

Evidence for a neural signature of musical preference during silence

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ABSTRACT

One of the most basic and person-specific affective responses to music is liking. The present investigation sought to determine whether liking was preserved during spontaneous auditory imagery. To this purpose, we inserted two-second silent intervals into liked and disliked songs, a method known to automatically recreate a mental image of these songs. Neural correlates of musical preference were measured by high-density electroencephalography in twenty subjects who had to listen to a set of five pre-selected unknown songs the same number of times for two weeks. Time frequency analysis of the two most liked and the two most disliked songs confirmed the presence of neural responses related to liking. At the beginning of silent intervals (400–900 ms and 1000–1300 ms), significant differences in theta activity were originating from the inferior frontal and superior temporal gyrus. These two brain structures are known to work together to process various aspects of music and are also activated when measuring liking while listening to music. At the end of silent intervals (1400–1900 ms), significant alpha activity differences originating from the insula were observed, whose exact role remains to be explored. Although exposure was controlled for liked and disliked songs, liked songs were rated as more familiar, underlying the strong relationship that exists between liking, exposure, and familiarity.

1. Introduction

Sometimes it's the space between the notes that makes all the difference in music. Silence in music conveys information of major importance that was efficiently used by composers like Mozart who mentioned that “music is not in the notes, but in the silence between”. Some authors have suggested that high-level musical information, such as familiarity, is also present during silence: “When you listen to Mozart, the silence that follows is still Mozart” (Guitry, 1947).

In the early 2000s, neuroimaging studies confirmed that familiarity was processed during silences, even when these silences were artificially inserted into music (Kraemer et al., 2005; Gabriel et al., 2016). When inserted in familiar music, these silences automatically convey the sensation of hearing a song internally without any audible sound, in continuation of what had just been heard before. This is referred to as spontaneous auditory imagery. As a consequence of spontaneous imagery, a neural activity within regions of secondary auditory cortex, of

the dorsolateral prefrontal cortex and of the supplementary motor area is generated (Kraemer et al., 2005). In electroencephalography (EEG), the response to familiar music is reflected by an increase in theta power during the whole silence period (Gabriel et al., 2016). Interestingly, the neural familiarity mechanisms occurring during auditory imagery are similar between familiar songs and songs passively learned for two weeks, showing the efficiency of passive learning processes in encoding musical information (Gabriel et al., 2016).

The present investigation sought to determine whether aesthetic musical judgement is also present during silence in music. When we like listening to Mozart, do we still like Mozart during the silences in its music? Music is a complex stimulus, and its affective dimension is an integral part of the artistic and aesthetic experience, and the hedonic appreciation of music, referred to as music liking, involves activation of areas responsible for the feeling of pleasure (Blood and Zatorre, 2001). The hypothesis of a preservation of liking during auditory imagery is based on the important influence of familiarity on liking: becoming

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more familiar with a particular piece of music increases the subject's liking ratings for it (Pereira et al., 2011). Familiarity and liking being two high level information processes often co-occurring when listening to music (Stalinski and Schellenberg, 2013), they may as well co-occur during musical imagery. A second argument supporting that liking may be maintained is based on the fact that emotions are preserved during auditory imagery (Lucas et al., 2010).

The neural structures responsible for the mechanisms of liking have only been explored while listening to music. Neuroimaging methods have linked the activation of several cerebral areas to pleasure states when listening to music: the dorsal and ventral striatum, right caudate nucleus, ventral putamen and nucleus accumbens in relation to dopamine release in the reward system (Salimpoor et al., 2011). A functional architecture including anterior cingulate cortex, amygdala, insula, orbitofrontal cortex and nucleus accumbens as areas providing evaluative responses such as the reward value of the stimulus has also been suggested (Salimpoor et al., 2015; Clark et al., 2014). Other structures such as the inferior frontal gyrus (IFG) and the superior temporal gyrus (STG) have been found to be specifically activated during liking/disliking processes (Pereira et al., 2011; Koelsch et al., 2006).

