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Tempo and intensity of pre-task music modulate neural activity during reactive task performance

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Abstract

Research has shown that not only do young athletes purposively use music to manage their emotional state (Bishop, Karageorghis, & Loizou, 2007), but also that brief periods of music listening may facilitate their subsequent reactive performance (Bishop, Karageorghis, & Kinrade, 2009). We report an fMRI study in which young athletes lay in an MRI scanner and listened to a popular music track immediately prior to performance of a three-choice reaction time task; intensity and tempo were modified such that six excerpts (2 intensities x 3 tempi) were created. Neural activity was measured throughout. Faster tempi and higher intensity collectively yielded activation in structures integral to visual perception (inferior temporal gyrus), allocation of attention (cuneus, inferior parietal lobule, supramarginal gyrus), and motor control (putamen), during reactive performance. The implications for music listening as a pre-competition strategy in sport are discussed.

Keywords: affect, basal ganglia, emotion, fMRI, sport

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The use of popular music to manipulate athletes' psychophysiological state was aptly illustrated throughout the 2012 London Olympic and Paralympic Games: the Organizing Committee developed a playlist of more than 2,000 tracks that were subdivided into five unique themed playlists, in an attempt to provide the most appropriate soundtrack to each of the Olympic sports. Artists such as *Florence and the Machine*, *Groove Armada*, *New Order*, and *The Smiths* filled the Olympic venues daily. At Athens 2004, all-time great Michael Phelps stood out as the only swimmer to enter the arena wearing a large pair of headphones. In 2012, such deliberate use of music as a pre-performance strategy could be witnessed not only in the swimming pool (e.g., Eleanor Simmonds), but also on the athletics track (Tahmina Kohistani), in the white water centre (Jasmin Schornberg), and in the velodrome (Chris Hoy). Music is clearly valued as a preparatory tool by Olympic athletes, including gold medallists – and this seems to parallel young people's daily use of music to manage their moods (Saarikallio & Erkkilä, 2007).

The structural qualities of music can interact to mediate the listener's responses. Webster and Weir (2005) examined the interactive effects of mode (major vs. minor), texture (nonharmonised vs. harmonised), and tempo (72, 108, and 144 beats per min) on listeners' experienced emotions. Major keys, non-harmonised melodies, and faster tempi were associated with happier responses, whereas their respective opposites were associated with sad ones. Coutinho and Cangelosi (2011) subsequently showed that six psychoacoustic features of music, including loudness (intensity) and tempo, contributed significantly to the affective states experienced by listeners; moreover, both tempo and intensity correlated moderately with participants' subjective arousal – a phenomenon that has been linked to neurophysiological activation (Malmo, 1959). However, more recent research has shown that the listener's emotional responses to music may be somewhat independent of these acoustical properties (Ladinig & Schellenberg, 2012) – but intrinsic sources of emotion such as tempo and intensity have the potential to mediate the intensity of the emotions experienced by young athletes (Bishop et al., 2007) and thereby promote action tendencies (Frijda, 1987). For example, research has shown that slow tempo background music elicits significantly slower movement in shop and restaurant customers than does music played at a fast tempo (Milliman, 1982, 1986). Such powerful links to action have clear implications for sport performance.

Our inherent tendency to synchronise with externally-generated rhythms is well established (Repp & Su, 2013), as are the neural mechanisms underpinning the perception of such rhythms (Grahn & Brett, 2007). Schneider, Askew, Abel, and Strüder (2010) examined the interrelationships of runners' bodily oscillations, heart rate, and electrocortical (EEG) activity as they completed outdoor running trials at three intensities (*low*, *high*, and *preferred*). Participants also provided their favourite "running music" pieces for subsequent spectral analysis. Schneider et al. showed that all three measures exhibited a tendency towards a natural frequency approaching 3 Hz – a frequency that was reflected in the spectral power distribution of participants' selected running music. Music preference may also be an important factor to consider in the elicitation of sensorimotor synchrony: there is evidence for greater activation of motor regions of the brain when listening to preferred music, as contrasted with that for non-preferred music (Kornysheva, von Cramon, Jacobsen, & Schubotz, 2010).

