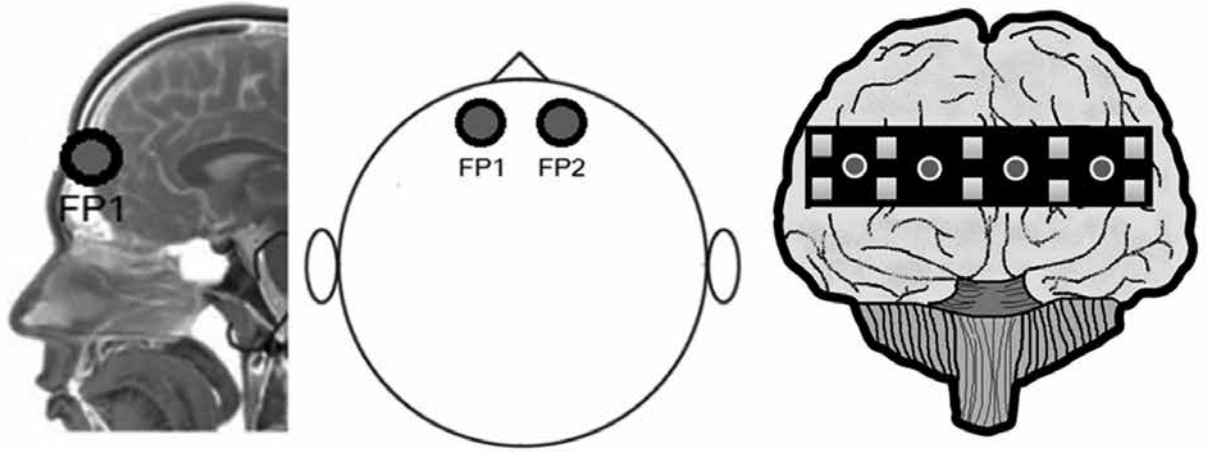

Figure 1. Illustrative description of the fNIRS sensors in line with positions FP1-FP2 according to the International 10-20 System, designed to record data from the PFC.

negative, neutral, or positive, using the question, "What did you think about this song?"

Five musical genres were tested: Rock (RO; "Iron Man," Black Sabbath, 77 beats per minute [bpm]), Folk (FO; "Mr. Tambourine Man," Bob Dylan, 84 bpm), Trance (TR; "Acperience," Hardfloor, 125 bpm), Classical (CL; "Air on G String," Bach, 60 bpm), and Soft Rock (SO; "Tears in Heaven," Eric Clapton, 85 bpm). The songs were carefully selected based on their likely effects on metabolic responses (Yamasaki et al., 2012). Furthermore, the subjects had chosen a preferred song (PR) and a motivational song (MO), for a total of seven song tracks. Instructions for choosing preferred songs were given so the subjects would choose songs that were capable of eliciting good sensations and memories. For motivational songs, the participants were asked to select a song that is capable of increasing perceptual arousal for exercising. All of the tracks were played using an MP4 device (Sony NWZ-E473), keeping the volume at 80 decibels, which was measured directly at the ear with a decibelimeter (Icel DL-4020). The order of the seven songs was random, and the ΔFS was calculated based on initial and final outcomes.

Data processing

A 20th-order low-pass filter was applied, with a normalized cut-off frequency of .1 Hz, which uses a Hamming window. Moving-average windows of .5 s were applied to each dependent variable of the fNIRS. Channels 1-8 were considered the left hemisphere of the PFC, and channels 9-16 were considered the right hemisphere of the PFC (León-Carrión & León-Domínguez, 2012). All of the data processing followed a rigorous treatment method that is provided in the manual of the equipment. The difference between the test values and baseline values is represented as u.a.·μM. The O_2Hb and HHb values were summed to represent blood flow variation (ΔBFL, left PFC blood flow; ΔBFR, right PFC blood flow) after music exposure. The final Hb (average) result provided by the equipment was subsequently divided for each channel. The fNIRS outcomes were analyzed using Microsoft Excel 2010 software to stratify the blood flow according to channels and hemispheres of the PFC.

Data analysis

The statistical analysis was performed using SPSS 17.0 software (SPSS, Chicago, IL, USA). The normality and homogeneity of the data were tested using Shapiro-Wilk's test and Levene's test, respectively. When homogeneity was violated, Greenhouse-Geisser correction was applied. Analysis of variance (ANOVA) was conducted (7 × 2; tracks × gender), followed by Bonferroni's *post hoc* test to separately identify significant differences in ΔBFL and ΔBFR. The significance level was $p < .05$. Cohen's d effect size (ES) was calculated for each dependent variable according to song tracks and gender, based on the description and classification of Cohen (ES > .2, small effect; ES > .5, moderate effect; ES > .8, large effect; Cohen, 1988, 1994).

