International Journal of Psychophysiology 129 (2018) 9–17

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Electrophysiological correlates of timbre imagery and perception

Przemysław Tużnik*, Paweł Augustynowicz, Piotr Francuz

Department of Experimental Psychology, The John Paul II Catholic University of Lublin, Lublin, Poland

A R T I C L E I N F O

Keywords:
Auditory imagery
Timbre
Auditory evoked potentials (N1, P2)
Event-related potentials
Late positive component (LPC)

A B S T R A C T

The primary objective of the present study was to verify whether the differences in imagined timbre are reflected by the event-related potentials (ERPs). It was verified the hypotheses that imagining of sounds, varying in spectral characteristics of timbre, influence the amplitude of the late positive component (LPC), associated with auditory imagery-related processes. It was also verified whether the manipulation of the perceived timbre corresponds to the amplitude fluctuations of the auditory evoked potentials (AEPs) N1 and P2. Also, it was expected that the amplitudes of the LPC, N1 and P2 components depend on musical expertise.

Musicians and non-musicians took part in two experiments, each of which involved timbre manipulation in term of one parameter of the sound spectrum – spectral centroid or spectral irregularity. Each experiment consisted of auditory perception task followed by auditory imagery training and auditory imagery task.

The present study showed that differences in perceived timbre associated with spectral centroid and spectral irregularity are reflected by fluctuations in the amplitude of the N1 and P2 potentials. Perceived differences in spectral centroid are sufficiently distinctive that generation of auditory images of sounds differing in this property induces changes in the amplitude of the late positive component (LPC), recorded during auditory imagery. This means that the LPC is sensitive to changes in the timbre of the imagined sound. Musicians are more accurate in performing auditory imagery task related to timbre than non-musicians. However, musical expertise does not affect the amplitude of the N1, P2 and LPC potentials.

1. Introduction

Auditory imagery is defined as introspective auditory experience, other than hallucinations, occurring in the absence of auditory stimuli affecting the sense of hearing (Hubbard, 2013). Our knowledge of this phenomenon is scarce in comparison to our understanding of visual imagery (Hubbard, 2010; Jensen, 2005). It has been established that the basic sound parameters (e.g., pitch) are mentally reproduced, yet little is known about timbre imagery (Hubbard, 2010, 2013). Timbre is defined as a set of perceptual attributes which make it possible to differentiate tones having the same pitch, loudness, duration, and location (ANSI, 1973). It consists of a few dimensions, their exact number being a matter of dispute. It is most frequently suggested that perceptual timbre space is three dimensional (Caclin et al., 2005; Grey, 1977; Iverson and Krumhansl, 1993; Kong et al., 2011; Krumhansl, 1989; McAdams et al., 1995). Most studies assume that acoustic correlates of timbral dimensions include attack time and spectral center of gravity (Caclin et al., 2005; Caclin et al., 2006; Caclin et al., 2007; Caclin et al., 2008; Iverson and Krumhansl, 1993; Krimphoff, 1993; Krimphoff et al., 1994; Krumhansl, 1989; McAdams et al., 1995). Attack (initial transient) is a transitory state in which amplitudes of the specific harmonics increase from the level of perceptual threshold to the maximum. The shorter the attack time, the more abrupt onset of the sound. On the other hand, the spectral center of gravity defines the relationships between low and high-frequency harmonics, also taking into account their amplitudes. The greater the amplitudes of high-frequency components in relation to those of lower harmonics, the higher the spectral centroid, with the sound being perceived as sharper and brighter. Caclin et al. (2005) directly manipulated sound parameters associated with perceptual timbre dimensions. They found that timbre dissimilarities in the specific dimensions are most effectively explained by attack time, spectral centroid and spectral irregularity. Spectral irregularity is connected with the intensity of the even harmonics relative to the intensity of the odd harmonics. With lower amplitudes of the even harmonics relative to the odd ones, the sound is perceived as hollower. Kong et al. (2011) confirmed the findings reported by Caclin et al. (2005) in a study of a group of normal-hearing subjects.

