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Music perception and imagery in EEG: Alpha band effects of task and stimulus

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ABSTRACT

Previous work has shown that mental imagination of sound generally elicits an increase of alpha band activity (8–12 Hz) in the electroencephalogram (EEG). In addition, alpha activity has been shown to be related to aspects of music processing. In the current study, EEG signatures were investigated for perception and imagery of two different natural musical phrases. The responses are compared between tasks and between stimuli. For all tasks and stimuli, posterior alpha band activity was seen, but differences are shown in the power of this response. As expected, imagery resulted in a significantly stronger alpha activation than perception. The comparison of the averaged responses to the stimuli also showed a difference in alpha power, although this effect is seen in different directions. These results are interpreted to indicate that both the tasks and the stimuli modulate an attentional network, which may relate to the inhibition of non-task relevant cortical areas, as well as engagement with the music.

1. Introduction

The most commonly measured rhythm in the human electroencephalogram (EEG) is the alpha rhythm, generally referring to the frequency band spanning from 8 to 12 Hz (exceptions in other studies are noted explicitly). Early studies have related this response to internally directed attention and imagination, showing high alpha amplitudes for varying imagination tasks (Klinger et al., 1973; Ray and Cole, 1985, imagining people, and sentences/arithmetics, with activity found in the left occipital and right hemispheres respectively). Fuentes Cabrera and Demstrup (2008) report a peak in activity around 10 Hz for auditory and spatial imagery in right parietal EEG channels. It has been suggested that alpha synchronization reflects an active process of inhibition (Klimesch et al., 2007; Jensen and Mazaheri, 2010), notably in areas that are task-irrelevant (possibly explaining the range of scalp distributions seen). This is also seen in modality specific attention: using an 8–14 Hz frequency band, Fu et al. (2001) showed that auditory expectation caused a posterior alpha increase, and an investigation of working memory for pitch (van Dijk et al., 2010, using 5 to 12 Hz) resulted in left-lateralized parieto-occipital alpha activation. A more specific investigation using music perception and imagery to compare 'internally and externally directed attention' replicates this finding (Cooper et al., 2003) in occipital and frontal measurement locations. Here, random tone sequences were played and repeated internally, and the alpha activity was shown to increase with increased task demands (in the form of answering questions about the stimuli). However, random tone sequences may not activate the same music processing networks that are at work when natural music is imagined. The perceptual process of listening to music involves a network of multiple brain structures (Platel et al., 1997), and an early EEG study already reported differently lateralized alpha activation topographies for monotone and scale patterns versus melodic patterns (Breitling et al., 1987). It has been shown that posterior alpha activity increases for rhythmic stimuli (Rogers and Walters, 1981), as well as for both stimulating and calming music (Iwaki et al., 1997, using the 9.6 to 11.4 Hz band). However, a number of early EEG studies also report conflicting findings (decreases, increases and null responses in the alpha band when listening to music, as discussed in Katayama et al., 1992). More recently it was shown that alpha desynchronization is also seen in response to musical-syntactic incongruency (using only the 9–10 Hz band, for musicians and non-musicians alike, Ruiz et al., 2009) and thus is involved in musical information processing. Varying alpha responses to different musical stimuli had also been reported by Bruya and Severtsen (1984, using 8–13 Hz) and Katayama et al. (1992, using 8–9 Hz). Moreover, Günther et al. (1991, using 8–13.5 Hz) showed that alpha increases with musical complexity in music listening in healthy controls (which is not seen in schizophrenic patients, interpreted to reflect cerebral 'hyperactivation' in this patient group), with stable test–retest results. Together, these studies indicate that alpha activity is seen during imagination of music, and increasing with both task demand (Cooper et al., 2003) and musical complexity (Ruiz et al., 2009; Günther et al., 1991), but also vary across participants in music listening. Without more information on the distributions, either could be explained by attentional mechanisms driven by either the task or the stimulus.

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Recent results show that in the event-related potential (ERP), perception and imagery of music share activation patterns (Schaefer et al., 2009, 2011; Vlek et al., 2011), however, the longevity of this process is not clear (see for instance Janata, 2001). In the current paper we report on the alpha-band frequency content of the EEG during imagination of short natural, well-known musical phrases, as well as perception of the same phrases. Short phrases of overlearned music stimuli were chosen as to minimize working memory operations. We measured the alpha response to hearing and imagining two separate musical fragments, and are thus able to compare between tasks (perception and imagery) or between musical stimuli (by averaging over task). Although we expect both the task of imagining as well as the musical content of the stimuli to elicit alpha activity, we are interested to see if the different comparisons yield different results.

