

# Brain networks mediating the influence of background music on selective attention

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## Abstract

Prevalent across societies and times, music has the ability to enhance attention, a property relevant to clinical applications, but the underlying brain mechanisms remain unknown. It is also unclear whether music produces similar or differential effects with advancing age. Here, we used event-related functional magnetic resonance imaging to investigate the influence of music exposure evoking four types of emotions on distinct attentional components measured with a modified attention network test, across 19 young ( $21 \pm 2.6$ ) and 33 old participants ( $72 \pm 5.4$ ). We then determined whether music-related effects differed across age groups and whether they were associated with particular acoustic features. Background music during selective attention requiring distractor conflict resolution was associated with faster response times and greater activations of fronto-parietal areas during happy and high-arousing music, whereas sad and low-valence music was associated with slower responses and greater occipital recruitment. Shifting and altering components of attention were unaffected. The influence of music on performance and brain networks was similar between age groups. These behavioral and neuroimaging results demonstrate the importance of affective music dimensions, particularly arousal, in enhancing selective attention processes. This study adds novel support to the benefits of music in the rehabilitation of attention functions.

**Key words:** acoustic features; aging; emotion; executive control; fMRI; neuroimaging

## Introduction

Prevalent in human culture, music is pervasive in daily environments, including public restaurants or shops, but also widely used as an accompanying stimulus during various cognitive or physical activities, such as driving, running, reading or even at work. In consequence, one might wonder about the impact of music on performance in these activities. Previous research reported that background music may improve both mental and physical capabilities in neurological conditions (Thaut *et al.*, 1997; Trombetti *et al.*, 2011; LaGasse and Thaut, 2012; Hars *et al.*, 2013), as well as enhance cognitive performance in certain tasks in healthy individuals (Thompson *et al.*, 2001). In particular, an

effect of music has frequently been observed on attention, a key cognitive ability to allocate processing resources to specific and relevant sensory information. However, the exact mechanisms mediating music-related benefits on attention, including the ability to respond swiftly or selectively to targets in the presence of concomitant distractors (Rowe *et al.*, 2007; Bolger *et al.*, 2013; Trost *et al.*, 2014), remain poorly understood, and their neural substrates are still unresolved.

On one hand, music is known to induce strong emotions in listeners (Blood and Zatorre, 2001), which might in turn influence attentional states (Mitchell and Phillips, 2007; Vanlessen *et al.*, 2016). Most behavioral studies assessing the impact of music

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on attention (Rowe et al., 2007; Jiang et al., 2011; McConnell and Shore, 2011) used music expressing basic categories of emotions (Ekman, 1992), e.g. sad or happy, and typically reported selective changes in attentional control following happy music exposure (Rowe et al., 2007), particularly when the music was considered as highly arousing (McConnell and Shore, 2011). However, the range of emotions evoked by music is much wider than these dichotomous categories, and some theoretical models have suggested music-specific dimensions to account for emotional feelings experienced during music listening across various genres. For instance, it has been proposed that musical emotions encompass nine main affective states (Zentner et al., 2008), which are organized along two continuous and orthogonal dimensions of valence (positive to negative affect) and arousal (calm to excitement) according to the 'circumplex model' of affect (Russell, 2003; Trost et al., 2012). Therefore, investigating a larger range of music-induced emotions systematically varying along these dimensions would be necessary to better characterize the effect of music on attention and its relationship with affective states.

On the other hand, previous work also demonstrated that particular features of music, such as metrical structure, can determine its influence on attention. For instance, attention to visual information is boosted specifically when a strong beat occurs simultaneously with the visual stimulus, suggesting that attention is entrained rhythmically with music meter (Bolger et al., 2013; Trost et al., 2014). However, it remains unclear whether these effects on attentional performance depend on the arousing nature of rhythmic/acoustic features of music, such as tempo and energy, or whether they might be mediated by changes in the emotional states induced by these musical features. Hence, a better understanding of musical effects on attention would require more explicit dissection of both the affective and acoustic parameters of music exposure.

Finally, cognitive research on attentional processes has classically distinguished three different components underlying selective visuospatial processing (Posner and Petersen, 1990; Petersen and Posner, 2012), each of which could possibly be modulated by exposure to music and associated emotions. These attentional components comprise executive control, alerting and orienting processes, which can be separately measured in a single task such as the attention network test (ANT; Fan et al., 2002; Fan et al., 2005). Executive control is defined as the ability to selectively attend to a given sensory information by ignoring surrounding distractors; whereas alerting is the ability to generate or maintain a high state of responsiveness toward stimuli and orienting is the ability to direct or shift the focus of attention to a particular localization or feature of stimuli. Besides its usefulness to assess distinct attention components, the ANT is highly sensitive to modulatory effects and individual differences due to various factors, including music (Rowe et al., 2007; McConnell and Shore, 2011) as well as age (Jennings et al., 2007) or mood and affective states (Phillips et al., 2002; Pacheco-Unguetti et al., 2010).

In the current study, we addressed these issues by systematically evaluating how exposure to naturalistic music modulates attention performance in the ANT, and examining its effect on brain networks engaged by each attention component, namely, executive control, alerting and orienting. More specifically, we aimed at determining the role of particular affective properties of music, along both the valence and arousal dimensions, as well as particular rhythmic or acoustic features, such as tempo, pitch or pulsation. By evaluating the influence of background music on attention, this study might contribute to a better understanding of which type of music, regarding their affective

dimension, might benefit or hamper daily-life activities performed under music exposure, such as driving. Moreover, given growing interest in exploiting music for remediation of both motor and cognitive function in health promoting perspectives, we also investigated whether music exposure might produce differential effects on attentional performance with advancing age, and therefore compared two groups of young and older adults, respectively.

