Laterality, 2014
http://dx.doi.org/10.1080/1357650X.2014.959525

Routledge
Taylor & Francis Group

The "consonance effect" and the hemispheres: A study on a split-brain patient

Giulia Prete[1], Mara Fabri[2], Nicoletta Foschi[3], Alfredo Brancucci[4], and Luca Tommasi[4]

[1]Department of Neuroscience and Imaging, 'G. d'Annunzio' University of Chieti-Pescara, Chieti, Italy
[2]Department of Clinical and Experimental Medicine, Neuroscience and Cell Biology Section, Polytechnic University of Marche, Ancona, Italy
[3]Regional Epilepsy Centre, Neurological Clinic, "Ospedali Riuniti", Ancona, Italy
[4]Department of Psychological Science, Humanities and Territory, 'G. d'Annunzio' University of Chieti-Pescara, Chieti, Italy

The association between musical consonance and pleasantness, and between musical dissonance and unpleasantness ("consonance effect") is well established. Furthermore, a number of studies suggest the main involvement of the left hemisphere in the perception of dissonance and that of the right hemisphere in the perception of consonance. In the present study, the consonance effect was studied in a callosotomized patient, D. D. C. and in a control group. In binaural presentations, the patient did not attribute different pleasantness judgements to consonant and dissonant chords, differently from the control group who showed the consonance effect. However, in dichotic presentations (e.g. a chord in one ear and white noise in the other ear), a trend towards the consonance effect was found in D. D. C., but only when chords were presented in his right ear (left hemisphere), whereas the control group confirmed the known hemispheric asymmetry in labelling the pleasantness of consonant and dissonant chords. These results suggest that the right-hemispheric superiority in appreciating consonance might hide the inability of the right hemisphere to classify dissonant chords as unpleasant in the split-brain, whereas the left hemisphere seems capable to differently label the pleasantness of consonant and dissonant chords, even if it is more sensitive to dissonance.

Keywords: Split-brain; Consonance; Pleasantness; Hemispheres; Corpus callosum.

Address correspondence to: Giulia Prete, Department of Neuroscience and Imaging, University of Chieti, BLOCCO A, Via dei Vestini 29, I-66013 Chieti, Italy. E-mail: giulia.prete@unich.it

We thank D. D. C. for his cooperation and Professor Gabriele Polonara for providing us with the MRI image of the patient.

A chord is a set of musical notes that can be played simultaneously (harmonic chord) or sequentially one by one (as in arpeggio or in broken chords). In both cases we perceive the relationship among individual sounds, and it is this relationship that creates the consonance or dissonance of chords.

A clear preference for consonant chords arises from the first months of life (Gosselin et al., 2006; Schellenberg & Trehub, 1994), and some authors proposed that this is due to the fact that the statistical distribution of language sounds makes listeners more sensitive to consonance (Schwartz, Howe, & Purves, 2003). However, a preference for consonance has been shown also in monkeys and birds (Chiandetti & Vallortigara, 2011; Fishman et al., 2001), so this kind of preference may be due to a universal tendency to prefer consonant sounds.

In Western tonal music, consonant chords are more frequent and are generally judged as more pleasant than dissonant chords. However, if this relationship between consonance and pleasantness of chords is generally observed in healthy perceivers, studies on patients with amusia have shown no preference for consonance (e.g. Cousineau, McDermott, & Peretz, 2012). Several researchers attempted to show brain activations during the processing of consonant and dissonant sounds, and it was shown that the cerebral substrates of these two categories are different, albeit the evidence is far from being unequivocal. For example, in an electroencephalographic (EEG) study, Passynkova, Neubauer, and Scheich (2007) showed that while consonant chords activate the whole right hemisphere, dissonant chords are primarily processed anteriorly in the left hemisphere. A combined functional Magnetic Resonance Imaging (fMRI)/ Event-Related Potentials (ERPs) study (Minati et al., 2009) confirmed these results and showed that cerebral lateralization associated with sound processing was less pronounced in a group of musicians compared to non-musicians, resulting in a more bilateral activation for both consonant and dissonant intervals. However, in dichotic listening tasks, a left ear (right-hemispheric) advantage was shown in processing pitches of consonant and dissonant chords, with a stronger right-hemispheric specialization in dissonance processing, both in musicians (Itoh, Miyazaki, & Nakada, 2003) and in non-musicians (Sidtis, 1981). A study on infants showed that lateralization in music processing and its various features is present from birth: while the right hemisphere is dominant in stationary pitch processing, the left hemisphere is dominant in processing the temporal aspects of music (Perani et al., 2010). Similar results were obtained with dichotic listening in adults (Brancucci, Babiloni, Rossini, & Romani, 2005; Brancucci, D'Anselmo, Martello, & Tommasi, 2008). Bidelman and Krishnan (2009) showed strong correlations between behavioural and neural results: listeners preferred consonant over dissonant chords, and consonant chords induced more robust neural pitch salience in the brainstem. The neural substrates of sound pleasantness and unpleasantness were also recorded in a fMRI study, showing that the activation of the right temporal pole and some limbic structures (amygdala, left hippocampus, left parahippocampal gyrus) correlated with the presentation of dissonant music, whereas the left inferior frontal gyrus, insula, striatum, Heschl's gyrus and Rolandic operculum were more activated during the presentation of consonant music (Koelsch, Fritz, v. Cramon, Müller, & Friederici, 2006).