The use of music in sport and exercise settings is commonplace, but with relatively little empirical research to match its ubiquity. More than 100 studies published to date, including recent reviews (Karageorghis & Priest, 2012a, 2012b), highlight that the main functions of music in these domain are performance preparation (*pre-task music*), in-task auditory-motor synchronisation (*synchronous music*), in-task dissociation and mood/emotion regulation using *asynchronous* (background) *music*, and post-task recovery using *recuperative music* (Karageorghis, Terry, Lane, Bishop, & Priest, 2012). The use of music in the present study comes under the rubric of *pre-task music* – for which the gap between empirical research findings and application in the field is perhaps most conspicuous.

In the last decade, two sets of researchers have examined the impact of pre-task music on maximal cycle ergometer performance (Eliakim, Meckel, Nemet, & Eliakim, 2007; Yamamoto et al., 2003). Eliakim and colleagues examined basketball players' Wingate Anaerobic Test performance after two types of warm-up: with and without music. Not only did music accompaniment lead to higher warm-up heart rates, but it also yielded higher peak anaerobic power during the ergometer test. Yamamoto et al. exposed participants to either fast- or slow-tempo music for 20 min prior to a 45 s supramaximal ergometer test. Although neither condition influenced power output, the authors showed that fast-tempo music elevated circulating levels of norepinephrine, while slow-tempo music had the converse effect. Collectively, these studies suggest that music heard prior to completion of a physical task may yield an ergogenic effect; one that is underpinned by physiological mechanisms.

More recently, Bishop, Karageorghis, and Kinrade (2009) recruited a sample of young tennis players to examine how changes to musical tempo and intensity (volume) influenced their affective responses and subsequent choice-reaction task performance. A researcher-selected piece of music was modified to create six versions (three tempi x two intensities) that were compared against white noise and silence. Listening to fast, loud music produced emotional states that were more pleasant/arousing and yielded faster reaction times when compared to the same music played at a moderate intensity. However, the neural activity underlying this finding and other such findings in the sport and exercise domain has yet to be examined.

Profound neural responses to music have consistently been observed, even when the music is unfamiliar. Brown, Martinez, and Parsons (2004) observed activation in many limbic and paralimbic structures, including subcallosal gyrus, hippocampus, and the nucleus accumbens (NAc) – an important reward processing centre in the brain. Menon and Levitin (2005) subsequently found increased activation in NAc, insula, orbitofrontal cortex, and ventral tegmental area (VTA) when participants listened to pleasant music, as contrasted with concatenated, randomised, chunks of the same tracks. There is also evidence to suggest that tempo can affect the neural response to emotive music: Khalfa, Schon, Anton, and Liegeois-Chauvel (2005) manipulated the emotional valence of music excerpts by altering tempo and mode. They found that, despite activation of dorsolateral prefrontal cortex by both sad (slow, minor key) and happy (fast, major) music, sad excerpts also elicited stronger activation in left orbitofrontal cortex – which is strongly implicated in both emotion processing (Rolls, 1999) and the evaluation of rewards in decision-making (Gluth, Rieskamp, & Büchel, 2012). Accordingly, alteration of tempo may be an important means by which we can manipulate not only the listener’s affective state, but also their ability to make fast and accurate decisions.

Although listeners can accurately identify the emotional content of a music excerpt within as little as one second (Bigand, Filipic, & Lalitte, 2005), neurophysiological evidence suggests that neural responses to music unfold over time. Koelsch et al. (2006) played excerpts of pleasant and unpleasant music approximately one minute in duration, and subsequently examined the difference between participants’ emotional responses to the first and second 30 s of each excerpt. Despite the fact that similar activations were found to those identified in previous studies (amygdala, hippocampus, parahippocampal gyrus, temporal poles, insula, and ventral striatum), the magnitude of the response was enhanced in the latter 30 s relative to that for the previous half a minute. This enduring response has clear potential for sporting contexts: most, if not all, international sport governing bodies prohibit the use of personal music during events, meaning that athletes must harness its potential during the lead-up to their performance.