## Materials and methods

### Participants

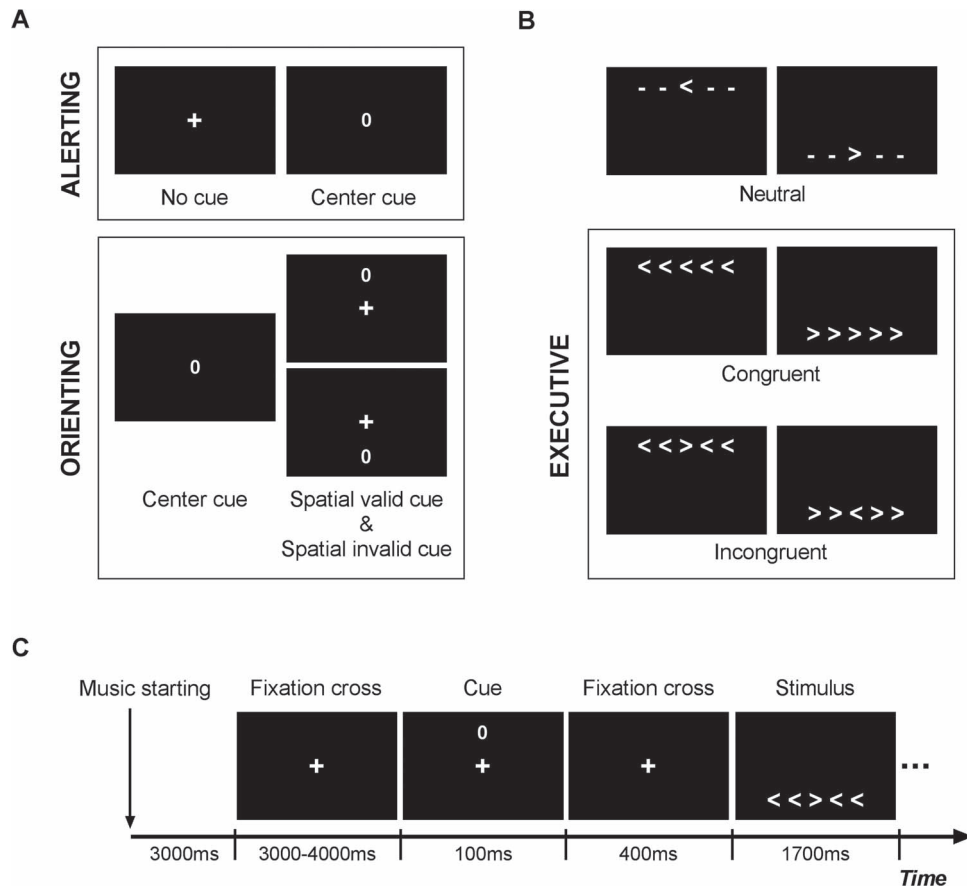
About 19 young ( $M=21$  years  $\pm 2.6$ ) and 33 older adults ( $M=72$  years  $\pm 5.4$ ) matched for education ( $M=14$  years  $\pm 1.7$  and  $M=13$  years  $\pm 2.3$ , respectively) participated in the functional magnetic resonance imaging (fMRI) experiment. Besides standard inclusion criteria (i.e. no neurological, psychiatric and toxicological history), all participants were female, French speakers, right-handed, with normal or corrected-to-normal vision. They had no professional musical expertise, but enjoyed listening to classical music in everyday life. The study was approved by the local ethic committee of the University of Geneva.

### Auditory material

Musical excerpts were validated in a previous study (Trost et al., 2012) and included 12 pieces of instrumental classical music, each evoking one out of four distinct emotions, namely joy, tension, sadness and tenderness. These four categories are part of the nine-dimensional Geneva Emotional Music Scale (Zentner et al., 2008) and organized along two orthogonal dimensions of valence (i.e. unpleasant–pleasant) and arousal (i.e. relaxing–stimulating) (Trost et al., 2012). Thus, joy and tenderness are defined as highly pleasant along the valence scale, while tension and sadness are associated with low valence ratings. Orthogonally to this, joy and tension are highly arousing, while sadness and tenderness are low on arousing. Our set of musical excerpts comprised three pieces for each of these four emotion categories and was presented twice each during the experiments. They all had a duration of 45 s. Ratings of the subjective affective experience evoked by each musical piece were recorded after each scanning session for both valence (from 0=low pleasantness to 6=high pleasantness) and arousal dimensions (from 0=very relaxing to 6=very stimulating). These ratings were consistent with our emotional classification of the pieces, with high valence scores ( $>3$ ) for joy and tenderness, as well as high arousal scores ( $>3$ ) for joy and tension. These values did not differ between the two age groups ( $F_{(1,39)}=0.93$ ;  $P=0.34$  for valence, and  $F_{(1,39)}=1.38$ ;  $P=0.24$  for arousal; see mean scores for each group in [Supplementary material](#)), indicating that age had no impact on the liking of classical music among our participants.

### Experimental design

Following a practice session, participants were installed inside the MRI scanner, where visual stimuli were back-presented on a rectangular screen from a distance of 100 cm, while auditory stimuli were delivered binaurally through high-quality headphones (CONFON HP-SC 01 and DAPcenter mkl, MR confon, GmbH, Germany), with optimal tolerable loudness determined for each participant. Both stimuli presentation and response recording (through an MRI compatible joystick device) were controlled with the Cogent toolbox (developed by Cogent 2000 and



**Fig. 1.** The modified ANT. Illustration of the ANT design, with (A) different types of cues and (B) visual target stimuli used to assess the executive, alerting and orienting components of attention. The double cue is not illustrated here. (C) Standard trial time course at the beginning of a given musical block. After the music started, the first and all subsequent trials began with presentation of a cue (spatial invalid condition here), followed by a visual target with flankers (incongruent condition here). Participants had to indicate the direction of the central arrow (right or left) as fast and accurately as possible (within 1700 ms max after target presentation).

Cogent Graphics) implemented in Matlab 2009b (Mathworks Inc., Natick, MA, USA).

We used a modified ANT, based on previous work by Fan *et al.* (2002), allowing us to probe for three distinct components of attention (executive control, alerting and orienting). Each trial required judging the direction of a central arrow (right or left), presented together with one of three possible distractors, namely congruent, incongruent or neutral flankers (Figure 1). These visual stimuli (arrow with flankers) were preceded by one of four possible types of cues, either a central, double, spatial (valid or invalid) or no-cue conditions, all in the form of a small circle. While the congruent and incongruent conditions were used to evaluate the executive component of attention regardless of the type of cue, the alerting and orienting components were assessed by comparing conditions with different cues (i.e. center and no-cue conditions for alerting; center and valid spatial cue conditions for orienting) (Fan *et al.*, 2005).

While being exposed to naturalistic music pieces (selected as described above), the participants performed the ANT task in a series of 24 short blocks (12 trials per block, each block with a different music piece). The order of musical excerpts as well as the type of cues and target stimuli were presented in a pseudo-randomized order. At the beginning of each block, the musical excerpt started 3000 ms prior to the presentation of any visual stimuli. Each trial began with a central fixation cross (duration pseudo-randomly distributed between 3000 and

4000 ms), followed by one of the four possible cues displayed for 100 ms (see details in Fan *et al.*, 2002). During the no cue-condition, only the fixation cross was presented; whereas in the center, cue condition the cue circle was presented at the screen center. In the double cue condition, two circles were presented simultaneously at the usual position of target stimuli (above and below the central fixation cross), whereas a single circle was presented in the spatial cue condition to indicate either the position of the upcoming stimuli (i.e. spatial valid) or the opposite position (i.e. spatial invalid). Following the cue, a 400 ms interval with the fixation cross alone preceded the presentation of the target stimuli on the screen (duration of 1700 ms). These consisted of a row of five horizontal arrows (corresponding to a visual angle of  $6.18^\circ$ ), where the central arrow was the target (visual angle of  $1.05^\circ$ ), randomly presented (frequency close to 50%) at a visual angle of  $4.35^\circ$  above or below the central fixation cross. In two third of the trials (192 trials), the arrowheads could point toward the same or the opposite direction of the other flanker arrows, referred to congruent condition (Con) and incongruent condition (Inc), respectively. In the remaining third (96 trials), added as a control neutral condition (Neu), the central arrow was flanked by two dashes on each side. No explicit instructions were given to the participants with respect to the cues, but they were asked to focus on the fixation cross and to indicate by button-press the direction of the central arrow as fast and accurately as possible after its presentation. Button

presses as well as reaction times (RT) were recorded throughout the experiment. Please note that detailed analyses and results for both the behavioral and imaging data are presented only for the executive control component of attention, as alerting and orienting components showed more limited effects and are described in [Supplementary material](#).