A few recent studies have described the use of EEG in listening situations to investigate the temporal dynamics of liking. Partially discordant results were found in terms of brain rhythms among these studies. When comparing consonant to dissonant music, a positive correlation between the synchronization in the mid-frontal theta band and the liking score emerged, especially towards the end of the excerpts (Sammler et al., 2007). Two other studies (Hadjidimitriou and Hadjileontiadis, 2012, 2013) reported that beta and gamma bands were the best features to separate pleasant from unpleasant music, followed by alpha and theta bands. In a recent study a biomarker of music liking has been defined, relying on brain activations recorded over the left prefrontal cortex and focusing on the functional coupling between high-beta and low-gamma oscillations (Adamos et al., 2016). The discrepancies observed in all EEG studies may be attributed to the interference of the physical processing of sounds that impair the detection of the electrophysiological activity related to liking.

Should liking processes be present during spontaneous auditory imagery, we aimed to investigate whether the spatiotemporal dynamics would be similar to those observed in listening situation. Such a preservation of high-level information processes has already been observed during deliberate auditory imagery. Several studies report similar spatial and temporal processes during the musical perception and the voluntary imagery of a song (Halpern and Zatorre, 1999; Linke and Cusack, 2015; Schaefer et al., 2011; Vlek et al., 2011; Zatorre et al., 1996). The mental perception of a familiar piece of music occurs with a high efficiency, and concerns not only the lyrics but also the tempo (Halpern, 1988; Levitin and Cook, 1996), pitch (Halpern, 1989; Janata and Paroo, 2006) and timbre (Halpern et al., 2004). To study these dynamics, we chose to use high-density EEG, whose spatial resolution allows localizing the neural structures involved in liking processes and whose high temporal resolution is adapted to the time-frequency analysis of these events. Our main hypothesis was based on the presence of similar spatiotemporal mechanisms during imagery to those found during music perception. However, no predicted directions were given for time frequency analysis because of the discordant results obtained in previous EEG studies investigating liking during the perception of music. Specific EEG liking responses were thought to spontaneously emerge, especially in the theta band, with neural activations at least partially similar to those observed during listening situations.

2. Methods

The present study is a complementary analysis of the data from the study of (Gabriel et al., 2016) whose primary objective was to explore the onset of the memory dynamics that lead to the automatic completion of missing lyrics during spontaneous musical imagery.

2.1. Participants

Twenty volunteers (7 male, 13 female, mean age = 32 ± 5 years old) participated in the experiment. All participants were right handed, non-musicians (i.e. had not received any formal musical training or had done so for < 6 years), with no neurologic or psychiatric diseases and normal audition. Written consent was obtained from participants prior to taking part in the study, and all received a monetary compensation of 50€. Research methods were approved by the Committee for the Protection of Human Subjects at the Clinical Investigation Center of Besançon (n°14/458).

2.2. Experimental design

Five familiar songs chosen by the participant and five unfamiliar songs selected by the experimenter among original soundtracks recorded by independent or relatively unknown singers were used. Familiar and unfamiliar songs were paired to belong to the same musical genre, sang by a singer of the same sex. All songs were in participants' native language. Loudness levels of all songs were equalized with the Replay Gain algorithm.

The first EEG recording was performed immediately after song selection. All songs were randomly played over headphones and repeated twice. Each Song was 2 min in length and twenty portions were replaced with two-second silent intervals randomly embedded between 10 and 100 s after song onset and with a distance ranging from 2.5 to 3.5 s between gaps. This resulted in 200 trials within familiar songs and within unknown songs. Silence and song presentation were accomplished using the E-Prime software (Psychology Software Tools Inc. Sharpsburg, PA). Participants were instructed to close their eyes and remain still while passively listened to the song. They were requested to rate each song using a visual analog scale (0: unfamiliar; 10: unfamiliar). The knowledge of each song could thus be checked to ensure that subjects did not know any of the unfamiliar songs. After the EEG recording, subjects were required to rate whether they were mentally completing the gaps during the experiment. As expected, all reported mentally completing the gaps except for unknown songs.

Then there was a two-week learning period during which each subject was inquired to listen regularly to the unfamiliar songs, and to note the frequency of song listened to per day in a self-monitoring logbook. The participants listened to each song for an average of 33.89 times (average = 2.39 listening per day). All subjects listened to each of the five unfamiliar songs the same amount of time.