According to another perspective, the processing of consonance would be based on activation of right frontal areas, whereas the processing of dissonance would be correlated with right parahippocampal activation (Blood, Zatorre, Bermudez, & Evans, 1999; Wieser, 2003). In agreement with these findings, a study on patients with anteromedial temporal surgery showed an increased pleasantness perception of consonant and dissonant music excerpts in patients with right-hemispheric surgery but not in patients with left-hemispheric surgery (Khalfa et al., 2008). Another study showed that a patient with bilateral lesions in the temporal cortex was able to classify music as happy or sad, but she did not show any preference for consonant over dissonant intervals (Peretz, Blood, Penhune, & Zatorre, 2001). The same conclusion is supported by Gosselin et al. (2006), who confirmed that the temporal cortex is necessary for the perceptual but not for the emotional analysis of sounds, whereas paralimbic regions are responsible for the emotional evaluation of dissonance. In this study, the lack of responsiveness to unpleasantness in patients with variable degrees of parahippocampal damage was related to the extent of impaired volume in the parahippocampus, whereas the judgement of pleasantness was not related to this impairment (Gosselin et al., 2006).

Double dissociations confirm this distinction: some patients can judge chords as pleasant or unpleasant, but they cannot recognize melodies; some other patients can identify melodies even if they are not able to emotionally classify music (Blood et al., 1999). Intracranial recordings in an epileptic patient showed that dissonant chords elicited early ERPs in the auditory areas, then the activation reached the orbitofrontal cortex and eventually it involved the amygdala and the anterior cingulate gyrus—suggesting that these paralimbic areas are involved in emotional evaluation of dissonant music (Dellacherie et al., 2009).

Tramo and Bharucha (1991) tested two split-brain patients in a "target chord intonation task": prime and target chords could be related or unrelated major triads (such as C maj and $B^{\flat}$ maj, or C maj and $G^{\flat}$ maj, respectively). The task consisted in judging target chords as in-tune or out-of-tune; half of the target chords were mistuned by altering the chord by a semitone. Chords were presented in free field and patients were asked to use the ipsilateral hand to point to one of two faces (one happy and one sad, that represented "in-tune" and "out-of-tune", respectively), tachistoscopically presented in the left- or right-visual field. In the control group, an interaction between harmonic relatedness and intonation was shown, with higher accuracy in related trials when the target was in-tune, and higher accuracy in unrelated trials when the target was out-of-tune. This pattern was also present in patients, but only when faces were presented in their left-visual field. When faces were presented in their right-visual field there was a bias for out-of-tune responses. The authors concluded that the patients' left hemisphere was unable to detect consonance. To assess whether this result was due to consonant–dissonant ratings or to the priming task, in a second experiment, patients were asked to judge the intonation of chords, without using a prime sound. In this condition, one patient showed the same bias (he answered more frequently "out-of-tune" when response alternatives were presented in the right-visual hemifield); the other patient showed a bias for "in-tune" responses in both visual hemifields. In conclusion, this study showed that the right hemisphere is capable to distinguishing consonant from dissonant sounds; the left hemisphere may be unable to correctly evaluate consonance and dissonance (first patient) or it may be able to carry out this task, but it is less capable than the right hemisphere.

The issues we wanted to investigate were the following: do the disconnected hemispheres attribute differently pleasantness judgements to consonant and dissonant chords? And are there any differences between the hemispheres in this task? To answer these questions, we carried out an experiment exploiting both binaural and dichotic presentations of consonant and dissonant chords to a split-brain patient, D. D. C., and a control group, asking participants to judge the pleasantness of stimuli. We wondered whether the performance of the control group would be predictive of that of the patient or the hemispheric disconnection would reveal lateralized effects that remain unnoticed in the healthy participants.