All task conditions were performed during exposure to the four emotional music categories. No silent condition was used during fMRI as this was not possible due to the rhythmic noise background inherent to echo planar MRI acquisitions, which was efficiently canceled during music presentation but too salient during silence, potentially interfering with attentional performance in uncontrolled ways (Bolger et al., 2013; Trost et al., 2014). We therefore ran an additional behavioral sub-study performed outside the scanner in order to verify the direction of attentional effects during music exposure relative to a baseline condition of the same task without music. This sub-study used the exact same paradigm (testing executive, alerting and orienting components of attention) as well as identical musical excerpts in addition to a silent condition, and was conducted on 46 participants (different from the fMRI group) encompassing 18 young adults (19–32 years,  $M=26$ ,  $SD\pm 4.2$ ) and 28 old adults (58–79 years,  $M=68$ ,  $SD\pm 6.0$ ). Statistical analyses on attentional performance (AC and RT) were similarly computed as in the main fMRI study.

### Behavioral data analysis

Both accuracy (AC; percentage of correct responses) and average RT of correct trials were computed for each participant and each group separately (young and older adults), for each of the four emotions (joy, tenderness, tension and sadness) and for each of the target conditions (congruent and incongruent). A trial was considered as correct when the participant was accurate to indicate the direction of the central arrow within the imposed time limit (1700 ms). Statistical analyses of behavioral data were conducted using R Software, version 3.2.4 (R, R Development Core Team). AC analyses were performed using Wilcoxon rank tests to assess differences between groups and stimulus conditions. The ceiling effect observed for AC rates for both age groups (>90% correct) suggested no major effect of musical emotion. This is the reason why the analysis on AC data and its results are not detailed in this article. RTs were first analyzed using a  $2 \times 2 \times 4$  mixed-model repeated measure ANOVA with congruency conditions (Con and Inc) and emotions (joy, tenderness, tension and sadness) as within-subject factors, plus group (older vs young) as a between-subject factor. In addition, data from the four emotion categories were also reorganized into valence and arousal dimensions and entered in another  $2$  (groups)  $\times$   $2$  (stimuli)  $\times$   $2$  (valence)  $\times$   $2$  (arousal) mixed-model repeated measure ANOVA. Finally, the efficiency of executive control was calculated by subtracting the RT of congruent from incongruent conditions (i.e.  $[\text{mean } RT_{\text{Inc}} - \text{mean } RT_{\text{Con}}]$ ), as described in previous attentional studies (Finucane et al., 2010; Pacheco-Unguetti et al., 2010; McConnell and Shore, 2011) including Fan's work (Fan et al., 2005) and analyzed using a  $2$  (group)  $\times$   $4$  (emotions) ANOVA. As no significant music-based modulatory effects were observed on the executive index, the findings related to this index will not be reported in the current article. For all behavioral analyses and post-hoc tests,  $P$ -values were adjusted with Bonferroni correction.

### Functional MRI acquisition

MRI data were acquired on a 3 T Trio TIM system (Siemens, Erlangen), with a standard 12-channel head-coil. Functional

images ( $T_2^*$ -weighted) were obtained using a multi-slice echo-planar (EPI) sequence (TR/TE = 2000/30 ms, flip angle =  $85^\circ$ , voxel dimensions = 3 mm isotropic, field of view [FOV] =  $192 \times 192$  mm). Structural images (high-resolution  $T_1$ -weighted) were acquired using a magnetization-prepared rapid acquisition gradient echo (MPRAGE) sequence (TR/TE = 1900/2.27 ms, flip angle =  $9^\circ$ , voxel dimensions = 1 mm isotropic, matrix =  $256 \times 256$ ). All fMRI analyses were performed using Statistical Parametric Mapping (SPM8; Wellcome Trust Center for Imaging, London, UK; [www.fil.ion.ucl.ac.uk/spm](http://www.fil.ion.ucl.ac.uk/spm)).

### Analysis of fMRI data and influence of music

Following standard preprocessing (realignment, co-registration, slice-timing correction, normalization to MNI and 8-mm kernel smoothing), a first-level analysis was performed using the general linear model to model correct trials in the ANT. Executive control was assessed by combining the different conditions from this component (Neu, Con and Inc) and the different emotion types (joy, tenderness, tension and sadness) in a SPM matrix, where the condition regressors (onset of the visual stimulus with a 1700 ms duration) were separately modeled and convolved with the canonical hemodynamic response function. Movement parameters (six realignment values) were also entered as non-interest covariates. The second-level whole-brain analysis included each of these regressors in a flexible-factorial design, with the factor of group (older and young) in addition to congruency and emotion. Thus, we could compute the main effect of executive control by comparing incongruent to congruent conditions (Inc > Con) across both groups, and determine the age-related effect on this component by contrasting the two groups (i.e. [Older (Inc > Con) > Young (Inc > Con)]). Note that given the number of trials available for each of our main experimental conditions, we only examined main effects of attention components (see [Supplementary material](#) for detailed fMRI analyses of alerting and orienting), but did not explore any interaction between them.

To then test how brain networks activated by the executive component were modulated by the affective value of music, we computed inclusive masks comprising all voxels whose activity tended to increase (or decrease) during music eliciting a specific emotion relative to all other emotion types (e.g. joy > tenderness + tension + sadness;  $P < 0.01$  uncorrected for multiple comparisons), or during music with different levels of valence (e.g. positive Val+ vs negative Val-) or different levels of arousal (high vs low). These masks were applied on the attention networks recruited by the main effect of executive control (Inc > Con). Please note that the masking procedure did not affect  $P$ -values of statistical contrasts for activated regions, but only excluded non-attention related voxels from analysis. For all second-level whole-brain fMRI analyses, we report activations with significant  $P$ -values ( $P < .05$ ) after family-wise error (FWE) correction for multiple comparisons across the whole brain.

We also performed additional analyses on specific regions of interest (ROIs) to directly probe for a differential effect of the valence and arousal dimensions (not modeled in the whole-brain analysis) and compare the two age groups. For each participant, beta values were extracted from bilateral ROIs using spheres (27 voxels) centered on the main peak coordinates of fronto-parietal and occipital areas identified by SPM analyses of main effect of attention [Frontal:  $x=36$ ,  $y=2$ ,  $z=61$  (right);  $x=-27$ ,  $y=-4$ ,  $z=67$  (left); Parietal  $x=27$ ;  $y=-70$ ;  $z=46$  (right);  $x=-21$ ,  $y=-70$ ;  $z=52$  (left); Occipital  $x=45$ ;  $y=-82$ ;  $z=-2$  (right);  $x=-42$ ;  $y=-85$ ;  $z=-5$  (left)]. In a first step, the differential effect of

valence and arousal dimension was evaluated by submitting the resulting beta values in a 3 (regions) x 2 (stimuli) x 2 (valence) x 2 (arousal) mixed-model repeated measure ANOVAs. In a second step, the effect of age was addressed by entering the values resulting from the same ROIs in 2 (groups) x 2 (stimuli) x 2 (valence) x 2 (arousal) mixed-model repeated measure ANOVAs. All statistical analyses were performed using R Software, and all *P*-values resulting from *post-hoc* tests were adjusted with Bonferroni correction.