Timbre is contained in auditory imagery (Crowder, 1989; Halpern et al., 2004; Pitt and Crowder, 1992) even though it is not always a consciously processed dimension of the image (Bailes, 2007). Studies investigating auditory imagery for timbre have predominantly adopted behavioral approach (Bailes, 2007; Crowder, 1989; Pitt and Crowder,

* Corresponding author at: Department of Experimental Psychology (room C-509), The John Paul II Catholic University of Lublin, Al. Racławickie 14, 20-950 Lublin, Poland.
E-mail address: przemek.tuznik@gmail.com (P. Tużnik).

https://doi.org/10.1016/j.ijpsycho.2018.05.004
Received 10 January 2018; Received in revised form 7 May 2018; Accepted 10 May 2018
Available online 11 May 2018
0167-8760/

1992; Serafine, 1981). An exception was a fMRI experiment conducted by Halpern et al. (2004) who showed that there was a similarity between the perceived and the imagined multidimensional timbre spaces. Unfortunately, the latter experiment, as well as most other studies related to this issue, used stimuli based on instrumental sounds (Bailes, 2007; Crowder, 1989; Halpern et al., 2004; Serafine, 1981), and the differences between them in terms of the specific properties of timbre were not controlled. Pitt and Crowder (1992) were the only ones to manipulate spectral and temporal characteristics of timbre in the context of auditory imagery. They demonstrated that the spectral properties are reproduced in imagery, unlike the temporal characteristics. Therefore, it should be expected that out of the timbre characteristics distinguished by Caclin et al. (2005) and Kong et al. (2011), it is spectral centroid and spectral irregularity that might be reflected in imagery.

The study reported in the present paper was designed to verify Pitt and Crowder's conclusions (1992) suggesting that the spectral centroid and spectral irregularity should be reproduced in imagery, and secondly to identify ERPs sensitive to differences between imagined sounds related to these timbre properties. A brain potential which is characteristic for auditory imagery is the late positive component (LPC) (Janata, 2001; Meyer et al., 2007; Wu et al., 2006; Wu et al., 2011). We made an assumption that, if spectral characteristics of timbre are reproduced in imagery, as hypothesized by Pitt and Crowder (1992), it might be possible that manipulation of the spectral centroid and spectral irregularity would be reflected in LPC amplitude modulations. Recorded while auditory images are being generated, the LPC behaves much like the N1 component during perception in response to similar manipulation of the sound's pitch and loudness (Wu et al., 2011). Amplitudes of both components decrease with growing pitch and increase with loudness. The present study investigated whether such similarity could be observed between any of the auditory evoked potentials (AEPs) and LPC in response to different timbres.

Previously reported electrophysiological studies of timbre perception investigated the following components: P1, N1, and P2 – with the use of EEG as well as P1m, N1m, and P2m – with MEG. (Aramaki et al., 2009; Meyer et al., 2006; Pantev et al., 1998; Pantev et al., 2001; Shahin et al., 2004; Shahin et al., 2005) Pantev et al. (1998) showed that in musicians activation of the N1 m component generators is higher in the case of piano tones in comparison to pure tones. It was also found that elicitation of the N1m component in musicians depends on what instrument they play most often as well as on the type of instrument generating the sound, i.e., its timbre (Pantev et al., 2001). A study by Shahin et al. (2004) analysed AEPs (P1, N1, P2) during perception of sounds produced by piano and violin as well as pure tones. It was found that the P1 component has a higher amplitude in the case of sounds generated by instruments than in the case of pure tones, which means that it is higher for sounds with complex spectrum. The N1 component was identified only for piano sounds.