MATERIALS AND METHODS

Participants

D. D. C. is a 36-year-old man, who underwent a complete resection of the corpus callosum because of medically intractable epilepsy. He underwent partial callosal resection in 1994, and full callosotomy in 1995; also the anterior commissure was partially resected (see Figure 1). D. D. C.' s laterality score was +40 (Fabri et al., 2005) according to the Edinburgh Handedness Inventory (Oldfield, 1971); the patient reported that he wrote with his left-hand until he was 10, and then he was forced to use his right-hand. His post-operative IQ was 83 (Fabri et al., 2005) and his educational level is 8 years. D. D. C. has normal hearing in both ears, as assessed by means of a standard audiometric evaluation, in which a complex tone of 270 and 400 Hz was presented via earphones with increasing intensities, showing that no different hearing thresholds between the left and the right ear (±5 dB) were present. He has neither linguistic nor motor relevant impairments.

The control group included 10 participants without neurological or psychiatric history. All participants in the control group were male, and their mean age was 24 (±1.37). The fact that we tested a control group of male participants younger than D. D. C. is justified by a number of studies which showed no difference in callosal morphometry in adulthood (Good et al., 2001; Sullivan, Rosenbloom,

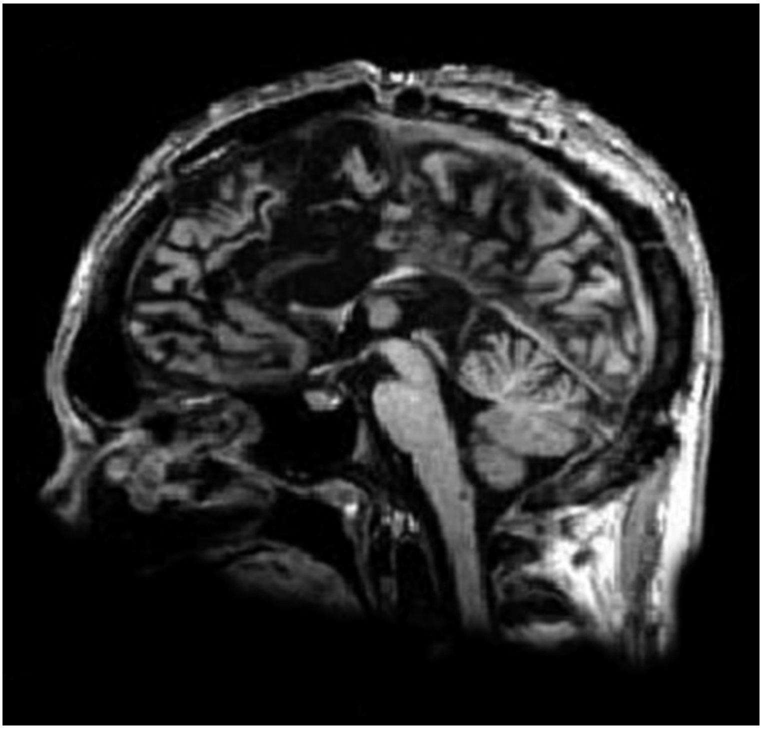

Figure 1. Midsagittal MRI of patient D. D. C.' s brain, showing the complete absence of callosal fibres.

Desmond, & Pfefferbaum, 2001). In fact, callosal morphometric changes are shown to be present at different ages, but only before reaching adulthood (Witelson & Kigar, 1988), when the callosal fibres are not completely myelinated. The mean laterality quotient of healthy participants was +63.49 (±17.93), according to a short version of the Edinburgh Handedness Inventory (Oldfield, 1971), and all of them had normal hearing in both ears, as assessed by means of a standard audiometric evaluation that showed that no different hearing thresholds between the left and the right ear (±5 dB) were present.

Stimuli

Twenty-four triad chords (three-notes chords) were constructed, 12 of them being consonant chords and 12 being dissonant chords. Stimuli were chosen according to Western music definition of consonance and dissonance: consonant chords consisted of major third intervals (interval ratio 4:5), perfect fifth intervals (interval ratio 2:3) and minor third and sixth intervals (interval ratio 5:6 and 5:8, respectively); dissonant chords consisted of minor and major second intervals (interval ratio 15:16 and 8:9) and in minor and major seventh intervals (interval ratio 9:16 and 8:15). In particular, three consonant and three dissonant chords were constructed: in consonant chords all intervals among three notes were consonant (C – $E^\flat$ – G; C – E – G; C – E – $A^\flat$); in dissonant chords all intervals among three notes were dissonant ($B^\sharp$ – $C^\sharp$ – D; C – $D^\flat$ – B; C – $A^\sharp$ – B). These six chords were transposed up by 4, 6 and 9 semitones, by using GoldWave v5.25 software (GoldWave Inc., Canada), to build four chords for each of the original chords, by changing the position of the tonic of each chord, but leaving the distance among notes unaltered. Overall, 24 three-notes chords were generated, half of which were consonant—3 original chords × 4 tonic positions (0, 4, 6, 9 semitones): 12 consonant chords; the other half of which were dissonant chords—3 original chords × 4 tonic positions: 12 dissonant chords.