We predict that, based on the previously cited literature on imagery, the finding that more alpha activity is found for imagery (or internally directed attention) will be replicated for natural music. Reasoning according to the hypothesis of alpha activity as inhibition, this should have a parieto-occipital distribution (thus inhibiting visual areas). Considering the results on music perception, mostly showing alpha effects in the right hemisphere (i.e. Ruiz et al., 2009; Breitling et al., 1987), and the frontal effect reported by Cooper et al. (2003) for pitch sequence imagery, the effect of the stimulus is hard to predict. As we are interested in the influence of the specific stimulus, we will compare the response to the two different musical stimuli in an exploratory way. Although the use of naturalistic music makes it very hard to formulate precise predictions, the fact that alpha has been shown to be implicated in music processing would warrant the possibility of a stimulus-induced effect. However, as responses to music remain extremely variable, it would be expected to see variable responses over participants (an indication of the contribution of music information processing networks which are partly shaped by the listeners' experience, as for instance described in Altenmüller, 2001).

2. Method

2.1. Participants

Ten participants were measured, aged 23–51, of which six were males. Musical training was not necessary for inclusion; two participants received formal music training, an additional four play an instrument regularly and four do not. All have normal hearing and normal or corrected to normal vision, none reported neurological abnormalities. The study was carried out in accordance with the principles of the WMA Declaration of Helsinki.

2.2. Stimuli

Two musical stimuli were selected based on their length, ability of the participants to imagine them, and how well they were known, meant to minimize working memory mechanisms. All the audio files were normalized by matching the peaks in the signal, but no other manipulation of the sound was performed, to keep it as close to the overlearned original as possible. The stimuli are described in Table 1, the waveforms and reduced score (i.e. showing the most salient musical content) are shown in Fig. 1.

The sequences were built up as shown in Fig. 2. Each sequence started with one fully sounded repetition with a second phrase played at half the intensity, these phrases were not used in further analyses (denoted by the dotted fragments in Fig. 2). After this, the musical phrase was played 10 times (‘Perception’), alternating with silences of the same duration (‘Imagery’), allowing the participants to imagine the repetition and keep up with the tempo. The stimuli can be listened to on www.nici.ru.nl/mmm under ‘Demos and stimuli’.

The first 6 participants heard some additional stimuli not reported in the current study. Four of these participants received four sets of 16 sequences with breaks in between, the total experiment time adding up to about 1.5 to 2 h, resulting in 160 trials per stimulus. Two additional participants received more repetitions: six sets of 20 sequences, resulting in 400 trials per stimulus. From these trials, the first 160 artifact-free trials were used so as not to bias the means and avoid the trials where participants were more fatigued. The four final participants performed a slightly shorter experiment with only the stimuli investigated here, and thus only needed three sets of sequences, still yielding 160 trials per stimulus. Although the complete sessions were not identical for all participants, the task, stimulus sequences and trial numbers were.

2.3. Equipment

EEG was recorded using a Biosemi Active-Two system with 256 EEG channels and 6 EMG channels (horizontal and vertical EOG, EMG of the long neck muscle (longus capitis) to check for head nodding and the laryngeal muscle (cricithyroid) to check for subvocalization). The DC offsets of the active electrodes were kept below 25 mV at the start of the measurement. The analyses were carried out in MATLAB (The Mathworks, Natick, USA) making use of the FieldTrip toolbox for EEG/MEG-analysis (Oostenveld et al., 2011). The experiment was programmed in Matlab and run on the BrainStream platform, which is a Matlab code package available on request (see http://www.brainstream.nu). Audiofiles were edited using Audacity 1.2.5 (http://audacity.sourceforge.net). The instructions and fixation cross were displayed on a 17″ TFT screen, and stimuli were played through passive speakers (Monacor, type MKS-28/WS) at a comfortable listening level, adjusted to the preference of the participant.