Young athletes purposively listen to music in order to manipulate their affective state, and the acoustical properties of the music are a consideration in their selections; specifically, tracks with faster tempi are selected and subsequently played at higher intensities to elicit a more subjectively aroused and pleasant pre-performance state (Bishop et al., 2007). Moreover, tempo and intensity manipulations have yielded significant changes in participants' pre-performance affective state and consequent reactive performance (Bishop et al., 2009). Therefore, the aim of the present investigation was to manipulate the tempo and intensity of a popular music track, in order to explore the neural mechanisms underlying previously witnessed improvements in affective state and subsequent reactive performance. Because increased activation of motor areas (e.g., supplementary motor area, sensorimotor area) correlates with performance on reaction time tasks (Mohamed, Yousem, Tekes, Browner, & Calhoun, 2004), it was predicted that these areas would be more active as a result of listening to music played at a higher intensity. It was also anticipated that these activations would be accompanied by parallel activation in structures previously identified in emotional responses to music (e.g., paralimbic regions, Blood, Zatorre, Bermudez, & Evans, 1999). Faster tempi have been associated not only with improved stimulus detection during reactive task performance (Amezcua, Guevara, & Ramos-Loyo, 2005), but also with higher valence and arousal in sport contexts (Bishop et al., 2009). Therefore, we predicted that music played at a fast tempo would also elicit greater activation of motor areas and those areas previously identified in positive emotional responses (e.g., NAc, Menon & Levitin, 2005) than would music played at a slow tempo.

Methods

Participants

Twelve[1] full-time tennis players (6M, 6F) based at an international sports academy in London, UK volunteered to take part in the present study; ages ranged from 18 to 28 yrs (M_{age} = 21.2 yrs, *SD* = 3.0 yrs). Nine participants described their ethnicity as *White UK*; the remaining three were *White French*, *South African*, and *Ukrainian*. All were right-handed.

Equipment and Materials

Stimuli.

Auditory stimuli. The music track used was *Deepest Blue* by the artist *Deepest Blue*, which was sold under the *Data* record label (catalog no. 55CDS). This track was selected because it was likely to be familiar to all participants: it had been in the Top 40 of the UK music charts for 8 weeks in 2003, but only reached position 7; we anticipated that such cultural exposure would engender only moderate, not extreme, affective responses (cf. North & Hargreaves, 1995). The track was digitally modified to yield three recorded excerpts played at 99 bpm (slow tempo), 129 bpm (normal tempo), and 161 bpm (fast tempo)[2]. All excerpts were cropped in length to a duration of 90 s, enabling participants to hear a portion of the verse and chorus; this duration was also likely to yield more pronounced emotional response than would a shorter selection (cf. Koelsch et al., 2006). The intensity of each excerpt was modified such that three were heard at approximately 55 dBA (moderate intensity) and three at 75 dBA (loud intensity). A 90 s block of no-music was also recorded, to enable contrasts. All stimuli were presented binaurally via an MRI-compatible auditory presentation system (MR Confon;

Magdeburg, Germany), incorporating dynamic headphones (Confon HP-SI01; MR Confon, Magdeburg, Germany) with gradient noise-suppression properties (Baumgart et al., 1998). Presentation of all auditory stimuli was randomised, using experiment generator software (E-Prime v.2.0; Psychology Software Tools, Inc., Pittsburgh, Pennsylvania, US).

Visual stimuli. Experimental stimuli were presented in a randomized order via experiment generator software (E-Prime v.2.0; Psychology Software Tools, Inc., Pittsburgh, Pennsylvania, US). A black dot on a white background appeared in one of three possible locations in the display: Left, right or centre. The participants' task was to press a corresponding button on an MRI-compatible response box (LUMItouchTM; Photon Control, Inc., Burnaby, B.C., Canada). This task was designed to approximate a requirement of the tennis return of serve, in which there are three broad locations to which the oncoming ball will travel: directly at the returner's body, to the their right, or to their left. See Figure 1 for a schematic representation of the study protocol, incorporating visual and auditory stimuli.

fMRI data acquisition. Blood oxygen level-dependent images were acquired on a MAGNETOM Trio 3T MRI scanner (Siemens Medical Solutions; Bracknell, UK) using Siemens' parallel imaging technology (iPat), which was deployed with a generalised autocalibrating partially parallel acquisitions (GRAPPA, Griswold et al., 2002) acceleration factor of two, via a Siemens eight-channel array head coil. In order to limit excessive head movements and, concurrently, ensure the participant's comfort, the lateral spaces between the participant's head and the coil were padded with custom-built foam wedges. For each functional run, an ultra-fast echo planar gradient-echo imaging sequence sensitive to blood-oxygen-level dependent (BOLD) contrast was used to acquire 43 transverse slices (3 mm thickness) per TR (3000 ms, TE 31 ms, flip angle = 90°). Approximately[3] 505 volumes were acquired in a 192 mm x 192 mm field of view with a matrix size of 64 mm x 64 mm, giving an in-plane spatial resolution of 3 mm (generating 3 mm^3 voxels). Anatomical data were collected in the same orientation and plane as the functional data using an MP-RAGE (Mugler & Brookeman, 1990) T1-weighted sequence, in which 176 one-mm slices alternated with a 0.5 mm gap. The structural sequence incorporated a 1830 ms TR, 4.43 ms TE, FoV 256 mm and a GRAPPA acceleration factor of two.