All stimuli were created with a piano timbre and they were delivered by means of headphones (Philips SHP5400). Duration of each stimulus was 1,330 ms, including 630 ms of linear fade out, and the interval between the onsets of two stimuli depended on participant's reaction time, since the following stimulus started immediately after the participant's response.

Stimuli were delivered binaurally or dichotically. In the dichotic presentations, a chord was presented in the left ear while white noise was presented in the right ear, or vice versa. The white noise stimulus was created with GoldWave software and it lasted for the same duration as the chord.

Procedure

Participants were tested individually in two tasks (binaural and dichotic), and each task was administered in three sessions, requiring the use of three different response modalities (3 binaural sessions and 3 dichotic sessions). In the first response modality, after each stimulus participants were asked to say "I like it" or "I don't like it" when the chord was judged as pleasant or unpleasant, respectively; in the second response modality, participants had to respond by pressing one of two different keys depending on whether they judged the chord as pleasant or unpleasant, by using the index fingers of the two hands held together; in the third response modality, participants had to positively nod if they judged the stimulus as pleasant, or to negatively headshake if they judged the stimulus as unpleasant.

In each of the three binaural sessions, participants were presented with all 24 chords. In the dichotic task, a short training was carried out to let the participants get accustomed to the type of stimulus: two dichotic stimuli (1 consonant and 1 dissonant) were presented, and subjects were instructed that after each stimulus they had to judge its pleasantness, ignoring the noise. Then, the three dichotic sessions were administrated. In each of the three sessions, the 12 consonant and the 12 dissonant triads were repeated twice, once in the left ear and once in the right ear, and the simultaneous presentation of white noise provided the condition for dichotic listening.

Stimuli were randomized across sessions and participants, and they were delivered by using SuperLab software (Cedrus, Inc., San Pedro, CA, USA). Participants were asked to look at a fixation cross presented in the centre of the computer screen (Acer Aspire 5715z) for the duration of the whole task.

Statistical analyses were carried out by means of the software Statistica 8.0.550 (StatSoft. Inc., Tulsa, OK, USA).

RESULTS

Control group

Statistical analyses on the control group’s scores were carried out using the percentage of “pleasant” responses as the dependent variable.

In the binaural task, a preliminary repeated-measures ANOVA was carried out using Response modality and Consonance as within-subject factors. The main effect of Response modality was not significant, $F_{(2,\ 18)} = .39$; $p = .68$, showing that the response modality did not influence the judgements. Thus, the pleasantness ratings for the consonant vs. dissonant chords were compared by means of a paired *t*-test. The *t*-test showed that consonant chords were judged as more pleasant than dissonant chords, $t_{(9)} = 5.66$, $p < .001$; consonant chords: $M = 70.56$, $SD = 6.54$; dissonant chords: $M = 20.83$, $SD = 6.19$.

As regards the dichotic task, the ratings of the control group were analysed by means of a repeated-measures ANOVA, using Response modality, Consonance and Ear as within-subject factors. The main effect of Response modality was not significant, $F_{(2,\ 18)} = .93$; $p = .41$, thus it was excluded from the analysis. The ANOVA revealed a significant difference between the subjective pleasantness of consonant and dissonant chords, as the Consonance factor was significant, $F_{(1,\ 9)} = 24.47$; $p < .001$; $\eta_p^2 = .72$: control subjects perceived consonant chords as more pleasant than dissonant chords (consonant: $M = 66.67$, $SD = 6.04$; dissonant: $M = 27.92$, $SD = 6.63$). The main effect of Ear was significant, $F_{(1,\ 9)} = 6.48$; $p = .031$; $\eta_p^2 = .42$, and it showed that chords presented in the left ear were evaluated as more pleasant than those presented in the right ear (left ear: $M = 52.92$, $SD = 17.64$; right ear: $M = 41.67$, $SD = 13.89$). The interaction was not significant, Consonance × Ear: $F_{(1,\ 9)} = .115$, $p = .74$.

The percentage of “pleasant” responses in the binaural and the dichotic tasks were also compared by means of exact *t*-tests, in which the mean response values of consonant and dissonant chords in the binaural task were used as reference values for the responses to consonant and dissonant chords in the dichotic task. These comparisons did not show differences between responses in the binaural and the dichotic tasks, for both types of chords.

D. D. C.

Statistical tests on D. D. C.' s scores were carried out by means of χ^2 tests: positive responses, corresponding to pleasantness ratings, were scored as 1, whereas negative responses were scored as 0. Positive results were added in order to obtain the pleasantness frequency for each stimulus category.