The second EEG recording was scheduled after the two-week learning period. The recording had exactly the same design as for the first EEG, at the exception of the order of the songs that was randomly selected. At the end of the recording, subjects were requested to rate subjective liking/disliking (from 0: disliked to 10: liked a lot), emotions (from 0: very sad to 10: very joyful) and familiarity (from 0: unfamiliar to 10: very familiar) for each song with a visual analog scale.

2.3. Data acquisition and analysis

In this study, we focused on the liking of newly-learned songs, i.e. unknown songs that were learned over the time course of two weeks, because they were controlled to be listened to the same amount of time. Among the five newly-learned songs listened to by participants, the two more preferred and the two least preferred songs were selected. Only the neural responses from the second EEG were considered.

Subjects were seated in a comfortable chair in a dark quiet testing room. EEG signals were recorded using a 256-channel Geodesic Sensor Net (Electrical Geodesics Inc.; EGI, Eugene, OR). Data were continuously recorded with a high-pass filter at 1 Hz, and a sampling rate at 1000 Hz. Epochs of 2500 ms were extracted from the raw data beginning 600 ms pre-silence onset and ending 1900 ms post-silence onset separately for liked and disliked songs. A total of 80 trials were

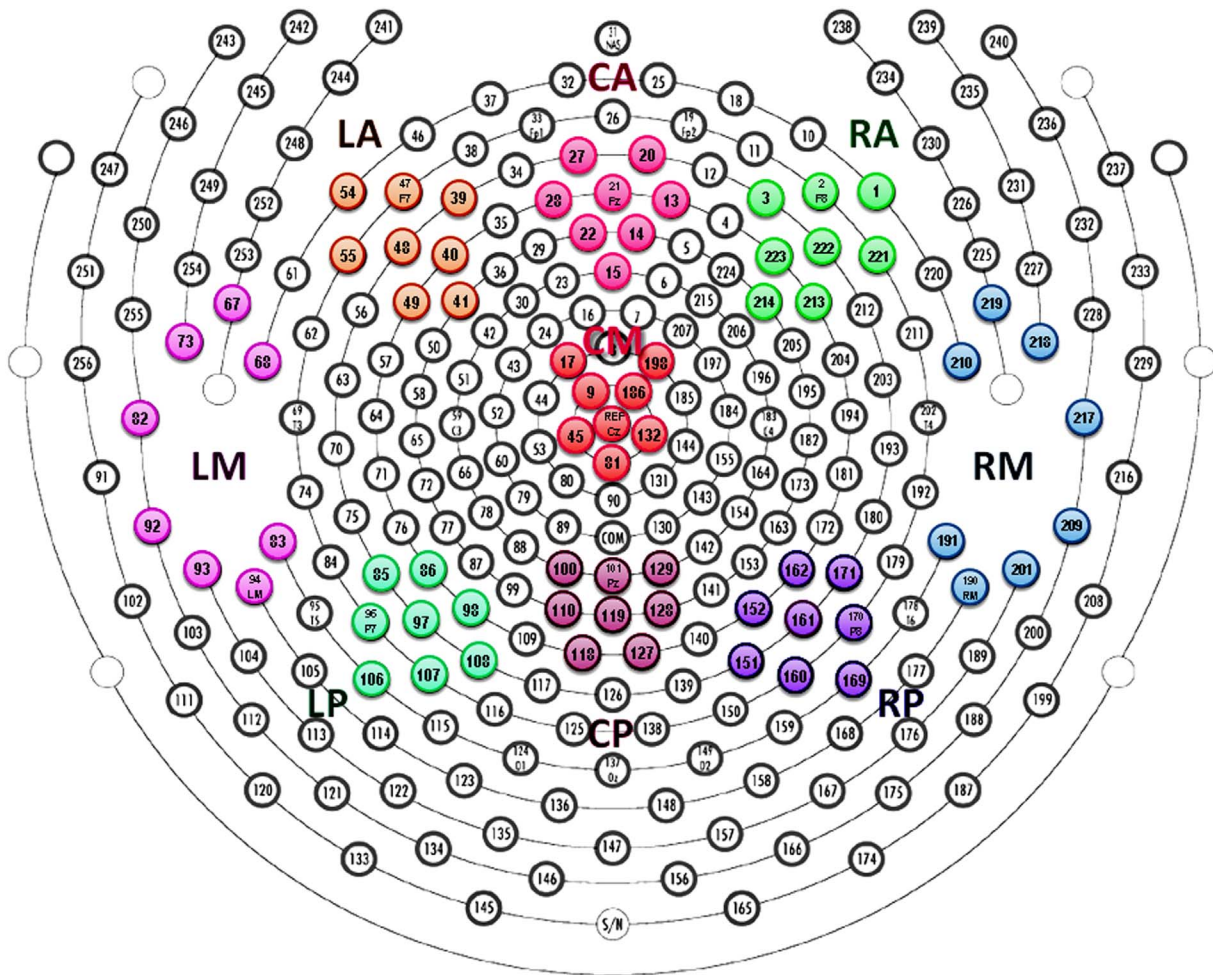


Fig. 1. The nine regions of interest. A: anterior, M: median, P: posterior; L: left, C: central, R: right.

extracted for the more preferred and the least preferred songs. A band-pass filter between 1 and 30 Hz and a notch of 50 Hz were applied to remove unwanted frequency components. A baseline correction was applied for each trial before silence onset (–600 to 0 ms). Periods with visually detectable artifacts were removed from the analysis. Individual channels with artifacts were interpolated using a 3-dimensional spline algorithm (maximum: 7% interpolated electrodes per subject).

Nine Regions of Interest (ROIs) were selected: left anterior, central anterior, right anterior, left median, central median, right median, left posterior, central posterior and right posterior (Fig. 1).

2.3.1. Time-frequency analysis