Experimental Procedure

Subsequent to university ethics committee approval and screening, the experimental procedure was explained to participants verbally and in writing. Participants provided their informed consent and were invited to raise any concerns prior to commencement of the study. All procedures were conducted in accordance with the Declaration of Helsinki.

A repeated-measures blocked design was employed, wherein participants were exposed to each of the conditions in a randomised order. Each block comprised a 45 s relaxation period, in which the following auditory relaxation script was played during a blank screen presentation:

> I would like you to close your eyes…you feel warm inside…your legs, arms, and head feel very heavy, and you sink into the bed….Breathe in slowly and deeply through your nose for a count of three, and then breathe out slowly through your mouth for a count of four…as you do this, notice your belly button rising and falling in time….You feel calm…[10-s pause]…Now open your eyes.

Ninety seconds of auditory stimulus immediately followed, which was in turn followed by a subsequent CRT task with no auditory accompaniment; the participants' aim was to respond as quickly as possible to each of 24 randomised visual stimuli, after one block of 24 practice trials. A 1-s blank screen preceded each trial.

Data Analysis[5]

fMRI data were pre-processed and analysed using SPM2 (http://www.fil.ion.ac.uk/spm). Functional images were spatially realigned to the first image in the series to moderate the effects of participants' interscan head motion (Ashburner & Friston, 1997). All functional images were then coregistered with the T1 image. Images were stereotactically normalised to the Montreal Neurological Institute ICBM-152 template to account for neuroanatomical variability, and to facilitate reporting of activation sites according to standard space (Ashburner & Friston, 1997). Finally, data were smoothed using a Gaussian kernel of 7 mm full-width half-maximum (FWHM) to increase the signal-to-noise ratio according to the matched filter theorem.

The selected design matrix convolved the experimental design with a haemodynamic response function to model the haemodynamic lag; this model was estimated using proportional scaling over the session to remove global effects, and with a high pass filter of 128 s. Using a mean group contrast image, exploratory first-level analysis was performed in order to estimate the fixed effects of the experimental conditions upon the present sample. Regions-of-Interest (ROI) analyses were subsequently performed using MarsBaR (Brett, Anton, Valabregue, & Poline, 2002), for each of three contrasts – *Music-No music*, *Loud-Moderate*, and *Fast-Slow* – for each of the effects witnessed in the first-level analysis. In keeping with the exploratory nature of these analyses (see Poldrack, 2007), ten mm radius spherical ROIs were created at the peaks of activation clusters, using MNI coordinates; this search volume represented a suitable compromise of sensitivity and accuracy. Contrast values were then analysed using a one-sample *t* test to enable identification of significant activation above baseline for all identified contrasts and regions. Although response data were collected, equipment faults rendered these unusable.

Results

For the group fMRI data, and using familywise error correction for multiple comparisons, *t*-maps for music listening conditions and subsequent CRT task performance conditions displayed significant activations for the contrasts of interest. Significant activations for all contrasts other than *music–no-music* are displayed in Table 1.

Activations during listening. There were significant activations bilaterally for all music conditions (*music* > *no-music*) in primary auditory cortex, as predicted; there was also activation in right cerebellum. Music played at the faster tempo elicited significant activations in left inferior temporal gyrus compared with music at the slower tempo (*fast* > *slow*). Music played at the higher intensity elicited significant bilateral activations in supramarginal gyrus and in right inferior parietal lobule (*loud* > *moderate*).

Activations during CRT task performance. There was a significant activation in the CRT task following music conditions, when contrasted with no music, in the right cerebellum. Music played at the faster tempo elicited significant activations in left inferior temporal gyrus, right cuneus, and subcallosal gyrus when contrasted with music played at the slower tempo (*fast* > *slow*; Figure 2). Music played at a loud intensity elicited significant bilateral activations in supramarginal gyrus and inferior parietal lobule; and in left putamen, right middle frontal gyrus, and right middle temporal gyrus (*loud* > *moderate*; Figure 3).

FWE-corrected significant activations for all derived ROIs are displayed in Table 2.