The most interesting potential taken into account in their study is the P2 component. Its amplitude was highest for tones produced by a piano, medium for violin-produced tones and lowest for pure tones. This suggests that P2 is most sensitive to changes in the timbre of the sound. Similarly, a study by Aramaki et al. (2009) in which environmental sounds were used confirms that amplitude of the P2 component depends on the timbre of the sound while the amplitude of the N1 component does not. Conversely, Meyer et al. (2006) demonstrated that both the N1 and the P2 components have higher amplitudes during perception of sounds generated by instruments than in response to pure tones. Based on this they concluded that amplitudes of both components depend on the spectral complexity of the sound. In the above electrophysiological studies, the researchers manipulated the timbre, yet they only used sounds produced by various instruments or materials. In most cases, the values of acoustical parameters related to timbre were not controlled. In order to decrease the variance, Shahin et al. (2005) manipulated the spectral complexity of piano sound by removing a specific number of harmonics. It was found that spectral complexity was not related to the N1 and N1 m responses, whereas the P2 and P2m components were larger in the case of sounds with a greater number of harmonics.

The present study investigated whether the spectral centroid and spectral irregularity of the sound are related to the amplitude of the N1 component (perception) and the LPC (imagery). Because manipulation of these spectrum parameters determines spectral complexity, the study was also designed to test the hypothesis that the P2 component with the greatest amplitude will be elicited by sounds with a high spectral centroid value and high spectral regularity and lowest by sounds on the opposite end of the continuum. Given the fact that an increase in the spectral centroid is associated with growing presence of high-frequency harmonics, we can justifiably conclude that in this case the manipulation also relates to spectral complexity. Indeed, the number of harmonics is the same at each level of the spectral centroid, yet an increase in its intensity leads to increased presence of higher harmonics in the sound, as a result of which it is perceived as sharper. Therefore, the level of sound complexity increases at the perceptual level. The matter looks similarly in case of manipulation of the spectral irregularity. Since manipulation of irregularity involved attenuation of even harmonics, it means that manipulation of timbre was also linked with a change in spectral complexity. In sounds with increasingly irregular spectrum, even harmonics are less present, which leads to simplification of the spectrum. The P1 component was not in our interest, because in the present study only complex sounds (with spectra consist of twenty harmonics) were used.

It can also be expected that the amplitudes of the relevant potentials depend on musical expertise. Aleman et al. (2000) showed that musicians are significantly more successful in tasks involving auditory imagery in comparison to musically naive subjects. Musically trained individuals achieve much higher scores than the general public in assessments of vividness of auditory imagery (Campos and Fuentes, 2016; Hishitani, 2009; Seashore, 1938). Electrophysiological studies into perception of sound timbre have shown that, in comparison to non-musicians, subjects with musical training are found to have higher amplitudes of the following AEPs: P1 (Shahin et al., 2004), N1/N1m (Kuriki et al., 2006; Shahin et al., 2004; Shahin et al., 2005) and P2/P2m (Kuriki et al., 2006; Shahin et al., 2004; Shahin et al., 2005). It was expected that the N1, P2, and also LPC amplitudes would be higher in musicians than in non-musicians.

2. Method

Two experiments were conducted that involved manipulation of different parameters of the sound spectrum, the value of the spectral centroid and the degree of spectral irregularity. In both experiments, the subjects performed perception and imagery tasks, with auditory imagery training carried out between the tasks. Musicians and non-musicians participated in both experiments. The study was approved by the research ethics committee operating at the Institute of Psychology at The John Paul II Catholic University of Lublin.

2.1. Participants

All the participants reported normal hearing, normal or corrected-to-normal vision, as well as lack of neurosurgical interventions and neurological or psychiatric disorders. Informed written consent was obtained from all the subjects. At the end, each subject was paid for his or her participation and received a basic explanation regarding the purpose of the study.

The first experiment, involving manipulation of the spectral centroid, was carried out in a group of 40 right-handed subjects (20 musicians, 20 non-musicians). Five subjects were excluded due to a large number of artifacts in EEG recording (for exclusion criteria: see EEG recording section). The 35 subjects (18 musicians, 17 non-musicians)