To evaluate the long-term signal synchronization in the frequency domain during the entire silent period, time-frequency analysis of silent was carried out in the whole time period on each ROI for liked and disliked songs. Spectral power from –50 ms pre-stimulus to 1950 ms post stimulus (in 10 ms steps). The length of the sliding time window was frequency dependent with 3 cycles at the minimum frequency of 3 Hz and 6 cycles at the maximum frequency of 30 Hz. Fifty log-spaced frequencies from 3 Hz to 50 Hz were calculated. We considered as theta the rhythmic activity occurring between 4 and 8 Hz, alpha the activity between 8.5 and 12 Hz, and beta the activity above 12 Hz and below 30 Hz. Time–frequency points were considered significant between liked and disliked songs by a nonparametric permutation-based statistical method (Delorme and Makeig, 2004). A total of 1000 permutations were used at each frequency to assess significance at $p < 0.01$. To increase statistical power, only clusters of significant responses on several frequencies and several time frames were considered as

significant.

2.3.2. Source localization

Based on the results of the time-frequency analysis, source localization was performed on the frequency bands showing significant differences between liked and disliked songs. Source localization was estimated using a distributed linear inversed solution based on a local auto-regressive average (LAURA) model (Grave de Peralta Menendez et al., 2001). Activations obtained by source imaging were compared for each condition and thus identified diverse regional brain activities. Voxelwise two-tailed t -tests were calculated on the mean LAURA source estimates for liked and disliked songs. Differences in the current source density at $p < 0.001$ are reported.

3. Results

3.1. Behavioral analysis

After two weeks of passive learning, the average liking rating was 5.3 ± 2.4 (range 0–10). When separating the songs into the two most liked and the most disliked for each subject, a 4 point difference was noted on average (Table 1). Since we selected the most and less liked music for each subject, a highly significant difference was observed between liking scores of liked and disliked songs ($t(19) = 9.55$, $p < 0.001$). The comparison of emotions conveyed by liked and disliked songs revealed no significant difference ($t(19) = 0.81$, $p = 0.4$). Although all songs were listened to for the same amount of time, a significantly increased familiarity for a liked song was observed (t

Table 1

Musical appreciation, familiarity, and emotions for all 5 songs, as well as for the most liked and disliked songs (mean followed by standard deviation). p value shows the difference of scores between liked and disliked songs.