Discussion

In accordance with our hypotheses, listening to music yielded greater activation in auditory cortex than did a period of no-music, as predicted and supported by previous research (e.g., Abbott, 2002). Some of these activations were located in superior temporal gyrus, which is a region that not only serves auditory functions, but also plays a role in visual search (Gharabaghi, Fruhmann, Tatagiba, & Karnath, 2006). Neither fast tempo nor loud intensity led to activations in pleasure centres of the brain, despite evidence that tempo is a strong determinant of positive emotional responses to music (Webster & Weir, 2005). However, during performance of the CRT task following faster tempo music, fixed effects analyses did reveal significant activation in subcallosal gyrus, which has been implicated in positive emotional responses to self-selected familiar music (Blood et al., 1999; Khalfa et al., 2005) and unfamiliar researcher-selected pieces (Brown et al., 2004; Webster & Weir, 2005). The analyses also yielded a number of other activations that relate to sports performance, which are discussed below.

Fixed-effects analyses showed that music played at the higher intensity elicited greater activation than did music played at moderate intensity, in visuomotor areas (e.g., inferior temporal gyrus); similar activation has been witnessed in skilled footballers when trying to interpret opponents' kinematics (Bishop, Wright, Jackson, & Abernethy, 2013). This activation also persisted beyond the listening period into the subsequent CRT reaction time task – although this effect was confirmed only for the putamen in subsequent ROI analyses. The durability of this response is similar to that witnessed by Koelsch et al. (2006), who showed that the emotional response to a 1-min music excerpt was greater in the latter 30 s. The fact that these effects lasted despite the absence of music during the task may be explained by our propensity to spontaneously engage in auditory imagery; however, we might also have expected activation in auditory cortex in this case (cf. Kraemer, Macrae, Green, & Kelley, 2005). Greater motor activation may be consistent with previously reported feelings of higher subjective arousal after listening to music played at a high intensity (Schubert, 2004). However, contrary to our predictions, there were no significant activations in other areas previously associated with improved RT performance (e.g., supplementary motor area , Mohamed et al., 2004). Nonetheless, the in-task activation observed in the putamen, a region of the basal ganglia, may reflect an inherent response to external rhythms (cf. Grahn & Brett, 2007) that is highly relevant for sporting tasks in which rhythmicity is required (e.g., when rallying in tennis).

Recently, Yarrow, Brown, and Krakauer's (2009) put forward their *affordance competition model*. This model comprises a complex cortico-subcortical network in which the basal ganglia *behaviourally bias* the best possible motor action, by encoding the difference between expected and actual reward of a given course of action. Yarrow and colleagues proposed that the basal ganglia and cerebellum work together to generate and select the most appropriate motor plans for any given context. Because these structures are also active in response to externally-generated rhythms (Grahn & Brett, 2007; Kornysheva et al., 2010), the putamen and cerebellum activations witnessed in the present data may underlie action tendencies (Frijda, 1987) that optimise the athlete's movements and ultimately their decision-making – possibly via greater sensorimotor synchronisation with relevant stimuli in the environment. However, in the absence of response data for the present study, we cannot draw firm conclusions about the behavioural consequences of these activations.

There were some novel and unexpected findings in the present data. Notably, right inferior parietal lobule was significantly activated in the first-level analysis, when high intensity music was contrasted with that of moderate intensity. The IPL is an area for sensorimotor integration, receiving input of visual information from the superior colliculus, as well as inputs from the hippocampus and cerebellum (Clower, West, Lynch, & Strick, 2001). Activation of IPL in the processing of apparent motion also appears to be dependent on the level of attention to the stimulus (Claeys, Lindsey, De Schutter, & Orban, 2003). Hence, the IPL activation witnessed in the present data may represent the culmination of increased attention to the visual stimuli, which did not move but may have been perceived as such, given the rapidly changing location. However, it should be noted that this finding can only be applied to the present sample, due to the fixed-effects nature of the analysis. The greater IPL activity when listening to louder music was accompanied during both the listening period and subsequent CRT task performance by activation in supramarginal gyrus, albeit only in the fixed effects analysis, also. Although this region seems to fulfil a number of functions, including the retrieval of memories through enactment (Russ, Mack, Grama, Lanfermann, & Knopf, 2003) and language processing (Nardone et al., 2012), it has previously been implicated in the appropriate allocation of attention during visual search tasks (Shulman, Astafiev, McAvoy, d'Avossa, & Corbetta, 2007). Thus, the activation witnessed may reflect participants' heightened attention allocation – undoubtedly relevant for this task, in which reactivity was required; other neuroimaging studies suggest that greater activation of brain regions integral to visual attention allocation is associated with superior anticipation in sport (Bishop et al., 2013; Wright, Bishop, Jackson, & Abernethy, 2011).