### Role of acoustic musical features

To examine the influence of musical features on attentional processing, we selected a set of acoustic parameters that were associated with different musical emotions (see [Supplementary material](#) for details). These were entered as parametric modulators of the stimulus onset regressors (correct trials) in a first level analysis of the ANT (as described above). A second level analysis was then performed using one-sample *t*-contrasts on the parametric modulators from the main contrasts of interest testing attention-related activity (e.g. Inc > Con). A threshold of  $P < 0.05$  FWE corrected with no cluster size restriction was applied on all resulting contrast maps. Differences between groups were again analyzed by comparing beta values extracted from ROIs in the two age groups.

## Results

### Behavioral results

AC and RT results during the main fMRI study are presented in [Supplementary Table 2](#) and in [Figure 2](#). As expected, participants were more accurate in congruent ( $M = 98\%$ ;  $SD = 2.9$ ;  $V = 119$ ;  $P < 0.001$ ) than incongruent conditions ( $M = 94\%$ ;  $SD = 12.6$ ). Regardless of conditions, older adults were less accurate ( $M = 95\%$ ;  $SD = 9.0$ ) than younger adults ( $M = 99\%$ ;  $SD = 1.0$ ;  $W = 209$ ;  $P < 0.04$ ). The RT analysis also revealed a main effect of stimulus ( $F_{(1,50)} = 332.71$ ;  $P < 0.001$ ) with faster responses in congruent ( $M = 677$  ms;  $SD = 131.41$ ) than incongruent conditions ( $M = 840$  ms;  $SD = 187.07$ ), and a main effect of age ( $F_{(1,50)} = 42.18$ ;  $P < 0.001$ ) with older being slower ( $M = 834$  ms;  $SD = 134.77$ ) than younger adults ( $M = 627$  ms;  $SD = 85.41$ ). In addition, there was a significant stimulus by group interaction effect on RTs ( $F_{(1,50)} = 10.87$ ;  $P = 0.001$ ), indicating better executive control in younger ( $M = 100$  ms;  $SD = 43.34$ ) than older adults ( $M = 199$  ms;  $SD = 89.04$ ). This ANOVA also revealed a main effect of musical emotions ( $F_{(3,150)} = 7.50$ ;  $P = 0.0001$ ), with faster responses to visual targets during joy than during both tender ( $t_{(51)} = -3.4$ ;  $P = 0.006$ ) and sad excerpts ( $t_{(51)} = -4.0$ ;  $P < 0.001$ ). No difference in RTs was observed when comparing tension to other emotions ( $P > 0.05$ ). Separate ANOVAs also indicated a main effect of arousal ( $F_{(1,50)} = 14.79$ ;  $P < 0.001$ ) with faster RT during high ( $M = 750$  ms;  $SD = 153.13$ ) than low arousing music ( $M = 766$  ms;  $SD = 158.98$ ), but no effect of valence (Positive:  $M = 757$  ms;  $SD = 158.04$  and Negative:  $M = 760$  ms;  $SD = 153.54$ ). No other effect or interaction was found ( $P > 0.05$ ), in particular for the stimulus by emotion factors ( $F_{(3,150)} = 0.71$ ;  $P = 0.54$ ). The effect of other attentional components (orienting and alerting) is described in [Supplementary material](#).

Finally, results from the behavioral control sub-study revealed a main effect of music condition ( $F_{(4,176)} = 2.67$ ;  $P = 0.03$ ) and fully replicated the findings observed in the fMRI group, with faster RTs during joyful music compared to sadness ( $t_{(45)} = -4.03$ ,  $P < 0.002$ ) and tenderness ( $t_{(45)} = -2.57$ ,  $P = 0.01$ ). There was no difference between tension and other emotions

( $P > 0.05$ ). Critically, faster RTs were found during joyful music compared to the silent condition ( $t_{(45)} = -1.97$ ,  $P < 0.05$ ), while no difference was observed during sad music compared to silence ( $P > .05$ ), demonstrating that the overall pattern of effects reflected a relative facilitation by joy rather than relative slowing by sadness.

### Functional MRI results

We first determined the main effect of attentional conflict (Inc > Con) across both groups and all music conditions ( $P < 0.05$  FWE). This comparison showed widespread activations consistent with networks controlling the executive component of attention, including the bilateral middle frontal gyri (MFG), anterior cingulate cortex/supplementary motor area (dACC/SMA), inferior frontal gyrus (IFG) and superior parietal lobules (SPL), as well as occipital areas, cerebellum and insula ([Table 1](#) and [Figure 3](#)). The between-group comparison revealed greater activation of the right superior parietal cortex ( $x = 21$ ,  $y = -70$ ,  $z = 63$ ;  $Z_{\text{score}} = 4.63$ ;  $P = 0.028$  FWE) in older than younger adults, but no other differences.

Then, we examined how attentional systems were influenced by emotional music exposure ([Table 1](#) and [Figure 3](#)). Specifically, we probed for areas within the executive attention network (defined by increases for incongruent > congruent trials), where activity was differentially increased by a given emotion type relative to the other three emotions (using an inclusive mask for the main effect of each emotion type). Results showed that joyful music enhanced activity in the right-lateralized posterior parietal cortex (SPL), but also in prefrontal cortex (MFG and IFG) and inferior temporal gyrus. On the other hand, tense music enhanced activity in more inferior parietal areas and occipital cortex, including the bilateral inferior occipital gyri (IOG), whereas sad music modulated more restricted clusters in the posterior occipital lobe bilaterally (middle occipital gyri [MOG] and IOG). Tender music produced no differential effect.

When considering only the basic affect dimensions of valence and arousal ([Russell, 2003](#)), we found that exposure to negative (*vs* positive) music enhanced bilateral areas in the MOG and IOG, whereas high (*vs* low) arousing music enhanced right-sided areas in the posterior parietal and prefrontal cortices (SPL, intraparietal sulcus [IPS], as well as MFG, IFG and dACC/SMA, respectively) ([Table 1](#) and [Figure 3](#)). Positive valence and low-arousal music produced no differential effects.