	All songs	Liked songs	Disliked songs	p value
Liking	5.4 ± 2.4	7.3 ± 2.1	3.3 ± 1.7	< 0.000001
Familiarity	7.4 ± 1.6	7.8 ± 1.4	7.0 ± 1.7	< 0.001
Emotions	4.8 ± 2.4	4.5 ± 2.2	5.0 ± 1.6	n.s.

(19) = 4.79; $p < 0.001$).

3.2. Time frequency responses

Time frequency analysis revealed three distinct time periods of significant differences between liked and disliked songs: the first between 400 and 900 ms, the second between 1000 and 1300 ms, and the third between 1400 and 1900 ms (Fig. 2). Differences were mostly significant in the theta and alpha bands, with a desynchronization of theta and a synchronization of alpha for liked songs. No differences were observed above 20 Hz.

Source localization was performed on the three time periods of difference. During the first time period, a significantly stronger theta

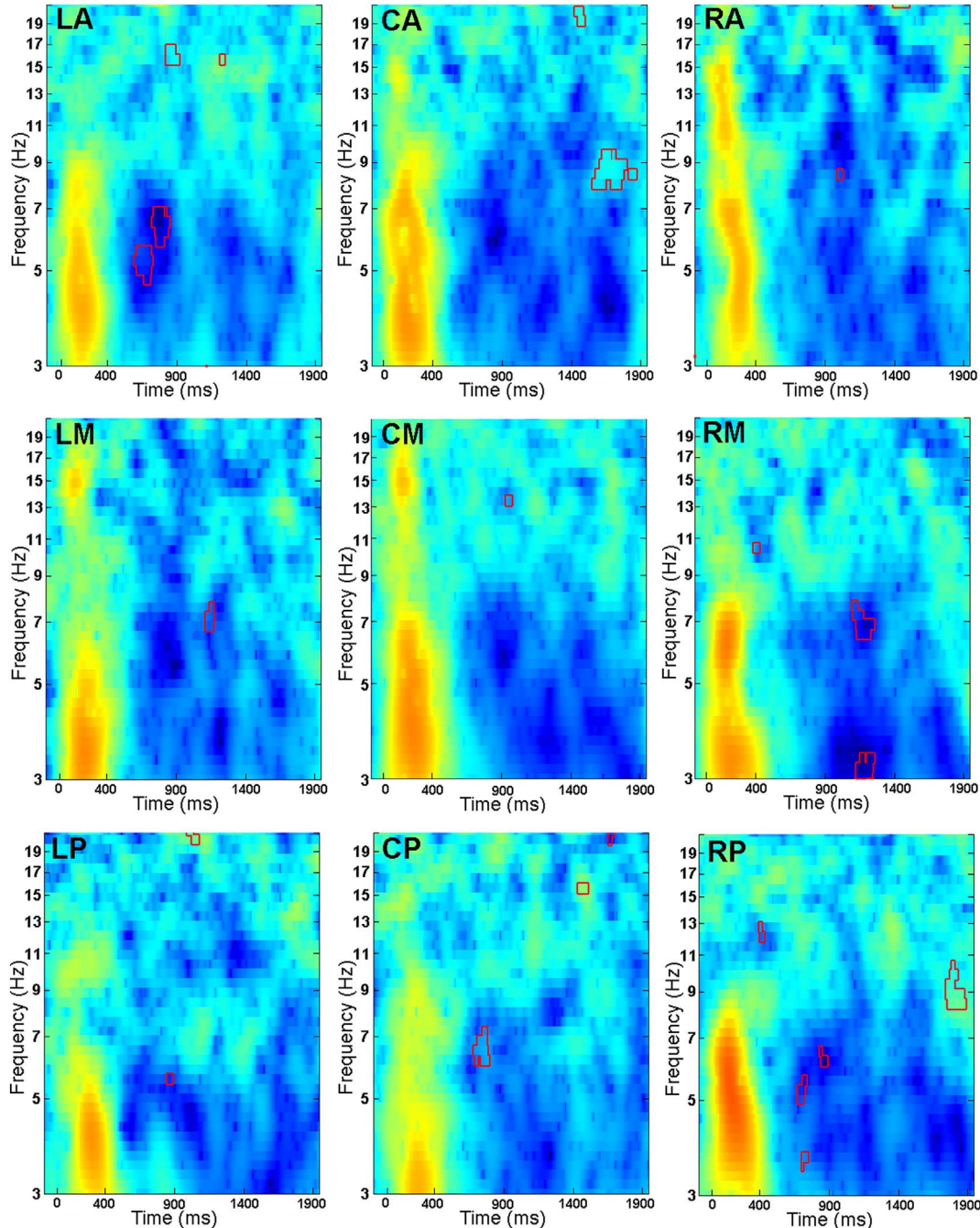


Fig. 2. Time frequency analysis performed over the nine ROIs during silence inserted into liked songs. Neural synchronizations (yellow) and desynchronizations (blue) are represented at different frequency bands. Areas of significant differences ($p < 0.01$) between liked and disliked songs are surrounded in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

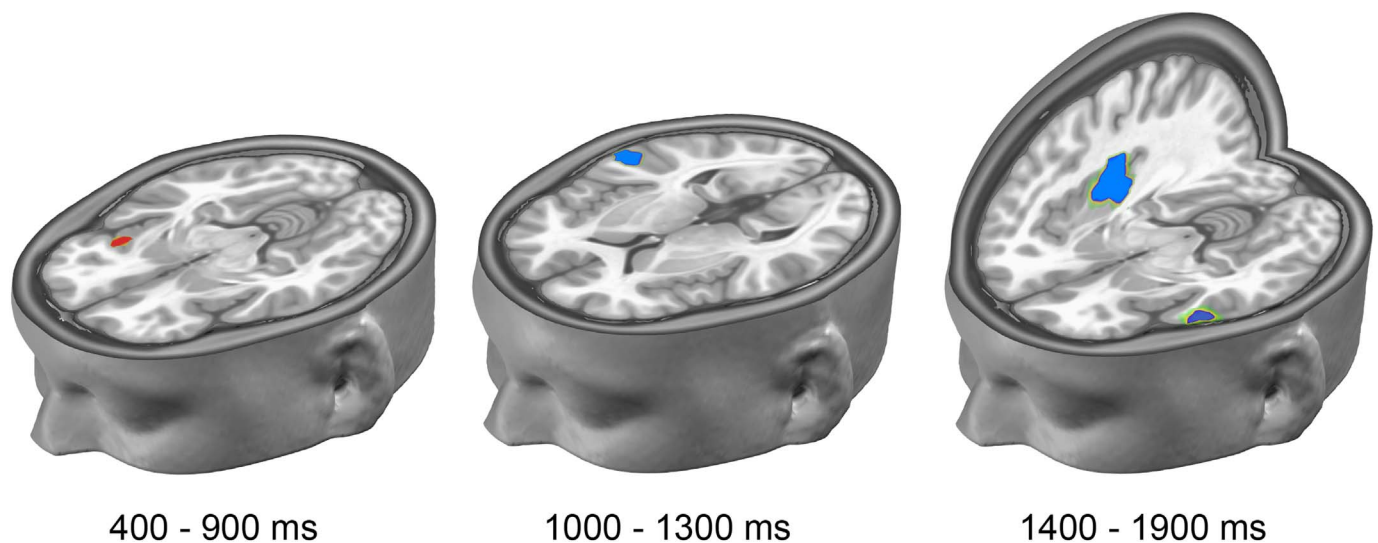


Fig. 3. Brain areas showing significant differences in activation between liked and disliked songs. Left: source of difference in theta activity in the first time period. Middle: source of difference in theta activity in the second time period ($p < 0.001$). Right: source of difference in alpha activity in the last time period ($p < 0.001$). Areas more strongly activated for liked songs are represented in red, and in blue for disliked songs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

activity was observed in the left anterior and central posterior ROIs (LA and CP in Fig. 2). Statistics performed on source localization could not reveal the source of the differences between both conditions, but the right inferior frontal gyrus (IFG) was differentially activated at a lower significance level of $p < 0.01$ (Fig. 3). In the second time period, a difference in theta activity was observed in the right median ROI (RM in Fig. 2). The main difference originated from a stronger activation of the right superior temporal gyrus (STG) for disliked songs. In the last time period, a difference in alpha activity was observed in the central anterior and the right posterior ROIs (CA and RP in Fig. 2). Source localization showed this difference originated from the left Middle Temporal Gyrus and the right Insula.