Results

The participants' ΔBFL values are presented in Figure 2. The PR condition showed significant gender differences (4.15 ± 2.4 a.u.·μM for men *vs.* .46 ± .36 a.u.·μM for women, $p = .002$, ES = 2.09) and was different from CL (1.13 ± 2.4 a.u.·μM, $p = .003$, ES = 1.29), FO (1.79 ± 1.44 a.u.·μM, $p = .023$, ES = 1.19), SO (1.92 ± 2.2 a.u.·μM, $p = .032$, ES = .99), RO (1.14 ± 2.4 a.u.·μM, $p = .004$, ES = 1.29), and TR (2.18 ± 2.2 a.u.·μM, $p = .048$, ES = .87) for men. The MO condition also showed significant gender differences (4.26 ± 4.1 a.u.·μM for men *vs.* .38 ± .65 a.u.·μM for women, $p = .001$, ES = 1.25) and was different from CL ($p = .002$, ES =

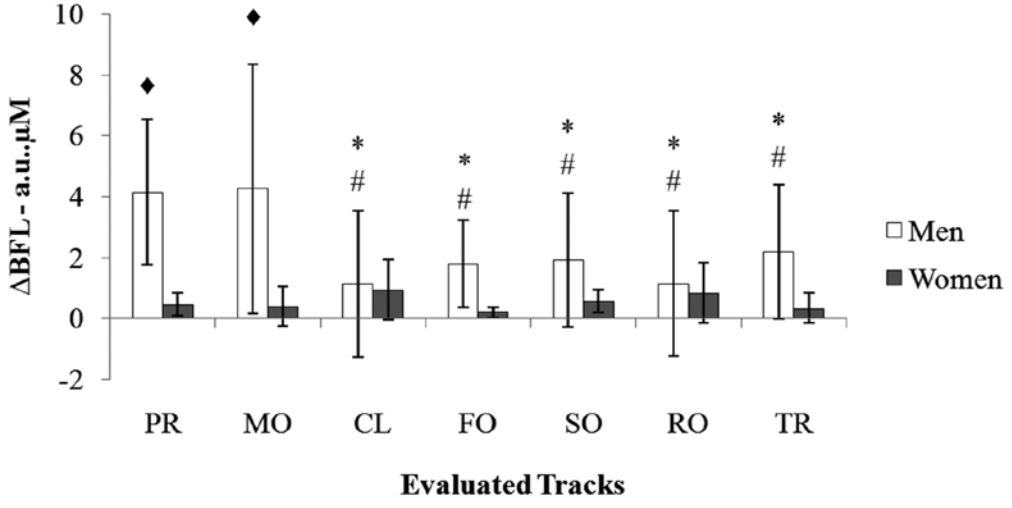

Figure 2. Blood flow variation in the left hemisphere of the prefrontal cortex (ΔBFL) during exposureto seven song tracks according to gender.PR, preferred song; MO, motivational song; CL, classicalsong; FO, folk song; SO, soft song; RO, rock song; TR, trance song; ♦Significant difference between men and women for the same song track; #significant difference comparedwith MO; *significant difference comparedwith PR.

.91), FO (p = .017, ES = .77), SO (p = .024, ES = .69), RO (p = .002, ES = .91), and TR (p = .045, ES = .61) for men. No significant differences were found for women during exposure to any song track (p > .05). ΔBFL was considered statistically similar between PR and MO for men (p = .91) and women (p = .94).

The participants' ΔBFR values are presented in Figure 3. The PR condition showed significant differences according to gender (2.99 ± 3 a.u.·μM for men *vs.* .26 ± .18 a.u.·μM for women, p = .018, ES = 1.24). The MO condition also showed significant differences according to gender (3.5 ± 3.1 a.u.·μM for men *vs.* .9 ± .33 a.u.·μM for women, p = .003, ES = 1.14). Furthermore, MO was different from CL (1.09 ± 2.1 a.u.·μM, p = .018, ES = .91) and RO (1.19 ± 1.9 a.u.·μM, p = .024, ES = .90) for men. No differences were found during exposure to any track for women (p > .05). ΔBFR was statistically similar between PR and MO for men (p = .61) and women (p = .89).

