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Faster native vowel discrimination learning in musicians is mediated by an optimization of mnemonic functions

Stefan Elmer[a,*,1], Marielle Greber[a,1], Arethy Pushparaj[a], Jürg Kühnis[a], Lutz Jäncke[a,b,c,d,e]

[a] Institute of Psychology, Division Neuropsychology, University of Zurich, Switzerland
[b] Center for Integrative Human Physiology (ZIHP), University of Zurich, Switzerland
[c] International Normal Aging and Plasticity Imaging Center (INAPIC), University of Zurich, Switzerland
[d] University Research Priority Program (URPP) "Dynamic of Healthy Aging", University of Zurich, Switzerland
[e] Department of Special Education, King Abdulaziz University, Jeddah, Saudi Arabia

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A B S T R A C T

The ability to discriminate phonemes varying in spectral and temporal attributes constitutes one of the most basic intrinsic elements underlying language learning mechanisms. Since previous work has consistently shown that professional musicians are characterized by perceptual and cognitive advantages in a variety of language-related tasks, and since vowels can be considered musical sounds within the domain of speech, here we investigated the behavioral and electrophysiological correlates of native vowel discrimination learning in a sample of professional musicians and non-musicians. We evaluated the contribution of both the neurophysiological underpinnings of perceptual (i.e., N1/P2 complex) and mnemonic functions (i.e., N400 and P600 responses) while the participants were instructed to judge whether pairs of native consonant-vowel (CV) syllables manipulated in the first formant transition of the vowel (i.e., from /tu/ to /to/) were identical or not. Results clearly demonstrated faster learning in musicians, compared to non-musicians, as reflected by shorter reaction times and higher accuracy. Most notably, in terms of morphology, time course, and voltage strength, this steeper learning curve was accompanied by distinctive N400 and P600 manifestations between the two groups. In contrast, we did not reveal any group differences during the early stages of auditory processing (i.e., N1/P2 complex), suggesting that faster learning was mediated by an optimization of mnemonic but not perceptual functions. Based on a clear taxonomy of the mnemonic functions involved in the task, results are interpreted as pointing to a relationship between faster learning mechanisms in musicians and an optimization of echoic (i.e., N400 component) and working memory (i.e., P600 component) functions.

1. Introduction

The investigation of the neural processes underlying phonetic discrimination learning does not constitute an encapsulated branch of research, but rather provides a window into a better understanding of the perceptual and cognitive mechanisms beyond elementary language learning mechanisms. In fact, the ability to discriminate phonemes varying in spectral and temporal attributes (i.e., pitch, timbre, voice-onset time, and duration) represents an important cornerstone of the language acquisition process, in both infants and adults (Kuhl, 2004). However, due to asymmetric maturational periods of brain regions supporting perceptual and cognitive functions during ontogenesis (Gogtay et al., 2004), there are important computational differences between these two cohorts. This perspective is supported by previous observations showing that infants and children hark back to implicit computational strategies enabling them to easily learn to discriminate phonemes, whereas adults rely more strongly on explicit cognitive control mechanisms and mnemonic functions (Kuhl, 2004). In addition, adults' neural commitment to the phonetic repertoire of the mother tongue, as well as stabilized phonetic categories, are known to hinder the detection of non-conforming patterns contained in a specific language system (Zhang et al., 2009). Consequently, adults often have difficulties when it comes to acquiring the phonetic repertoire of a new language or discriminating between novel sequences of sounds and similar ones (Zhang et al., 2009).

Surprisingly, until now, only few studies have been dedicated to investigating the brain mechanisms that underlie phonetic discrimination learning in adulthood (Alain and Snyder, 2008; Atienza et al.,

* Corresponding authors at: Institute of Psychology, Division Neuropsychology, University of Zurich, Binzmühlestrasse 14/25, 8050 Zurich, Switzerland.
E-mail addresses: s.elmer@psychologie.uzh.ch (S. Elmer), marielle.greber@uzh.ch (M. Greber), arethy.pushparaj@access.uzh.ch (A. Pushparaj), juerg.kuehnis@bluewin.ch (J. Kühnis), lutz.jaencke@uzh.ch (L. Jäncke).

[1] Shared first authorship.