The results were not influenced by the response modality used, both in the binaural task (verbal vs. keypress: $\chi^2_{(1)} = 0$, $p = 1$; verbal vs. nodding: $\chi^2_{(1)} = .14$, $p = .70$; keypress vs. nodding: $\chi^2_{(1)} = .14$, $p = .70$) and in the dichotic task (verbal vs. keypress: $\chi^2_{(1)} = 1.23$, $p = .27$; verbal vs. nodding: $\chi^2_{(1)} = .02$, $p = .90$; keypress vs. nodding: $\chi^2_{(1)} = 1.53$, $p = .22$). Thus, further χ^2 tests were computed collapsing the data collected in the three response modalities.

In the binaural task, the patient did not attribute different pleasantness judgements to consonant and dissonant chords ($\chi^2_{(1)} = .21$, $p = .64$).

In the dichotic task, D. D. C. did not assign different pleasantness ratings to consonant and dissonant chords ($\chi^2_{(1)} = .47$, $p = .49$); this result held true both considering the two ears of presentation together and each ear separately, even if a trend towards the "consonance effect" was shown for chords presented in the right ear (right ear: $\chi^2_{(1)} = 3.24$, $p = .072$; left ear: $\chi^2_{(1)} = .17$, $p = .67$). The patient, however, judged the stimuli presented in the left ear as more pleasant than those presented in the right ear ($\chi^2_{(1)} = 8.89$, $p = .002$). In particular, the patient judged dissonant chords presented in the left ear as more pleasant than those presented in the right ear ($\chi^2_{(1)} = 10.31$, $p = .001$).

Control group compared to D. D. C.

The control subjects' and the patient's responses were compared by means of exact *t*-tests: positive response frequencies were transformed into proportions computed with respect to the whole number of stimuli in a condition, and the subjects' mean proportions were compared to the patient's exact proportion in that condition.

In the binaural task, the control group—with respect to D. D. C.— judged as less pleasant dissonant chords, $t_{(9)} = -5.44$, $p < .001$, whereas no difference emerged as regards consonant chords, $t_{(9)} = 1.55$, $p = .15$, see Figure 2.

In the dichotic session, the participants in the control group—with respect to D. D. C.— judged as less pleasant dissonant chords, $t_{(9)} = -3.41$, $p = .008$, and chords presented in the left ear, $t_{(9)} = -5.16$, $p < .001$, whereas they judged consonant chords as more pleasant, despite the difference was almost significant, $t_{(9)} = 2.25$, $p = .051$. Moreover, the participants in the control group judged as less pleasant with respect to D. D. C. the dissonant chords presented in the left ear, $t_{(9)} = -7.76$, $p < .001$, whereas they showed a trend to judge consonant chords presented in the right ear as more pleasant, $t_{(9)} = 2.07$, $p = .067$; see Figure 3. No difference emerged in the other comparisons, dissonant chord

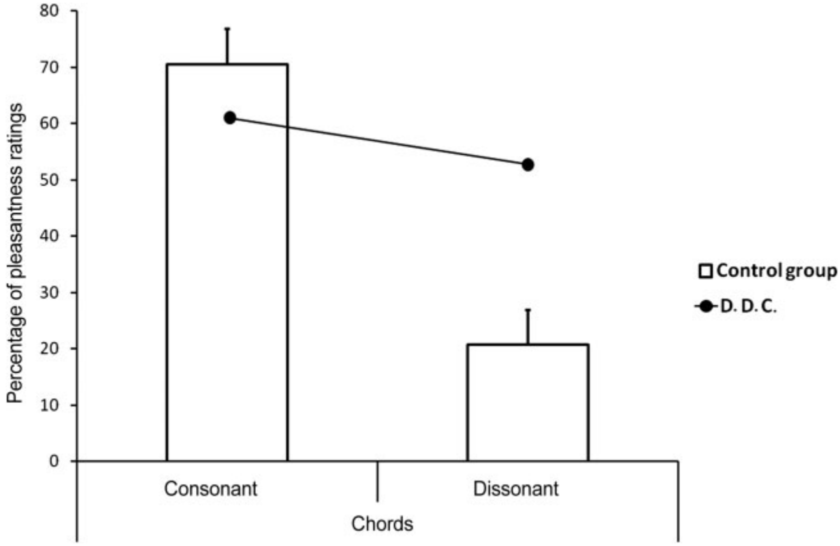

Figure 2. Percentage of chords rated as pleasant in the two binaural conditions (consonant and dissonant chords) for the control group (bars) and for the patient (dots).