We further examined whether valence and arousal produced distinctive or interactive influences on the attentional network by conducting a separate ROIs analysis (mixed-model repeated measure ANOVA with valence, arousal, condition and region as factors), using beta values from the frontal, parietal and occipital areas (see method section) that were identified in the main effect of attention above. This analysis revealed no arousal x valence interaction (across or within regions), but a significant region x arousal interaction ( $F_{(2,102)} = 3.42$ ;  $P = 0.03$ ), reflecting that the difference in brain activity between high and low arousal musical exposure was bigger in frontal than occipital regions ( $t_{(51)} = 2.93$ ;  $P = 0.01$ ). There was no region x valence interaction.

Likewise, we also performed an additional mixed-model ANOVAs on these ROIs to assess any distinctive effects of age on responses to arousal or valence in attention-related networks (with valence, arousal, congruency and age as factors). However, there was no interaction of age with any of these emotional dimensions all ( $P > 0.05$ ), indicating similar effects of emotional music on brain activity patterns across both age groups.

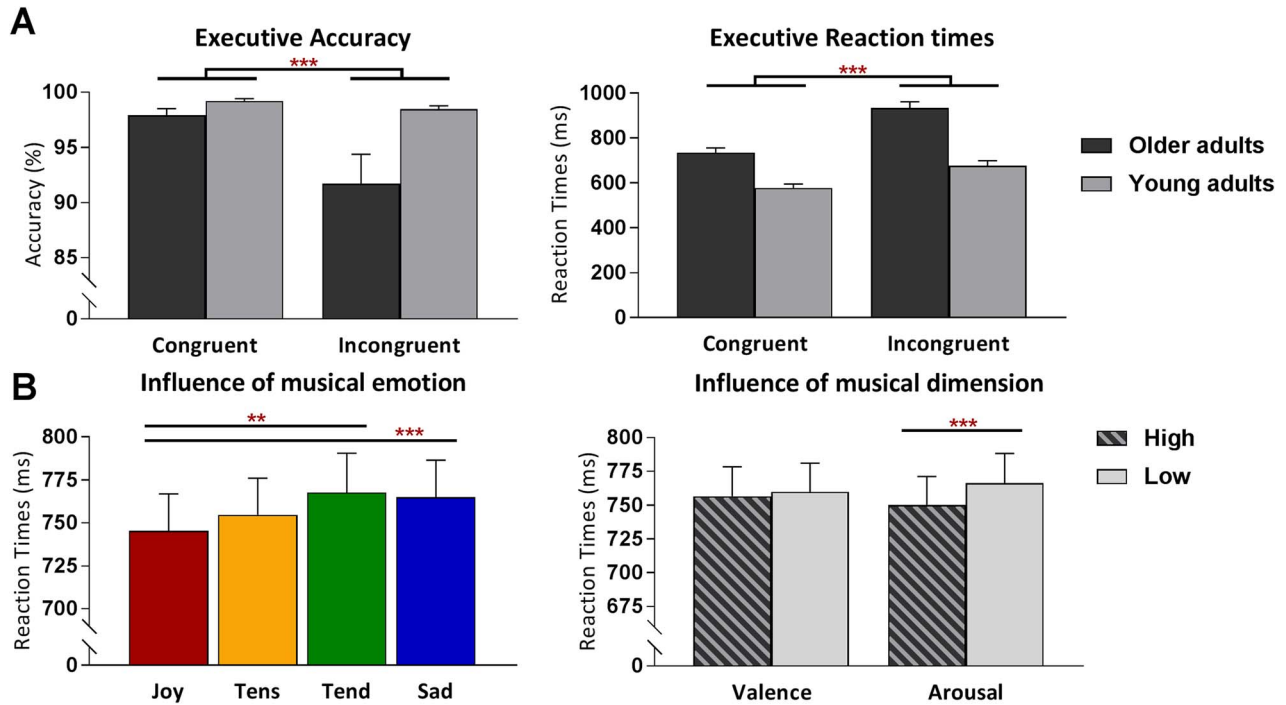


Fig. 2. Behavioral results. Behavioral results for the executive control component of attention, shown for young and old adults separately. (A) Mean accuracy (%) (left) and RT (in milliseconds, ms) (right) for trials with congruent or incongruent flankers. (B) Mean RT (ms) regardless of congruence and group, as a function of the emotion category (left) or the valence and arousal dimensions (right) of background music during the task. Graphs also depict the standard errors of the mean (SEM) and P-values (asterisks) with the following meaning: \*P-value < 0.05; \*\*P-value < 0.01; \*\*\*P-value < 0.001.

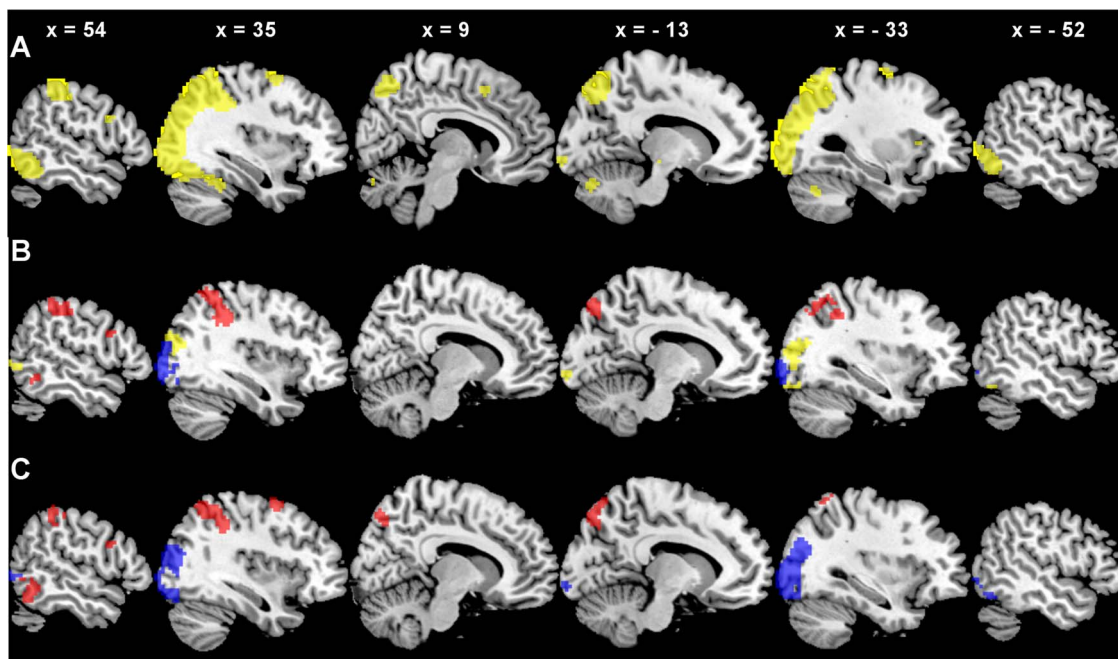


Fig. 3. Brain activations associated with the executive control component. Brain activations evoked by the attentional conflict (incongruent > congruent trials) and recruited across both age group, with areas showing increased activation (A) regardless or (B) as a function of the emotion evoked by background music. Areas differentially engaged according to the emotion category of music are depicted in different colors, namely joy (red), tense (yellow) and sad music (blue). (C) Areas differentially engaged according to basic dimensions of affect in music are depicted for high arousal (happy and tense, red) and low valence (sad and tense, blue). All clusters are significant at the peak-level at  $P < 0.05$  after FWE correction for multiple comparisons.