4. Discussion

An original aspect of the present study was to explore the neural mechanisms of liking during spontaneous auditory imagery, thus offering the possibility of studying its emergence while removing any acoustical interference. To study music liking in a naturalistic condition, we voluntarily chose songs instead of using artificial excerpts of music and asked the participants to simply listen to these songs for two weeks, as if they were hearing a new song on the radio, for example. Moreover, we preferred using songs as material over using instrumental music because we were interested in the integrated memory representation for text and melody in songs (Crowder et al., 1990; Peretz and Zatorre, 2005). In addition, the songs were not chosen according to the emotions they raised. Although studies on liking usually focused on happy musical extracts, since it is this type of music which most frequently leads to the highest liking scores (Hunter et al., 2008; Vuilleumier and Trost, 2015), it has been shown that sad music can also be highly appreciated by listeners (Brattico et al., 2015). We thus chose the most appreciated and least appreciated songs regardless of their emotional valence. Moreover, since we have averaged over many different songs, based on preference, we thereby canceling out differences related to the stimulus.

Our results show that, although participants were instructed to simply listen to the songs in the experimental tasks, specific neural responses related to aesthetic judgements occurred during spontaneous auditory imagery, which is similar to familiar judgements that have already been noted in identical conditions (Gabriel et al., 2016; Kraemer et al., 2005).

4.1. Electrophysiological correlates of liking

The subjective aesthetic appreciation of a song was reflected by responses in theta and alpha frequency bands in three time periods included in silent intervals. First responses, frontal theta oscillations, have not only been reported in subjects listening to pleasant musical pieces (Sammler et al., 2007), but also in subjects performing a broad range of cognitive tasks requiring attention or short term memory (Burgess and Gruzeliier, 1997; Inanaga, 1998; Smith et al., 1999). Here, it is likely that theta activity observed in the two first time periods reflects both attentional and emotional mechanisms that could be part of the same process since an emotionally significant stimulus automatically attracts attention (Lang et al., 1997). It is, therefore, conceivable that participants were more attentive during silences occurring in pleasant songs, waiting for the music to resume so they could enjoy it again.

Variations in parieto-occipital alpha oscillations observed for liked and disliked songs could be related to auditory attention mechanisms, and it is thus possible that liked music attracted more attention than disliked songs, but this hardly explains why it occurred in such a late period. A suggestion could be that participants were eager for the pleasant songs to start again, and were attentively waiting for the end of silence gaps. However, alternative explanations could explain the increase in alpha oscillations. For example, it has also been suggested that alpha synchronization reflects an active process of inhibition of task-irrelevant areas (Klimesch et al., 2007). As a consequence, variations in alpha oscillations may also be related to increased relaxation consecutive to increased enjoyment and fewer cognitive resources allocated to liked songs (Caldwell and Riby, 2007).

It should be noted that we did not find evidence that oscillations above 20 Hz were involved in music liking, which contradicts some previous studies investigating music liking through EEG signals (Adamos et al., 2016; Hadjidimitriou and Hadjileontiadis, 2012, 2013). In addition to the methodological discrepancies, a major difference between these studies and ours lies in the fact that they measured liking at the same time as music was perceived. In that respect, it is well known that frequencies above 20 Hz fluctuate during musical beat processing (Fujioka et al., 2009; Edagawa and Kawasaki, 2017; Gordon et al., 2011), a parameter especially difficult to control in naturalistic conditions. Studying liking during silence may have reduced the interference between beat processing and liking, even though some studies have shown that tempo was well preserved during auditory

imagery (Halpern, 1988; Levitin and Cook, 1996). Of course, it is also possible that the processing of liking differs during silence and music perception and that aesthetic information is not encoded the same way in both situations. However, the difference in theta oscillations observed in our study, also found when listening to consonant and dissonant music (Sammler et al., 2007), may be more a signature of music liking.