Another novel finding was the activation of inferior temporal gyrus – a key area in object recognition (Tompa & Sáry, 2010) – which remained active during performance of the CRT task after listening to fast-tempo music. Such activation of a predominantly visual brain region is highly novel for investigations of music; hence, this activation may reflect some degree of audiovisual integration. Faster tempi may be interpreted in terms of their iconic representation (Sloboda & Juslin, 2001) of a more highly aroused, more positive, and ergo, more motivated state. The present data may reflect a neural state in which the individual scans his or her environment in a more vigorous manner, thereby identifying pertinent targets more rapidly. Given the connectivity between auditory and visual cortices (Falchier, Clavagnier, Barone, & Kennedy, 2002), this is particularly relevant for sporting scenarios in which rapid reaction to a stimulus, be it auditory (e.g., a team mate's call) or visual (e.g., a rapidly moving ball), is required.

Limitations

Although the stimuli used in the present study enabled us to draw firmer conclusions about the effects of tempo – all other variables were kept constant – this also served to minimise the differences between emotional responses to the stimuli; other researchers have used highly contrasted stimuli in order to maximise such differences (e.g., Menon & Levitin, 2005). However, the fact that significant differences still emerged for this ecologically valid manipulation is encouraging; using contemporary technology, any athlete can modify the tempo of their preferred music in order to maximise its effects. Another limitation of the present study is that the block lengths were too great to optimise fMRI data collection (see Amaro Jr. & Barker, 2006); this meant that low-frequency noise emanating from scanner drift might have contaminated the data, thereby reducing the overall number of significant activations. Finally, the fixed effects data that we present may only be generalised to the present participants – nonetheless this study was exploratory in nature, and hence the ROIs derived reflect this.

Future Research

The notions that (a) we naturally gravitate towards a rhythm of 3 Hz in terms of both our music preferences and movement tendencies during physical activity (Schneider et al., 2010); and (b) greater activation of motor regions of the brain is observed in response to preferred music

(Kornysheva et al., 2010) are individually and collectively worthy of further exploration. Pre-task music played at a fast tempo has previously been associated with more positive affect and greater responsiveness in a sample similar to the present one (Bishop et al., 2009); and the tempo of the fastest track in the present study mirrored the frequencies witnessed in Schneider et al.'s participants' music selections (2.68 Hz). Hence, music played at tempi in the region of 160 bpm may be conducive to optimising responsiveness in more dynamic and intrinsically rhythmic activities such as tennis groundstroke rallying.

Conclusion

This is the first study, to our knowledge, to explore the neural basis for the commonly witnessed effects of pre-task music listening in sport; specifically, we examined the effects of manipulating two intrinsic sources of emotion – tempo and intensity – on brain responses during reactive task performance. Fast-tempo music elicited mild emotional responses that were accompanied by heightened visuomotor activity, suggesting greater attentiveness and potential responsiveness as a result. Additionally, music played at a loud intensity yielded persistent activation in the basal ganglia, which have been implicated not only in the tendency to synchronise with external periodicities (Grahn & Brett, 2007), but also in effective decision-making and preparation for action in sport (Yarrow et al., 2009). The data we present add to the existing corpus of research into the use of pre-task music (e.g., Eliakim et al., 2007; Yamamoto et al., 2003) to include a task for which heightened perception and discriminative motor output are crucial. The activations witnessed herein may underpin such performance-determining factors.

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Footnotes

1. Fifteen participants were recruited initially, but three participants' data were discarded due to excessive movement artefacts. The resultant sample size is acceptable given the effect sizes yielded by the present data (see Zandbelt et al., 2008, for a discussion of sample size).
2. Participants' subjective perceptions of the track's qualities were determined by asking, "Did the slowed-down and sped-up versions of the track appear significantly different to the original version in any way other than the speed?" In addition, participants were asked, "Was the original version of the track you heard familiar to you prior to participating in this study?" in order to gauge the success of the selection strategy; familiarity moderates preference for musical stimuli (Peretz, Gaudreau, & Bonnel, 1998). All participants claimed that the track used was familiar, but they were unable to perceive any qualitative changes to the modified music excerpts other than the tempo.