**Table 1.** Localization (MNI coordinates) and peak activation values (Z score) for brain areas engaged during attentional conflict (regardless of music condition). Music effects were evaluated as a function of the emotion category or emotion dimension conveyed by music. All reported peaks are significant at  $P < 0.05$  after FWE correction for multiple comparisons. Asterisks indicate the following peak values: \* $P$ -value  $< 0.05$  (FWE); \*\* $P$ -value  $< 0.001$  (FWE). Abbreviation: Con: Congruent condition. Inc: Incongruent condition. Lat.: Hemisphere lateralization. Z-score values refer to the activation maxima to the SPM coordinates

Region	Lat.	P-value peak	Z score	MNI coordinates			
				x	y	z	
Executive control							
Attentional conflict (Inc > Con)							
Frontal	Middle – Frontal eye field	R	**	5.77	36	2	61
	Middle – Frontal eye field	L	**	5.69	-27	-4	67
	Inferior – Pars opercularis	R	**	5.43	51	8	25
	Posterior-Medial – dACC/SMA	R	*	5.26	6	14	49
Parietal	Post-central gyrus	R	**	7.29	51	-34	55
	Post-central gyrus	L	**	5.48	-45	-40	58
	Superior posterior cortex	R	**	>100	27	-70	46
	Superior posterior cortex	L	**	>100	-21	-70	52
Occipital	Intraparietal sulcus	L	**	5.44	-36	-46	43
	Inferior – middle	R	**	>100	45	-82	-2
Other	Inferior – middle	L	**	>100	-42	-85	-5
	Cerebellum – Lobule VI (Hem)	R	*	4.66	9	-79	-23
	Cerebellum – Lobule VI (Hem)	L	**	5.91	-9	-76	-26
	Insula	R	*	4.68	33	23	4
	Insula	L	*	4.73	-33	20	7
Attentional conflict modulated by joy (Inc > Con) [Incl. masked Joy]							
Frontal	Inferior – Pars opercularis	R	**	5.42	51	11	25
	Middle – Frontal eye field	R	*	4.51	42	2	58
Parietal	Superior posterior cortex	R	**	>100	39	-52	58
	Inferior gyrus	R	**	6.95	48	-37	46
Temporal	Inferior gyrus	R	**	>100	51	-55	-14
Other	Insula	L	*	4.73	-33	20	7
Attentional conflict modulated by tension (Inc > Con) [Incl. masked Tens]							
Parietal	Superior posterior cortex	L	**	5.51	-21	-67	64
Occipital	Inferior – fusiform gyrus	L	**	7.33	-48	-67	-17
	Inferior – lingual gyrus	R	**	5.54	36	-88	-17
	Inferior – lingual gyrus	L	**	>100	-39	-88	-14
Attentional conflict modulated by sadness (Inc > Con) [Incl. masked Sad]							
Occipital	Middle gyrus	R	**	>100	39	-88	16
	Inferior gyrus	R	**	>100	39	-91	-5
	Inferior gyrus	L	**	>100	-36	-94	-2
Attentional conflict modulated by low valence (Inc > Con) [Incl. masked Val-]							
Occipital	Middle gyrus	R	**	>100	36	-85	10
	Middle gyrus	L	**	>100	-36	-88	10
	Inferior gyrus	R	**	>100	45	-82	-8
	Inferior gyrus	L	**	>100	-45	-85	-5
Attentional conflict modulated by high arousal (Inc > Con) [Incl. masked Ar+]							
Frontal	Middle – Frontal eye field	R	**	5.77	36	2	61
	Inferior – Pars opercularis	R	**	5.43	51	8	25
	Posterior – Medial – dACC/SMA	R	**	5.26	6	14	49
Parietal	Superior posterior cortex	R	**	>100	33	-61	58
	Superior – precuneus	R	**	7.62	12	-76	49
Temporal	Inferior gyrus	R	**	>100	57	-58	-14

### Functional MRI results: effects of auditory features

Finally, we tested for the influence of specific acoustic features in music that might be differentially present in the four emotion conditions. We identified five relevant candidates, out of eight potential musical parameters (see Methods and [Supplementary material](#)). These acoustic features were event density, pulse clarity, brightness, number of attacks and inharmonicity. They were selected based on auditory scores, computed for each feature and each musical piece that showed significant differences between emotion conditions. Namely, we retained only those

features scoring higher in joyful music excerpts compared to tender and sad excerpts, or vice versa. In addition, loudness and tempo features were also selected because they are commonly related to music-induced arousal ([Schubert, 2004](#); [Trost et al., 2015](#)) (see methods in [Supplementary material](#) for detailed information about all musical features, their assessment, and their selection).

We then conducted additional fMRI analysis assessing how brain activation associated with executive control varied as a function of these different acoustic features ([Supplementary](#)

Table 5). Results revealed a positive correlation between beat perception (i.e. pulse clarity scores) and activity in the superior temporal gyrus (STG) bilaterally, as well as occipital areas (MOG and IOG). Event density and tempo scores, which reflect more rhythmic dimensions, were also positively correlated with bilateral STG activation, whereas only event density negatively correlated with the occipital cortex. Concerning the timbre-related dimensions, the right STG was associated with higher brightness scores, while the left STG was associated with a lower number of attacks. Finally, there was a correlation between lower inharmonicity scores and activity of the left STG. High loudness scores were associated with bilateral STG activations.

### Alerting and orienting components of attention

Behavioral performances based on RT indicated expected main effect of cue and group for both the alerting and orienting components, reflecting a facilitation when participants were temporally (i.e. alerting) or spatially (i.e. orienting) informed about the upcoming target, as well as overall slowing in the older compared to the younger adults. Across all alerting and orienting conditions, RTs were also faster during high-arousing and joyful music, as found above in the analysis of executive control. Main effects of alerting and orienting components on brain activity are described in [Supplementary material](#), but showed only limited effects and no consistent modulation by music.

### Discussion

The current study investigated the influence of music exposure on attention, and more specifically on the executive control component of selective visuospatial processing, in a cohort of healthy participants with a wide age range (comprising both young and older adults). The effect of music was evaluated with regard to different emotions evoked by music and major musical features co-varying with these emotions. Behavior and brain imaging converged to highlight the role of both the affective nature and the associated acoustic properties of music in the modulation of selective attention, with better attentional processing and enhanced recruitment of parietal and frontal areas when exposed to high-arousing musical background, particularly pleasant and joyful music. To our knowledge, this study is the first to systematically disentangle the effects of specific emotional and acoustical properties of music on attention processes.