2.4. Procedure

Up to four sequences were practiced before starting the measurement. The task was merely to keep the tempo and synchronize the imagery with the onset of the next occurrence of a musical phrase, without any response at the end. Between sequences, there was a self-paced pause in which participants were told they could blink and stretch as much as they wanted. During the sequences they were instructed to move as little as possible, and just listen to or imagine the music. As a pilot had shown imagery vividness ratings in between sequences to be difficult to give for a whole sequence, participants were instructed to signal the experiment leader if they found their attention wandering (however, this did not occur). Although the stimuli were selected for ease of imagery, a short set of questions was used afterward to check this, as well as general liking, annoyance, boredom, and preferences between the two stimuli, using a five-point Likert scale.

Table 1
A list of the recordings used for the stimuli. The last column indicates the length of the fragment that was used.

Stim	Title	Performer	Record label	Year	Duration
1	Tchaikovsky Nutcracker Suite: March	Kazuchi Ono and Bratislava Radio Symphony Orchestra	Compose records	1997	3.257 s
2	Daytripper	The Beatles	Capitol	1966	3.515 s

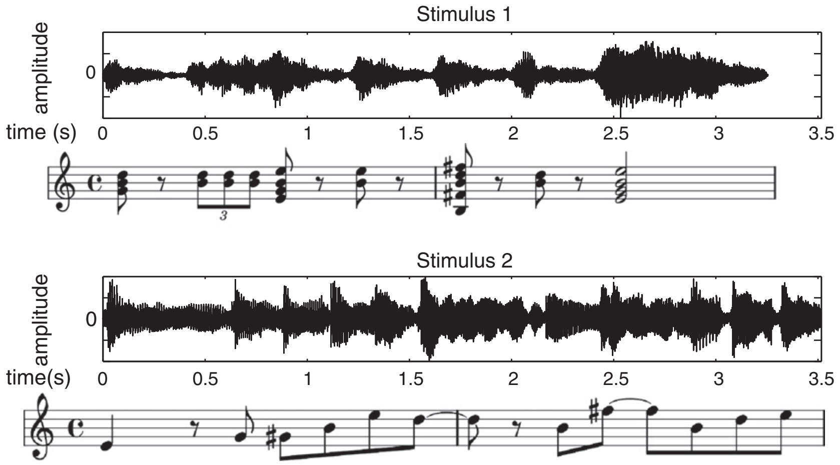

Fig. 1. The audio waveforms of the two musical fragments are shown here, in their final normalized form, with S1 (Tchaikowski) on the top panel, and S2 (Beatles) below. Time is shown in seconds below the waveform, music notation is added below each waveform to show the music in reduced form (i.e. the most salient musical content).

2.5. Analyses

To segment the data, a time window of 0 ms to +3000 ms was chosen starting at each marker, where 0 is the sound or silence onset. These single data segments of 3000 ms will from hereon be referred to as trials. Bad channels were identified for each trial individually based on four properties. Initially, any channel with a DC offset exceeding 40 mV was marked as bad, as well as channels exceeding 5500 μV^2 of power in the 50 Hz band (45 to 55 Hz) or a maximum derivative bigger than 200 μV/sample. Horizontal and vertical EOG channels were band-pass filtered between 0.2 and 15 Hz and decorrelated from the EEG (Schlögl et al., 2007), thus removing eye drifts or blinks if present. The raw EEG signal, originally sampled at 2048 Hz, was temporally downsampled to a sampling frequency of 128 Hz using a FIR lowpass filter to avoid aliasing. Additionally, as a fourth property for identification of bad channels, within-trial variance was computed and channels exceeding variance of 2000 μV^2 were marked as bad. If — according to these four criteria — more than 20% of the channels in a trial were bad, the trial was excluded from further analysis. For the remaining trials, bad channels were reconstructed by interpolation from the remaining good channels with a spherical spline interpolation algorithm (Perrin et al., 1989). For these trials the average number of bad channels that had to be reconstructed by interpolation was 4.7 (1.8% of all channels). The remaining trials were re-referenced to a common average reference (CAR) and linearly de-trended. If more than 35% of trials were rejected due to these criteria, the whole data set was not used. This resulted in exclusion of two participants and left an average of 152 trials (SD = 16) for each perceived musical phrase, as well as for each imagery event. To avoid possible start-up or state-change effects, the first trial of every sequence was not used.

The power spectral density (PSD) of the responses was estimated with Welch's method, using the average PSD of 12 overlapping Hanning windows on each 3000 ms trial, resulting in a spectral resolution of 2.20 Hz. The Welch method reduces noise in the estimated PSD in exchange for a reduction in frequency resolution. Although this causes a somewhat non-standard bin definition, the estimate is more precise. To estimate the task-related response, the stimuli were averaged and Perception and Imagery trials were compared, whereas for the stimulus-related response, the tasks were averaged for Stimuli 1 and 2.