Table 1 presents the ESs for ΔBFL and ΔBFR according to the seven song tracks and gender. The ES of ΔBFL in the PR condition was higher than in the CL,

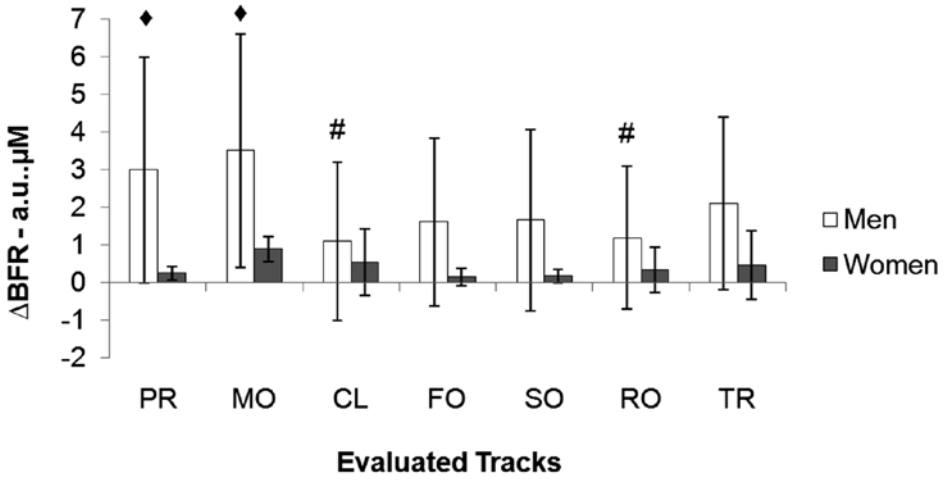

Figure 3. Blood flow variation in the right hemisphere of the prefrontal cortex (ΔBFR) during exposure to seven song tracks according to gender. PR, preferred song; MO, motivational song; CL, classicalsong; FO, folk song; SO, soft song; RO, rock song; TR, trance song; ♦Significant difference between gendersfor the same song track; #significant difference from MO condition.

Table 1. Effect size of prefrontal cortex blood flow (ΔBFL and ΔBFR) among seven song tracks for men and women.

ΔBFL – a.u.·μM							
Track	**PR**	**MO**	**CL**	**FO**	**SO**	**RO**	**TR**
PR	–	–.03	1.29*	1.19*	.99*	1.29*	.87*
MO	.16	–	.91*	.77	.69	.91*	.63
CL	.69	.7	–	–.35	–.42	.01	–.56
FO	–.91*	–.37	–1.00*	–	.07	.47	–.22
SO	–.27	.33	–.49	1.31*	–	.34	.02
RO	.54	.57	–.1	.97*	.4	–	–.46
TR	–.31	–.08	–.76	.37	–.54	–.64	–
ΔBFR – a.u.·μM							
PR	–	–.17	.74	.52	.49	.71	.33
MO	2.57*	–	.91*	.7	.67	.9*	.51
CL	1.6*	–.58	–	–.24	–.26	–.05	–.48
FO	–.54	–2.62*	–.66	–	.02	.2	–.19
SO	–.52	–2.76*	–.64	.1	–	.22	–.19
RO	.19	–1.21*	–.27	.4	.37	–	–.44
TR	.33	–.66	–.09	.45	.43	.15	–

PR, preferred song; MO, motivational song; CL, classical song; FO, folk song; SO, soft song; RO, rock song; TR, trance song; ΔBFL, variation in left hemisphere blood flow in prefrontal cortex; ΔBFR, variation in right hemisphere blood flow in prefrontal cortex; ☐, men; ▭, women; *large effect (ES > .8).

FO, SO, RO, and TR conditions for men (ES > .8, large effect). The MO condition had larger ESs compared with the CL and RO conditions and moderate ESs compared with the FO, SO, and TR conditions (> .5). The ES of ΔBFL in the FO condition for women showed a negative large ES compared with the PR, CL, SO, and RO conditions. The ES of ΔBFR in the PR condition was higher than in the CL, FO, SO, and RO conditions for men (moderate ES). The ES in the MO condition was higher than in the CL and RO conditions (large ES) and FO, SO, and TR conditions (moderate ES). The ES of ΔBFR in the PR condition was higher than in the FO and SO conditions for women (moderate ES). The ES in the MO condition was higher than in the PR, FO, SO, and RO conditions (large ES) and CL and TR conditions (moderate ES). The ES in the CL condition was higher than in the PR condition (large ES). All of the song tracks presented high variations in positive and neutral ratings on the SAE. All of the preferred and motivational song tracks were classified as positive.