Overall behavioral performance in our paradigm (adapted from the ANT) fully accorded with previous research, showing significant interference by conflictual visual information between target and flankers, that is, more errors and longer RT on incongruent compared to congruent trials (Fan et al., 2002; Zhu et al., 2010). Moreover, consistent with aging studies, behavioral performance was lower in the older than the younger group, in particular during incongruent trials that are associated with higher interference effects (Colcombe et al., 2005; Zhu et al., 2010). These data support the notion of a greater susceptibility to distractors in the elderly, usually imputed to a decline of inhibitory control (Hasher and Zacks, 1988).

At the brain level, attentional conflict due to incongruent visual distractors led to increased activation of brain areas commonly associated with executive control, encompassing a distributed fronto-parieto-occipital network (Zysset et al., 2007; Zhu et al., 2010; Huang et al., 2012; Fernandez et al., 2019). In particular, a greater recruitment of posterior parietal cortex (SPL and

IPL) and dorsolateral prefrontal cortex (around FEF) is consistent with the key role of these areas in top-down mechanisms that guide the attentional focus toward relevant target information and override interference by irrelevant stimuli (Hopfinger et al., 2000; Corbetta and Shulman, 2002), while activity in the dorsal ACC/SMA may reflect greater conflict monitoring under competing visual information (Van Veen et al., 2001; Botvinick et al., 2004). Only limited age-related changes in the executive control network were observed between groups, with selective over-recruitment of the right SPL in the older compared to the younger adults. Such age-related increase in right SPL might reflect greater attentional load to efficiently perform the task (Hopfinger et al., 2000; Berron et al., 2015) and mitigate the inhibitory decline related to aging (Fernandez et al., 2019). Interestingly, no over-recruitment was observed in frontal areas for the elderly group, contrasting with other aging studies on selective attention (Cabeza, 2002; Colcombe et al., 2005). This lack of prefrontal recruitment may reflect sufficient compensatory mechanisms through increased parietal activity in our group of healthy elderly.

Of primary interest for the present study, we tested for the impact of naturalistic background music on attentional functions. Notably, brain areas recruited during our task did not overlap with those activated by music listening *per se* (Blood and Zatorre, 2001; Koelsch et al., 2006; Trost et al., 2012), indicating that our fMRI results essentially highlighted the neural substrates of executive control processing that were further modulated by concomitant music rather than neural responses to music itself.

More specifically, in our study, we asked whether any effect of music on attention might relate to the different emotions evoked by music, and found evidence for improved attentional functioning when exposed to pleasant and arousing music, with faster RTs to targets among flankers during joyful than during sad and tender excerpts. This facilitator effect of joyful music was confirmed by our behavioral sub-study, which replicated these RTs findings and also demonstrated faster answers in joyful music compared to a silent condition. In parallel, joyful music was associated with greater activation in the attentional control network, including not only posterior parietal areas (SPL and IPL) but also frontal areas (MFG and IFG) in the right hemisphere. In contrast, exposure to tense music enhanced activity in more posterior areas, including the SPL and IOG, whereas sad music was associated with increases in visual cortex only (IOG). Further analysis of these effects in relation to the valence and arousal dimensions of musical emotions corroborated these results, by showing that negative excerpts (representing tense and sad music) produced selective increases in the occipital lobe (MOG and IOG), while high-arousing music (representing joyful and tense excerpts) increased activity in a wider fronto-parietal network (SPL, MFG, IFG and dACC/SMA). The latter network is frequently activated in the presence of competing visual information and associated with conflict monitoring and response inhibition (Casey et al., 2000; Botvinick et al., 2004), and its enhanced recruitment might account for faster performance during high-arousing compared to low-arousing music. Conversely, low-arousing/sadness music produced no differential effects on RTs (compared to e.g. silence or tenderness) as well as greater occipital activations, which may rather reflect an enhancement of the stimulus-driven/bottom-up sensory response to visual stimuli (Zysset et al., 2007; Korsch et al., 2013).

Although both our behavioral and imaging data converge to show enhanced attentional processing under joyful music, we note that we did not find any significant effect on a quantitative



performance index measuring executive control (i.e. efficiency score) at the behavioral level, in keeping with other studies using the ANT paradigm to compare different mood states (Finucane et al., 2010; Jiang et al., 2011). However, in other studies where emotions were induced by music prior to performance of the attentional task itself (Rowe et al., 2007; McConnell and Shore, 2011), significantly larger efficiency scores were reported for joyful compared to sad and neutral conditions (Rowe et al., 2007). Work by McConnell and Shore (2011) also highlighted the importance of both the valence and arousal dimensions of music to account for its impact on attention, but reported facilitation effects for negative mood and disruptive effects for positive mood under high-arousing conditions solely (McConnell and Shore, 2011).

The above results from mood induction designs appear in line with the 'broaden-and-built theory' (Fredrickson, 2004), which associates negative emotions with local perceptual processing and thus better resistance to attentional conflict from distractors, whereas positive emotions might instead induce a broadening of attentional scope that could explain slower performance in incongruent trials. However, such an account based on the 'broaden-and-built theory' appears inconsistent with our current findings (i.e. faster RTs in joyful condition), a divergence suggesting that naturalistic music, through both its temporal and emotional dimensions, might differently modulate attentional processing when it is played prior to a perceptual task or concurrently with the task. In the latter case, beneficial attentional effects could occur and lead to faster processing speed and greater recruitment of attentional brain circuits during direct exposure to high-arousing and joyful music (while either different or similar effects might arise after exposure). Moreover, a facilitation induced by high-arousing music in our study converges with previous studies demonstrating the capacity of auditory rhythmic stimuli to entrain and rhythmically modulate attentional processes (Olivers and Nieuwenhuis, 2005; Escoffier et al., 2010; Bolger et al., 2013; Trost et al., 2014). In particular, the metrical structure of music has previously been associated with implicit entrainment of attention, thus producing a boost of visual processing for targets appearing synchronously with strong beats of the music (Escoffier et al., 2010; Bolger et al., 2013; Trost et al., 2014). Moreover, it has been found that such attentional improvement induced by music meter is associated with greater recruitment of areas implicated in attentional control, including ACC and SPL, particularly under exposure to pleasant/consonant as opposed to unpleasant/dissonant music (Trost et al., 2014), which dovetails well with our current findings.

Moreover, we note that our findings are unlikely to reflect a change of attentional focus between conditions (e.g. higher attention of the participants to the joyful/high-arousing music compared to the music in other conditions). In fact, a shift of attentional focus from the task to the musical background would have simultaneously led to (i) an increase of errors in behavioral performance because of music distraction, as well as (ii) a greater activation in auditory cortical areas due to increased music processing and/or other cerebral areas associated with specific musical emotions, which was clearly not the case. Taken together, our findings thus support neither a distractive/diverting effect of joyful music on attention, nor a simple alerting effect of joyful music, but rather suggest an influence of the temporal and emotional dimension of joyful/high-arousing music.