Differences in estimated power in the alpha band were compared using a cluster randomization test, a nonparametric statistical test which provides a straightforward way to solve the multiple comparison problem present in EEG data while allowing biophysically motivated constraints, increasing the sensitivity of the test (Maris and Oostenveld, 2007; Maris, 2004). The two additional EMG channels (to control for sub-vocalization and head nodding) were analyzed using the same analysis pipeline, and did not yield any significant differences between the different conditions. We here compare the means of the two tasks (Perceptions and Imagery) and the means of each stimulus (averaged over task) to distinguish their specific effects.

3. Results

The short set of questions about the stimuli showed that the two stimuli received equal scores for ease of imagery, and although some participants expressed mild differences in imagery ease, the mean showed no bias towards either stimulus. Stimulus 2 was generally more preferred. Individual results are shown in Table 2 together with other results discussed below.

The distribution of the alpha power over the scalp is shown in Fig. 3, with the left panels showing the grand average for the Task (top) and the Stimulus (bottom) comparisons. The difference plots shown alongside each comparison are masked for significance. We see that for the grand average, the comparison between the tasks yields significant differences, whereas the comparison between stimuli does not. When looking at the distribution of the difference of alpha activity over the scalp in the Task comparison, we see that the biggest difference is seen over left occipito-parietal areas. Although the effect of the stimulus does not reach statistical significance in the grand average, the individual effects are highly significant and vary considerably over participants. To elaborate on this, we turn to the single subject data, of which three are shown in the other panels of Fig. 3. There, a large proportion shows a significant stimulus effect, only in differing directions (thus averaging out when combined). Table 2 shows the direction, location and significance of the

Fig. 2. A schematic overview of the sequences in which the trials were organized. Each sequence starts with a musical phrase (perception start or Ps), which is then repeated at half the intensity (fade or F), to start the repeating pattern. Then, the sounded (perceived, P) and silent (imagined, I) intervals are alternated, timed so that the internal repetition stays timelocked.

Table 2
Here, the direction, location and significance of the difference in alpha activation is shown for individual subjects for each task (Perception and Imagery) and the two stimuli. The locations are coded for lateralization (L, R M or B for left, right, midline or bilateral) and general location (F, P and O for frontal, parietal and occipital). Absence of any difference is denoted by X. The final two columns show the response on preference and ease of imagery, with an asterisk denoting a stronger answer.

Subject	Task			Stimulus				
	Dir	Loc	Sig	Dir	Loc	Sig	Pref	Ease
S3	X			X			2*	2
S4	P<I	LP	0.02	1<2	LP	<0.001	2	No
S5	X			1<2	BP/O	<0.001	1	No
S6	P<I	LP	0.06	1<2	BP	0.74	2*	1*
S7	P<I	BP	<0.001	1>2	LP, F	0.01	2*	1
S8	P<I	MP	<0.001	1>2	M	0.02	1	No
S9	P<I	MP, F	0.01	1>2	MP, F	0.08	2*	No
S10	X			X			2	2
All	P<I	LP	0.02	1<2	BP/O	0.17	2	No

difference in alpha distribution per participant, as well as their responses in terms of ease of imagery and liking. The latter two measures show no relation to the direction of the alpha response in the Stimulus comparison.

The results for three single subjects, plotted in Fig. 3 alongside the grand average, show that for a typical subject (P4), the left temporal alpha increase is there for all conditions, the task effect is distributed somewhat differently from the stimulus effect. The former shows a pronounced left temporal focus, consistent with reports on auditory working memory (van Dijk et al., 2010), whereas the latter is less focused, in concurrence with our prediction concerning music information processing. However, different patterns are also seen, and two specific cases are shown in Fig. 3, as some participants (with P7 as an example) showed a reversed stimulus effect and a few participants (for which P8 is representative) showed no stimulus effect at all. Although not all participants show a significant task effect, and the precise distributions vary, the difference (even if non-significant) is always in the same direction (i.e. more alpha increase for imagery as compared to perception). For the stimulus comparison however, the difference can go in all possible directions, as was already shown in Table 2. In each case, the alpha activation is located similarly for each condition within one subject, and thus the task and stimulus effects appear to be modulations of the same network. For alpha distributions for all participants see the supplementary materials (posted on www.nici.ru.nl/mmm under 'Demos and stimuli').