3. Due to the variable length of the CRT task block, the total number of volumes fluctuated from one run to the next.
4. Although affective data and response data were collected, the total number of trials in any one condition was deliberately low so as to prioritise fMRI data collection; hence analyses of these data are not reported.

Table 1

Significant t-Map Activations by Contrast and Region (Corrected for Multiple Comparisons)

Contrast (condition)	Region	Coordinates			*t* value
		x	*y*	*z*	
Music-No music (listening)	Superior temporal gyrus	66	-15	6	6.41^{***}
	Superior temporal gyrus	54	-21	6	5.74^{***}
	Transverse temporal gyrus	-54	-24	12	5.62^{***}
	Superior temporal gyrus	-51	-15	3	5.53^{***}
	Superior temporal gyrus	-63	-18	3	5.47^{***}
	Cerebellum (declive)	48	-60	-30	5.44^{***}
	Superior temporal gyrus	60	3	-3	5.07^{*}
Music-No music (CRT task performance)	Cerebellar tonsil	30	-57	-39	5.29^{***}
Fast-Slow (listening)	Inferior temporal gyrus	-63	-6	-21	5.32^{**}
Fast-Slow (CRT task performance)	Inferior temporal gyrus	-63	-9	-21	5.63^{**}
	Cuneus	18	-96	0	5.52^{**}
	Subcallosal gyrus	-24	6	-15	5.49^{**}
Loud-Moderate (listening)	Supramarginal gyrus	54	-57	30	6.30^{**}
	Inferior parietal lobule	54	-60	42	5.64^{**}
	Supramarginal gyrus	-54	-63	30	6.03^{**}
Loud-Moderate (CRT task performance)	Putamen	-18	6	-12	5.61^{**}
	Supramarginal gyrus	-57	-60	30	5.40^{**}
	Middle frontal gyrus	42	15	45	5.29^{**}
	Inferior parietal lobule	-45	-66	45	5.26^{**}
	Middle temporal gyrus	51	12	-30	4.87^{*}

Note. All observed activations occurred in 3 voxels (27 mm^3) or greater.
$^{*}p < .05$. $^{**}p < .001$.

Table 2

Significant Second-Level Activations by Contrast and Region-of-Interest (ROI)

Contrast	ROI	*t*(11)	Mean difference from zero	95% Confidence interval	
				Lower	Upper
Music-No-music (listening)	Right cerebellum	2.46	12.13^{*}	1.26	23.00
	Right STG	3.79	14.50^{**}	6.08	22.92
	Left STG	3.05	10.14^{*}	2.82	17.47
	Left TTG	4.14	10.90^{**}	5.10	16.70
Fast-Slow (listening)	ITG	2.37	2.49^{*}	0.18	4.80
Fast-Slow (CRT task performance)	ITG	2.33	2.46^{*}	0.14	4.79
Loud-Moderate (CRT task performance)	Left putamen	2.81	1.60^{*}	0.35	2.86

Note. All mean effect sizes were assessed with reference to a hypothesized null mean of zero. STG = Superior temporal gyrus; ITG = Left inferior temporal gyrus; IPL = Right inferior parietal lobule; Lower = Lower boundary; Upper = Upper boundary.

$^{*}p < .05$. $^{**}p < .005$.

Figures

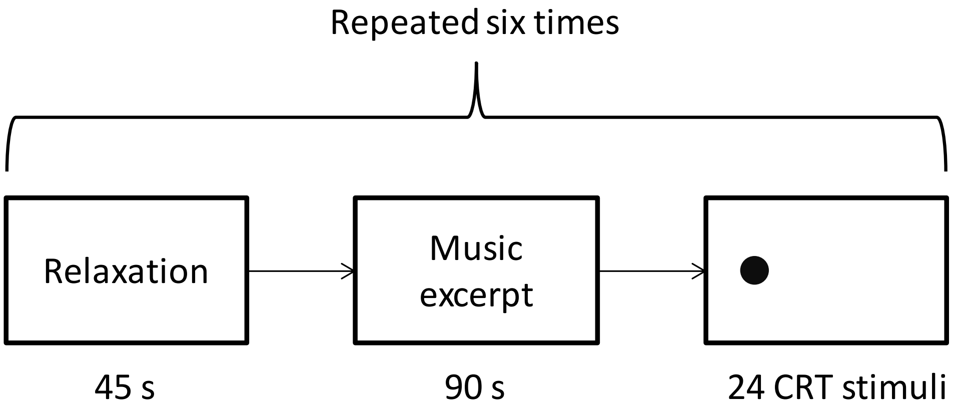

Figure 1. Study design. Both order of presentation of the music excerpts and CRT stimuli locations (left-located stimulus shown above) were randomised. The music excerpts were played at one of two intensities (55 dBA or 75 dBA), and at one of three different tempi (99 bpm, 129, bpm, and 161 bpm).