4.2. Neural sources of EEG activity

Interestingly, sources of theta activity observed during silence were found to originate from the IFG and the STG. These results corroborate previous fMRI studies that also reported a stronger activation of the IFG for pleasant music and of the STG for unpleasant music in listening situations (Pereira et al., 2011; Koelsch et al., 2006). The IFG and STG are two structures known to work together to process various aspects of music (Salimpoor et al., 2015). They are activated for musical memory retrieval (Halpern and Zatorre, 1999; Peretz and Zatorre, 2005; Platel et al., 2003) and participate in the formation of a musical image (Satoh et al., 2006). The IFG is notably involved in the long-term musical memory retrieval (Altenmüller et al., 2014), which is essential for making accurate predictions about music. The auditory cortex in the superior temporal region is a hub for liked, disliked and favorite music (Wilkins et al., 2014). Our spatiotemporal analysis of subjective liking/disliking during silence revealed that the IFG and the STG do not work simultaneously but successively, increases in liking inducing first a stronger activation of the IFG and then a reduced response of the STG. IFG being known to have an inhibitory role on a number of brain systems and related behaviors (Swann et al., 2009), this structure may inhibit the STG for processing information related to liked songs.

In the last period of silence, the differential activation of the insula suggests that hedonic processes are involved. The insula contributes to the conscious experience of emotion and its activation covaries with subjective feelings, which not only reflect physical stimulus intensity but also cognitive factors such as prediction (Suzuki, 2012).

There were surprisingly few cerebral areas activated for the aesthetic judgement of music in our study, which differs from the large number of cerebral activations observed in fMRI studies (Wilkins et al., 2014; Pereira et al., 2011; Koelsch et al., 2006). Since EEG surface signals are predominantly produced by cortical structures, source localization methods have difficulties to localize deep brain structures. This may explain why structures essential in liking processes such as the limbic system structures and the hippocampus (Wilkins et al., 2014), could not be detected in our study. Moreover, liking scores were not greatly different between liked and disliked songs, only 4 points on average, whereas some studies have been investigating participants' favorite songs (Wilkins et al., 2014) or compared dissonant and consonant music (Sammler et al., 2007). Finally, a possibility is that aesthetic judgement is altered during silence compared to during music perception, leading to a partially activated network of neural activations.

4.3. Relationship between liking, exposure, and familiarity

Since the liking for unfamiliar music is known to increase as a function of exposure time (Schellenberg et al., 2008; Szpunar et al., 2004), we wanted to avoid any confounding effect by assuring that participants listened to liked and disliked songs the same number of times. Despite this control, we found that liked songs were rated as more familiar than disliked songs, confirming that listeners do not only like music that they remember but also remember music that they like (Stalinski and Schellenberg, 2013). This strong relationship between preference and familiarity is supported by source localization. The IFG and STG are two structures involved both in memory processes and in liking. Moreover, emotion-related limbic and paralimbic regions as well as the reward circuitry are known to be significantly more active for

familiar relative to unfamiliar music (Pereira et al., 2011). If musical preference depends on predictive processes based on our knowledge of a song, it is then obvious that familiarity plays an important role. Further research is necessary to clarify this point, although it would be extremely difficult, if not impossible, to measure musical preference without any interference from familiarity and exposure.

5. Conclusion

Results from the present study show that when we like listening to a song, we still like this song during the silences inserted inside. Silences trigger auditory imagery and neural responses specific to liking under the form of oscillations in theta and alpha frequency bands originating from the IFG and STG. These brain structures having previously been shown to be activated when listening to liked music, similar neural networks may be involved in imagery and music. However, all liking processes may not be present because there were less cerebral areas activated for the aesthetic judgement of music during auditory imagery. The experimental design used here nonetheless offer the opportunity to study the emergence of the spatiotemporal dynamics of liking without physical interference of music.

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