4. Discussion

In the current study, the EEG signatures of perceived and imagined music were compared over task and over stimulus. Effects in the high alpha band (around 11 Hz) are found in both comparisons. Although the distributions varied over individual subjects, occipito-parietal alpha was found for all tasks and stimuli. Significant differences were found in the power of the alpha response, which is higher during imagery than during perception, while for the stimulus comparison effects are seen in different directions for different individuals. This confirms our prediction concerning the Task comparison. A similar left occipito-parietal alpha increase was also reported for auditory working memory (van Dijk et al., 2010), and it is very likely that the two tasks are very similar, especially where it concerns effortful imagery as was used in the current paradigm. However, it can be argued that there is a considerable difference between keeping a pitch in working memory, as was the task in van Dijk et al. (2010), and imagining a melody line or musical phrase, including a time structure. Moreover, very familiar stimuli were selected especially to minimize the need for rehearsal in working memory. Reasoning the other way, one can argue that effortful imagery is part of working memory, but not necessarily vice versa. Additionally, concurrent EEG and fMRI work has shown a dorsal attention network in the brain to be negatively correlated to low (7–10 Hz) alpha power (Sadaghiani et al., 2010). Deactivation of this same network has also been shown to predict lapses in auditory perception (Sadaghiani et al., 2009). An argument against this interpretation is that the frequencies we found to be implicated are generally higher than what was found in this study. Although replication in fMRI would be needed, the current results imply that a dorsal attention network is engaged by the task of music imagery.

The exploratory investigation of the effect of the stimulus yielded results with large inter-individual differences. The fact that musical stimuli were used in this case did not cause a right-lateralized distribution of the alpha effect, although it was seen in some participants. As alpha synchronization has been argued to be related to auditory attention in the shape of inhibition of visual areas (Fu et al., 2001), a possible explanation for the effects in all directions is that the

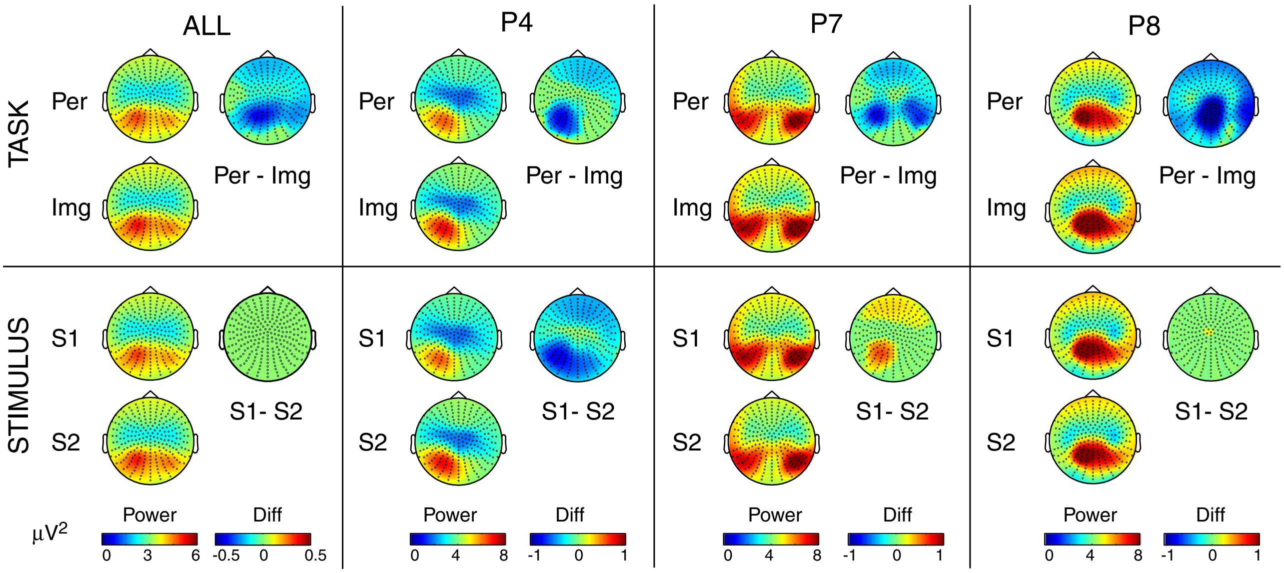

Fig. 3. The topographies for the alpha band power (9.93–12.14 Hz) are shown for the means of Perception, Imagery, Stimulus 1 and Stimulus 2 in columns, with the difference plots for task (Perception–Imagery) and stimulus (Stimulus 1–Stimulus 2), masked for statistical significance next to them. The grand average, and single subjects P4, P7 and P8 are shown. Color scales are shown in μV^2 below the plots, with the grand average plotted at a more sensitive scale.