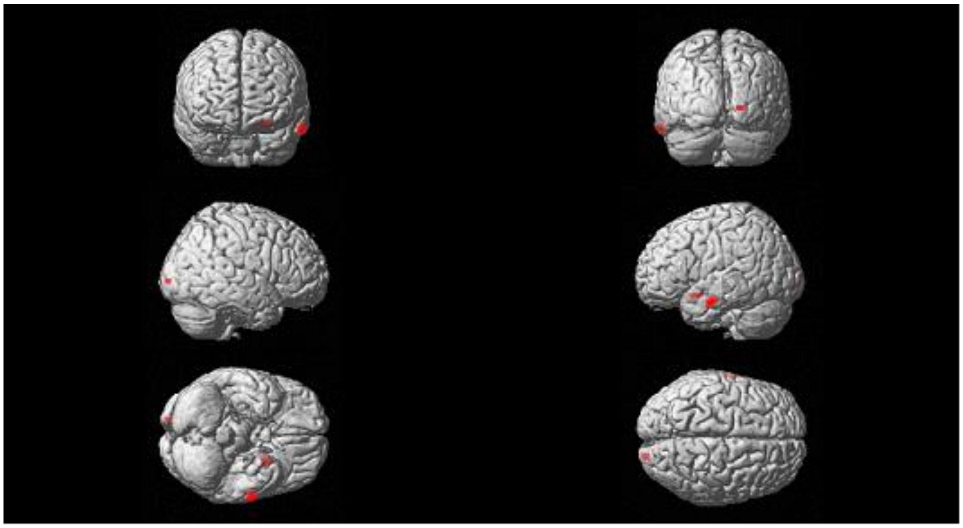

Figure 2. Group-level fixed-effects activation of inferior temporal gyrus, cuneus, and subcallosal gyrus during CRT task performance after listening to music played at a fast tempo (contrasted with slow music, *fast* > *slow*). ONE FIGURE PER PAGE

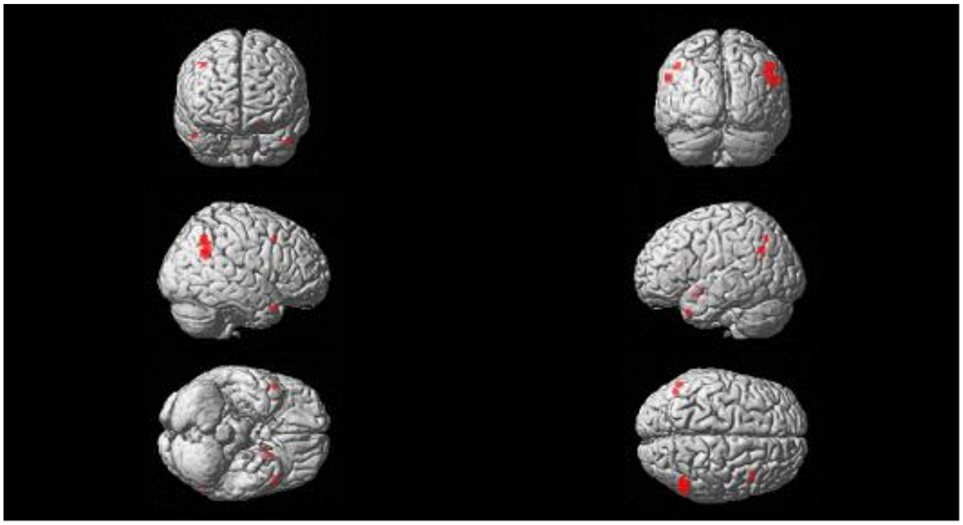

Figure 3. Group-level fixed-effects bilateral activation of supramarginal gyrus and inferior parietal lobule; and activation of left putamen, right middle frontal gyrus, and right middle temporal gyrus during CRT task performance after listening to music played at a loud intensity (contrasted with moderate intensity music, *loud* > *moderate*).