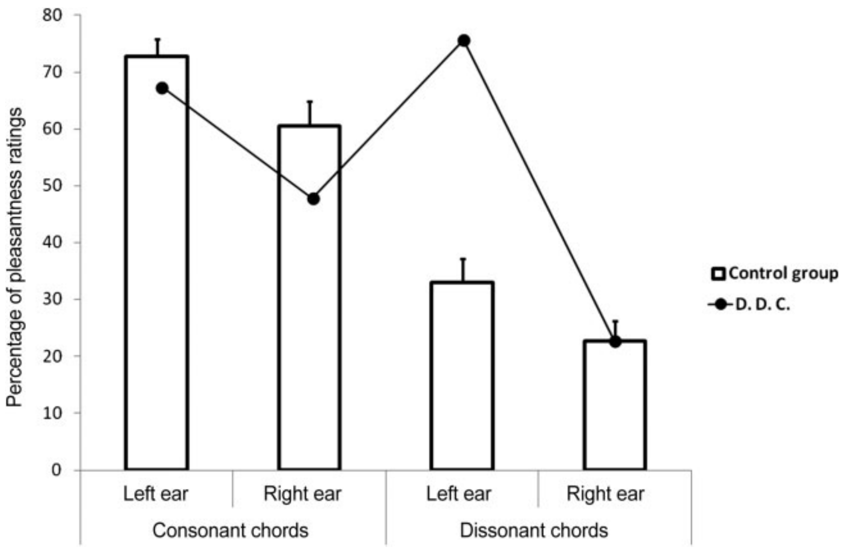

Figure 3. Percentage of chords rated as pleasant in each of the four dichotic conditions (consonant chords presented to the left ear; consonant chords presented to the right ear; dissonant chords presented to the left ear; dissonant chords presented to the right ear) for the control group (bars) and for the patient (dots).

presented in the right ear: $t_{(9)} = 1$, $p = .92$; consonant chords presented in the left ear: $t_{(9)} = -0.01$, $p = .99$.

DISCUSSION

Starting from the assumption that a correspondence exists between consonant sounds and pleasantness, and between dissonant sounds and unpleasantness (Gosselin et al., 2006; Schellenberg & Trehub, 1994), this "consonance effect" was confirmed in the control group in both the binaural and the dichotic tasks. As mentioned in the introduction, a number of neuroimaging and electrophysiological studies showed a left-hemispheric lateralization in dissonance processing and a right-hemispheric lateralization in consonance processing. This evidence seems to be confirmed by the results of the dichotic task in the control group, in which chords presented in the left ear (right hemisphere) were judged as more pleasant than chords presented in the right ear (left hemisphere). D. D. C.' s performance was not in agreement with the "consonance effect" pattern observed in the control group: overall, D. D. C. judged consonant and dissonant chords apparently in a random fashion, in both the binaural and the dichotic task. However, in the specific case of the dichotic presentation, this result must be taken together with the striking fact that D. D. C. judged chords more frequently as pleasant when they were presented in his left ear compared to when they were presented in his right ear. Moreover, such a bias seems to be due exclusively to the judgement of dissonant chords, which were perceived more frequently as pleasant when they were heard in the left ear than in the right ear. Crucially, the performance of D. D. C. is in line with that of the control group in all four conditions (dissonance/consonance in left ear/right ear) except for the presentation of dissonant chords in the left ear (right hemisphere), in which case D. D. C.' s evaluation was much more positive than that of control subjects. This peculiarity is also reflected by the fact that when chords were presented in D. D. C.' s right ear, the pleasantness ratings attributed to consonant and dissonant chords showed a trend towards the "consonance effect". This trend suggests that the left-hemispheric processing of chords pleasantness in the callosotomized patient is in line with that of the healthy subjects. This evidence is in agreement with the hemispheric asymmetry found in previous works and is confirmed by the control group's results, according to which the right hemisphere is superior than the left in appreciating consonance: in fact, D. D. C. judged all stimuli presented in his left ear (right hemisphere) as pleasant, confirming the fact that the right hemisphere tends to evaluate sounds as pleasant. On the other hand, according to this view, one could expect that D. D. C. should evaluate all stimuli presented in his right ear (left hemisphere) as unpleasant. However, in this case his judgements were roughly similar to those of the control group: he evaluated consonant chords presented in his right ear as almost significantly more pleasant than dissonant chords presented in his right ear. This could mean that the "consonance effect" is based on the activity of the left hemisphere, whereas in the right hemisphere the tendency in judging sounds as pleasant prevails.

All summed up, we can draw the following conclusions: (1) the control group confirmed the “consonance effect”; (2) the split-brain patient did not show the “consonance effect”; (3) the control group showed opposite hemispheric lateralizations in appreciating the pleasantness of consonant and dissonant chords, with a left-hemispheric dominance in evaluating dissonant chords and a right-hemispheric dominance in evaluating consonant chords; (4) the performance of the callosotomized patient was similar to that of the healthy participants when chords were presented in the right ear; (5) the performance of D. D. C. deviated from that of the control group when stimuli were presented in his left ear. In this case, D. D. C. did not evaluate consonant chords differently from the control group, but he judged dissonant chords as pleasant.