stimuli were engaging to the participants to different degrees. Considering the musical content, there are many musical aspects that may have caused a difference. Stimulus 2 was rhythmically more complex than Stimulus 1, and contained more sound events, Stimulus 1 however had a harmonically more salient structure, and included different timbres. Although the clips were peak-normalized, the mean amplitude of sound was somewhat higher for Stimulus 2. However, this is obviously not relevant for the imagined stimuli (as the imagery was performed in silence). The behavioral measures of liking and ease of imagery did not help to explain the direction of the alpha effects on an individual basis (although in average, more participants preferred Stimulus 2 over Stimulus 1). The specific source of the engagement with the music stimuli needs to be further investigated, but especially in the absence of any incoming sound, the difference in the alpha response is apparently purely caused by 'internal' musical processing. The choice to average over perception and imagery to investigate the effect of stimulus is validated by the significant individual effects seen in this comparison. As the shared mechanisms between auditory perception and imagery reported previously (Schaefer et al., 2009; Schaefer et al., 2011; Vlek et al., 2011) only focused on the ERP, seeing similar activation in the frequency content of the EEG provides new information. The distribution of shared activation in these ERP studies was fronto-central, concurrent with the projection of the auditory cortices (Mayhew et al., 2010). In a study focusing on the activation modality-independent imagery areas, Daselaar et al. (2010) found activation in a number of frontal and parietal areas, that are likely also implicated in the activation seen here. However, as their study only included auditory environmental sounds, the structure and timing of imagined music is likely to add extra subprocesses. The fact that the frontal activity found in Cooper et al. (2003, 2005) was not clearly visible may be relevant to the difference in stimuli (namely random tone sequences versus natural music)

The surprising finding here is that there do not appear to be specific responses related to either the task or stimulus processing, but rather that the same network appears to be differentially modulated. There are subtle differences in the distribution of the significant differences in the two tested comparisons, but in general the activation patterns look very similar over all conditions. Obviously more data is needed to solidify this interpretation, but for our modest sample size this is true for all participants. One explanation could be that the dorsal attention network described above also differentiates between different musical stimuli, interpreting the differing results as differing levels of engagement with the stimulus for different people. This in turn could be related to personal listening biographies (Altenmüller, 2001). Also, although the alpha response is generally posterior, the lateralization in different participants is different. As we would not necessarily expect this effect for imagery, we interpret this as a music-specific effect, reflecting the interpersonal differences in music processing. The extreme cases of these differing biographies, such as formal musical training, would definitely be of influence in these responses, and could be at the basis of the imagery strategy. However, as the alpha results for imagination and music listening are mostly reported for the general (non-musically trained) population, the current results are comparable, and show that even within the nonmusicians the differences in responses (and probably strategies) are considerable.

There are a few limitations to this study. Most notably, there is no real control over the quality of the imagery of the participants. The time-locked nature of the design prevented a vividness rating per trial, and in a pilot it was found to be hard to rate an entire stimulus sequence. However, in the case that participants were not motivated, the found effect would likely be smaller, not larger. Additionally, due to the choice of similar stimulus length, the tempi of the two stimuli did not differ greatly. To better investigate the effect of tempo and time-structure, stimuli would be needed where the difference is bigger. However, this too would hypothetically cause the found effect to be larger, not smaller, so both limitations would not cause an overestimation of the effects seen.

To summarize, the current work shows that imagining natural music causes a synchronization in parieto-occipital alpha, replicating earlier findings with artificial pitch sequences (Cooper et al., 2003, 2005). This may be related to modality-specific inhibition and auditory attention mechanisms. Additionally, this parieto-occipital alpha is also modulated by the stimulus, in different directions for different people. We believe that the engagement level of music, driven by personal preference or experience, may be at the basis of this finding. Further work is needed to further elaborate the musical aspects that are relevant for this response, as well as the cause of the particular inter-individual differences.

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Appendix A. Supplementary data

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