In the present study, we also examined the role of several auditory features of music that co-varied with the different types of emotion evoked by music. Although attentional control

was indeed modulated by these features, we found no direct associations between activity in specific areas of the attentional network and specific acoustic features. Instead, audio features produced activations mainly located in auditory areas, distinct from fronto-parietal regions that were engaged by the task and modulated by the emotion conveyed by music. It is important to note nevertheless that previous studies have linked a few elementary acoustic features of music to particular emotional responses in the listener. Specifically, subjective arousal ratings are related to the tempo (Schubert, 2004; Gomez and Danuser, 2007; Trost et al., 2015) as well as to other event/energy-related musical features, such as the event density or the loudness (Trost et al., 2015). Similar associations were found between dissonance scores and the perceived unpleasantness of music (Koelsch et al., 2006), while the timbre brightness appears to promote happiness in the listener (Juslin and Laukka, 2000). Based on this previous work, it is legitimate to expect that both musical features and music-induced emotions (or their corresponding valence/arousal dimensions) might produce at least partly similar modulatory effects on the executive control network. For instance, because brightness was linked to happiness (Juslin and Laukka, 2000), music excerpts with higher brightness scores might be expected to evoke similar neural influences as those we observed during joyful excerpts, namely greater recruitment of attentional areas. However, our data suggest that the attentional effects produced by joyful, high arousing music are unlikely to depend on one particular feature only, such as brightness, tempo or pulse clarity, but rather presumably result from a complex combination of distinct acoustical features. We note that further studies should be performed to relate the perceptual relevance of the different acoustic features measures with the MIR toolbox to particular auditory/musical/emotions dimension, in order to validate the perceptual representation of the features.

Finally, based on evidence suggesting age-related changes in attentional processes (Hasher and Zacks, 1988; Fraser and Bherer, 2013) as well as in emotion regulation (Mather and Carstensen, 2005), the present study also aimed to assess whether music exposure and associated emotions might produce differential effects on attentional performances with advancing age. On one side, in light of deficits in both distractor inhibition and divided-attention abilities (Hasher and Zacks, 1988; Fraser and Bherer, 2013), music exposure during a cognitive task might lead to additional distractibility and poorer performance in the older relative to younger adults (Reaves et al., 2015). On the other hand, aging leads to changes in emotion regulation, typically characterized as an 'age-related positivity bias' (Mather and Carstensen, 2005), suggesting that older adults favor more positive over negative information (Carstensen and Mikels, 2005; Carstensen et al., 2011). For example, older adults were found to report a visual dot faster after positive than negative faces (Mather and Carstensen, 2003) and recall positive better than negative pictures (Charles et al., 2003), while no such difference existed for young participants. Furthermore, an age-related attentional bias toward positive stimuli was supported by neuroimaging findings that activity in emotional brain regions, such as the amygdala or the medial prefrontal cortex, is directly correlated with age differences in positivity (Mather et al., 2004; Knight et al., 2007).

Contrasting with these findings, however, the modulatory effect of musical background observed in our study was similar across both groups at both the behavioral and imaging levels. Moreover, our data indicate that musical exposure concomitant to another task does not induce greater distractibility or generate divided-attention situation in the older population. Importantly,

our subjective rating scores indicated similar liking of the music excerpts in both age groups, ensuring comparable emotional effects. Our results therefore add to recent behavioral work that demonstrated the beneficial role of background music on processing speed (Bottiroli et al., 2014), memory abilities (Ferreri et al., 2014; Ratovohery et al., 2018) and working memory (Mamarella et al., 2007) in the elderly. By demonstrating here the beneficial impact of high-arousing and joyful music in enhancing attentional processes in the elderly, and uncovering their substrates in fronto-parietal areas, we provide novel support to the usefulness of exploiting music during cognitive training protocols or motor rehabilitation programs (Trombetti et al., 2011; Hars et al., 2013). There is indeed increasing interest to better understand how music-based procedures may help to restore or boost attentional control abilities in the elderly population, in addition to other potential benefits such as those on motor (Trombetti et al., 2011; Särkämö, 2018) or cognitive functioning (Hars et al., 2013; Bottiroli et al., 2014; Ferreri et al., 2014; Särkämö, 2018).

We acknowledge several potential limitations in our current study. First, we did not include a 'silent' control condition during fMRI, which may have allowed us to distinguish more precisely any facilitator vs disruptive effects of music exposure on attention (regardless musical emotion) compared to an attentional task performed alone. However, silence could not easily be achieved during fMRI and the facilitation by joy compared to silence was confirmed by our separate behavioral sub-study in a second group of participants. Further research with advanced noise-cancellation procedures should however address this question in the future.

A second limitation is the lack of familiarity evaluation for music excerpts used in the current study, despite this factor having been described as important in subjective affective responses to music (e.g. perceived pleasantness) (Peretz et al., 1998; Schellenberg et al., 2008). Critically, however, our analysis on the hedonic/liking ratings of musical excerpts showed not only that affective evaluation was fully consistent with our emotional classification (i.e. high valence scores for joyful and tender music) but also similar between the two age groups ( $F_{(1,39)} = 0.93$ ;  $P = 0.34$  for valence). Hence, our results appear to rule out that globally lower performance in older relative to younger adults might result from age-specific difference in music liking (e.g. due to age-related disparity in the familiarity of classical music). Moreover, emotion effects on attentional control and brain activation patterns did not differ between age groups either.

Third, our data suggest that enhanced top-down recruitment of attention control during joyful music may only contribute to faster RT without affecting performance accuracy. However, we argue such limited impact of music on RTs rather than AC is most likely to reflect a general ceiling effect in performance on this task, observed for both groups alike (>90% correct). Further research might address this issue in the future by using different, more challenging attentional tasks leading to higher error rates. Here, importantly, our data were not confounded by different affective reactions to frequent errors in the task. Finally, it is possible that other emotion appraisals from music may lead to different effects on attention and/or impact on different component processes (such as orienting). For instance, a higher intensity of threat feelings evoked by tense music might induce an attentional capture detrimental to performance, an issue that should also be explored in further studies, beyond the valence and arousal dimensions of tense music as considered in the current study. Such additional investigation would allow

more directly linking attentional effects of music observed here with other attentional mechanisms activated by threatening or rewarding stimuli (Fazio, 2001; Öhman et al., 2012; Soares et al., 2014; Vuilleumier, 2015).

## Conclusion

To our knowledge, this is the first study investigating the influence of background music, and the different emotions it may evoke, on the performance of a visual task assessing distinct components of attention. Our results highlight a significant impact of emotional music on visuo-spatial processing, with differential modulation depending on its valence and arousal dimensions. Critically, slower responses were observed during low-arousing music, namely tenderness and sadness excerpts, compared to high-arousing music and more specifically joyful excerpts. Corroborating behavioral findings, high-arousing and joyful music excerpts were associated with an enhancement of selective attentional processes through the recruitment of a bilateral fronto-parietal network typically associated with top-down executive control mechanisms, which might in turn facilitate general attentional performance. Acoustic parameters alone showed no such influences. Clearly, more research is needed to further scrutinize the musical ingredients of these beneficial effects of music on attention and their underlying brain processes.

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## Supplementary data

Supplementary data are available at SCAN online.

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## Conflict of interest

None declared.

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