Our results are partially congruent with those of Tramo and Bharucha (1991), who showed the inability of a callosotomized patient’s left hemisphere to tell consonance from dissonance, and particularly to recognize tonal consonance. However, in another patient they showed an almost normal ability of the left hemisphere to tell consonant from dissonant chords. It should be noted that these authors did not find right-hemispheric lateralization related to the discrimination of consonant and dissonant chords.

In the present study, however, the patient’s left hemisphere appears capable of differentially associating pleasantness judgements to chords (thus suggesting that a discrimination between consonance and dissonance is possible), whereas the right hemisphere judges as pleasant all chords, possibly because of its inability to tell consonant from dissonant chords. Dichotic listening of sounds ensured, in fact, that the patient’s responses reflected unilateral processing of acoustic stimuli (see Zaidel, 1983, for a review). Amongst the response modalities used, the verbal modality is predictably based on a left-hemispheric activation (it was used because it is the easiest to understand and to use for the patient), whereas key pressing using both hands and head nodding should not be lateralized. In fact, keys were pressed with both hands, so this response was based on both left- and right-hemispheric activation; concerning nodding, DeToledo, Minagar, and Lowe (2000) showed the ability of head nodding in an aphasic patient, suggesting that this head gesture is not associated to verbal responses, so there is no proof of its hemispheric lateralization.

The results of the present study shed new light on the relationship between music pleasantness and the hemispheres: although the disconnected right hemisphere can discriminate between consonance and dissonance (Tramo & Bharucha, 1999), the present data suggest that its activity is not sufficient to associate dissonance with unpleasantness. Assuming that the right temporal areas ensure the perceptual analysis of dissonance (Koelsch et al., 2006; Peretz et al., 2001) and that the unpleasantness judgement takes place in the right frontal cortex (Dellacherie et al., 2009), we speculate that reciprocal connections between the hemispheres must nonetheless be intact in order to appropriately label the outcome of such a judgement.

Manuscript received 31 May 2014
Revised manuscript received 23 August 2014
Revised manuscript accepted 25 August 2014
First published online 25 September 2014

REFERENCES

Bidelman, G. M., & Krishnan, A. (2009). Neural correlates of consonance, dissonance, and the hierarchy of musical pitch in the human brainstem. *Journal of Neuroscience*, *29*, 13165–13171. doi:10.1523/JNEUROSCI.3900-09.2009

Blood, A. J., Zatorre, R. J., Bermudez, P., & Evans, A. C. (1999). Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature Neuroscience*, *2*, 382–387. doi:10.1038/7299

Brancucci, A., Babiloni, C., Rossini, P. M., & Romani, G. L. (2005). Right hemisphere specialization for intensity discrimination of musical and speech sounds. *Neuropsychologia*, *43*, 1916–1923. doi:10.1016/j.neuropsychologia.2005.03.005

Brancucci, A., D'Anselmo, A., Martello, F., & Tommasi, L. (2008). Left hemisphere specialization for duration discrimination of musical and speech sounds. *Neuropsychologia*, *46*, 2013–2019. doi:10.1016/j.neuropsychologia.2008.01.019

Chiandetti, C., & Vallortigara, G. (2011). Chicks like consonant music. *Psychological Science*, *22*, 1270–1273. doi:10.1177/0956797611418244

Cousineau, M., McDermott, J. H., & Peretz, I. (2012). The basis of musical consonance as revealed by congenital amusia. *Proceedings of the National Academy of Sciences of the United States of America*, *109*, 19858–19863. doi:10.1073/pnas.1207989109

Dellacherie, D., Pfeuty, M., Hasboun, D., Lefèvre, J., Hugueville, L., Schwartz, D. P., … Samson, S. (2009). The birth of musical emotion. A depth electrode case study in a human subject with epilepsy. *Annals of the New York Academy of Sciences*, *1169*, 336–341. doi:10.1111/j.1749-6632.2009.04870.x

DeToledo, J. C., Minagar, A., & Lowe, M. R. (2000). Persisting aphasia as the sole manifestation of partial status epilepticus. *Clinical Neurology and Neurosurgery*, *102*, 144–148. doi:10.1016/S0303-8467(00)00091-3

Fabri, M., Del Pesce, M., Paggi, A., Polonara, G., Bartolini, M., Salvolini, U., & Manzoni, T. (2005). Contribution of posterior corpus callosum to the interhemispheric transfer of tactile information. *Cognitive Brain Research*, *24*(1), 73–80. doi:10.1016/j.cogbrainres.2004.12.003

Fishman, Y. I., Volkov, I. O., Noh, M. D., Garell, P. C., Bakken, H., Arezzo, J. C., … Steinschneider, M. (2001). Consonance and dissonance of musical chords: neural correlates in auditory cortex of monkeys and humans. *Journal of Neurophysiology*, *86*, 2761–2788.