Discussion

The aim of the present study was to investigate the effects of different music genres on PFC oxygenation according to gender. The results demonstrated that different song tracks may change cortical oxygenation in several ways, and such modulation may be related to gender. Motivational and preferred songs altered blood flow in the PFC in both hemispheres more than the other song conditions. The SAE values may suggest the influence of song preference, which supports our initial hypothesis that self-selected songs may entail a greater impact on the subject since it carries several factors such as memories and extra musical association that can affect the PFC differently. Importantly, neural connections between the PFC and hippocampus and amygdala (which are related to memory and emotion, respectively, as part of the limbic system; Murray, O'Doherty, & Schoenbaum, 2007) might represent responsible networks for the greater outcome produced by self-selected tracks.

Our findings are consisted with previous studies that reported the cultural and genetic components of social behavior (Seney & Forger, 2009; Wager & Ochsner, 2005) and their influence on cortical oxygenation when stimulated by external signals (León-Carrion et al., 2006). Music is able to increase arousal to improve performance or change mood states (Hall, Witelson, Szechtman, & Nahmias, 2004; Gorski, 2000; Schneider, Habel, Kessler, Salloum, & Posse, 2000), but this sensorial strategy appears to be more responsive in men than in women (Bradley et al., 2001). Women presented lower PFC blood flow values for most of the song tracks. This gender difference was also reported by León-Carrión et al. (2006), who presented similar results using a variety of movie scenes that carried emotional content, demonstrating that the magnitude of effect for men is higher compared with women. This intriguing finding may have a historical explanation. Females still retain some protection against external influences that makes them less amenable or susceptible to change based on environmental influences (Bradley et al., 2001; Gur et al., 2002; Wager & Ochsner, 2005).

Moreover, choosing motivational and preferred songs with certain intrinsic components is related to prior experience, including positive and negative memories, with that song. Prior experience with the songs was not controlled in the present study, which might have affected the results. The classical and rock songs had similar results, with a moderate ES for women compared with the MO and PR conditions. This could indicate a higher level of difficulty selecting suitable tracks in women.

The high PFC activity in the left hemisphere in the PR and MO conditions may have affective interpretations (Killgor, Gruber, & Yurgelun-Todd, 2007; Davidson & Irwin, 1999). The right hemisphere of the PFC is highly related to rhythmic counting, tone comparisons, and melodic analysis (Montinaro, 2010), which could explain the higher blood flow associated with the PR and MO conditions in men.

Moghimi et al. (2012) investigated emotional responses to music in the PFC using fNIRS. Nine individuals were assessed in a partial (cortical and emotional responses to music) psychophysiological model. A significant association was found between emotional consequences and the maximum wavelet coefficient, which was extracted from oxygenated hemoglobin indices. Larger maximum wavelet coefficients were highly associated with high arousal and negative emotions. Notably, the present study applied a simpler technique to identify the subjects' musical appreciation, but positive or neutral responses were reported by most of the participants for all of the song tracks.

In summary, the present study provided important information about personal responsiveness and external audio stimulation. The fNIRS device was able to demonstrate that different song tracks altered cortical oxygenation in the PFC, mainly in the PR and MO conditions. The participants chose their preferred songs for physical exercise purposes using a self-selection method. The preferred songs reliably activated the PFC, which may provide exercise-related improvements, inspire good feelings, and evoke emotions. However, the low number of participants in both groups is a limitation of the present study, and the present results should be interpreted with caution. We did not control for prior experience with music, which is also a limitation of the study. Prior experience with these specific song tracks may have compromised the outcomes. The music selection was based on a careful process of identifying songs that are representative of their genres. However, it is important to emphasize that those tracks represent peculiar features (e.g. lyrics, harmony and melody). Thus, the cerebral response produced by these influences are directly associated with these tracks. Testing other songs classified within the same music genre might

entail different responses. Presenting multiple tracks within the same genre would increase the number of trials performed and subsequently increase the statistical power. The lack of emotion-associated responses to music should be better explored in future studies to correlate the final outcomes with psychological and perceptual responses to each musical genre.

Conclusions

Music was able to modulate cortical oxygenation in the PFC in both the right and left hemispheres, and differences in cortical oxygenation were highly related to gender, in which men exhibited higher activation than women in the PR and MO conditions. Future studies should address the limitations of the present study and develop psychophysiological models to better understand the effects of different rhythms on cerebral, behavioral, and physiological responses.

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