Good, C. D., Johnsrude, I. S., Ashburner, J., Henson, R. N. A., Friston, K. J., & Frackowiak, R. S. J. (2001). A voxel-based morphometric study of ageing in 465 normal adult human brains. *NeuroImage*, *14*(1), 21–36. doi:10.1006/nimg.2001.0786

Gosselin, N., Samson, S., Adolphs, R., Noulhiane, M., Roy, M., Hasboun, D., … Peretz, I. (2006). Emotional responses to unpleasant music correlates with damage to the parahippocampal cortex. *Brain*, *129*, 2585–2592. doi:10.1093/brain/awl240

Itoh, K., Miyazaki, K., & Nakada, T. (2003). Ear advantage and consonance of dichotic pitch intervals in absolute-pitch possessors. *Brain and Cognition*, *53*, 464–471. doi:10.1016/S0278-2626(03)00236-7

Khalfa, S., Guye, M., Peretz, I., Chapon, F., Girard, N., Chauvel, P., & Liégeois-Chauvel, C. (2008). Evidence of lateralized anteromedial temporal structures involvement in musical emotion processing. *Neuropsychologia*, *46*, 2485–2493. doi:10.1016/j.neuropsychologia.2008.04.009

Koelsch, S., Fritz, T., v. Cramon, D. Y., Müller, K., & Friederici, A. D. (2006). Investigating emotion with music: An fMRI study. *Human Brain Mapping*, *27*, 239–250. doi:10.1002/hbm.20180

Minati, L., Rosazza, C., D’Incerti, L., Pietrocini, E., Valentini, L., Scaioli, V., … Bruzzone, M. G. (2009). Functional MRI/event-related potential study of sensory consonance and dissonance in musicians and nonmusicians. *Cognitive Neuroscience and Neuropsychology*, *20*, 87–92. doi:10.1097/WNR.0b013e32831af235

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*(1), 97–113. doi:10.1016/0028-3932(71)90067-4

Passynkova, N., Neubauer, H., & Scheich, H. (2007). Spatial organization of EEG coherence during listening to consonant and dissonant chords. *Neuroscience Letters*, *412*(1), 6–11. doi:10.1016/j.neulet.2006.09.029

Perani, D., Saccuman, M. C., Scifo, P., Spada, D., Andreolli, G., Rovelli, R., … Koelsch, S. (2010). Functional specializations for music processing in the human newborn brain. *Proceedings of the National Academy of the United States of America*, *107*, 4758–4763. doi:10.1073/pnas.0909074107

Peretz, I., Blood, A. J., Penhune, V., & Zatorre, R. (2001). Cortical deafness to dissonance. *Brain*, *124*, 928–940. doi:10.1093/brain/124.5.928

Schellenberg, E. G., & Trehub, S. E. (1994). Frequency ratios and the discrimination of pure tone sequences. *Perception and Psychophysics*, *56*, 472–478. doi:10.3758/BF03206738

Schwartz, D. A., Howe, C. Q., & Purves, D. (2003). The statistical structure of human speech sounds predicts musical universals. *Journal of Neuroscience*, *23*, 7160–7168.

Sidtis, J. J. (1981). The complex tone test: implications for the assessment of auditory laterality effects. *Neuropsychologia*, *19*(1), 103–112. doi:10.1016/0028-3932(81)90050-6

Sullivan, E. V., Rosenbloom, M. J., Desmond, J. E., & Pfefferbaum, A. (2001). Sex differences in corpus callosum size: relationship to age and intracranial size. *Neurobiology of Aging*, *22*, 603–611. doi:10.1016/S0197-4580(01)00232-9

Tramo, M. J., & Bharucha, J. J. (1991). Musical priming by the right hemisphere post-callosotomy. *Neuropsychologia*, *29*, 313–325. doi:10.1016/0028-3932(91)90045-A

Wieser, H. G. (2003). Music and the brain. *Annals of the New York Academy of Sciences*, *999*(1), 76–94. doi:10.1196/annals.1284.007

Witelson, S. F., & Kigar, D. L. (1988). Anatomical development of the corpus callosum in humans: A review with reference to sex and cognition. In: D. L. Molfese (Ed.), *Brain lateralization in children: Developmental implications* (p. xii, 612). New York, NY: The Guilford Press.

Zaidel, E. (1983). Disconnection syndrome as a model for laterality effects on the normal brain. In: J. Hellige (Ed.), *Cerebral hemisphere asymmetry: Method, theory, and application* (pp. 95–151). New York, NY: Praeger.