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2002; Ben-David et al., 2011; Tremblay et al., 2014). In addition, most of these previous studies compared auditory-evoked potentials (AEPs) before and after short- (Alain and Snyder, 2008; Ben-David et al., 2011) or long-term (Kraus et al., 1995; Reinke et al., 2003; Tremblay et al., 2009) training, and focused exclusively on functional changes in auditory-related brain regions. Even though this previous work consistently revealed an amelioration of discrimination that goes hand in hand with altered brain responses originating from auditory-related cortical fields (Vaughan and Ritter, 1970), there are nevertheless important gaps in the literature that need to be filled to more deeply understand the neural operations at the basis of phonetic discrimination learning. In fact, currently, the temporal dynamics of functional changes in the auditory-related cortex are not well understood. Furthermore, even though the results show that during phonetic discrimination learning, perceptual and cognitive functions are tightly coupled, none of the previous studies have focused on the contribution of mnemonic processes (i.e., echoic, short-term, and working memory) or on the dynamic interplay between perception and cognition. Such interplay takes place, for example, when participants have to judge whether pairs of vowels or consonant-vowel (CV) syllables are acoustically equivalent or not. In fact, during such judgements, participants must faithfully encode the two stimuli of the pair, to keep them in echoic memory, as well as to compare the two items by engaging working memory functions in order to make a decision (Albouy et al., 2017).

Nowadays, it is generally acknowledged that professional musicians can serve as a reasonable model for better comprehending the influence of experiential factors on both perceptual and cognitive functions (Jäncke, 2009; Schlaug, 2015; Strait and Kraus, 2014). Regarding the former, there is strong evidence showing that both short- (Chobert et al., 2014; Hyde et al., 2009) and long-term (Elmer et al., 2012; Seppanen et al., 2012) music training are associated with long-lasting (Parbery-Clark et al., 2011; Strait and Kraus, 2014) functional and structural changes throughout the entire auditory system, ranging from the brainstem (Parbery-Clark et al., 2013) to the auditory cortex (Elmer et al., 2016; Pantev et al., 2001; Schneider et al., 2005a, 2005b). Such an optimization of the auditory system has not only been shown to lead to a finer-grained acoustic resolution in response to a variety of musical items (i.e., pitch, duration, rhythm, timbre, and melody; Baumann et al., 2008; Schon et al., 2004; Vuust et al., 2012), but also to promote different aspects of speech processing. In this context, both active (Elmer et al., 2012; Marie et al., 2011b; Tervaniemi et al., 2009) and passive (Chobert et al., 2014; Kühnis et al., 2013a) discrimination paradigms converge to the notion that music training facilitates the processing of segmental and suprasegmental (Besson et al., 2011) speech cues varying in spectral and temporal attributes, including voice-onset time (VOT; Elmer et al., 2012; Kühnis et al., 2013a), duration (Kühnis et al., 2013a; Tervaniemi et al., 2009), pitch (Marie et al., 2011a; Wong et al., 2007), timbre (Bidelman et al., 2014b; Kühnis et al., 2013a), as well as linguistic and emotional prosody (Marques et al., 2007). Furthermore, music training has also been shown to have an influence on the categorical perception of speech sounds (Bidelman et al., 2014a; Elmer et al., 2014), as well as to accelerate the learning of pseudowords manipulated in terms of spectral information (Kühnis et al., 2013b).

In the last decade, research provided additional evidence on the vast influences of music training by focusing on cognitive rather than perceptual functions (Benz et al., 2016). Previous studies have documented behavioral advantages of musicians, compared to non-musicians, in a variety of cognitive functions, including attention (Baumann et al., 2008), short-term memory (Dittinger et al., 2016; George and Coch, 2011), working memory (Schulze and Koelsch, 2012; Zuk et al., 2015), inhibition (Moreno et al., 2014), verbal fluency, cognitive flexibility, processing speed (Zuk et al., 2015), and intelligence (Schellenberg, 2004). Furthermore, such an optimization of cognitive functions has recently even been shown to accelerate language learning mechanisms in musicians, compared to non-musicians, for example, when it comes to learning new words through picture-syllable associations (Dittinger et al., 2016).

In the present study, we empirically evaluated the temporal dynamics underlying short-term phonetic discrimination learning in professional musicians and non-musicians by combining behavioral and electrophysiological (i.e., EEG) measurements. With this purpose in mind, we made use of a phonetic discrimination task consisting of judging whether pairs of CV syllables manipulated in the first formant transition (i.e., F1 of the vowel) were acoustically identical or not. This specific task, in association with EEG, is particularly fruitful as it enables to track brain dynamics reflecting both perceptual (i.e., auditory encoding) and mnemonic (i.e., echoic and working memory) functions with a high temporal resolution. Based on previous work pointing to an amelioration of both perceptual (Strait and Kraus, 2014) and cognitive (Zuk et al., 2015) functions in musicians, here we predicted faster learning mechanisms in the experts, which are expected to be reflected by shorter reaction times and higher accuracy. Furthermore, we predicted that such a steeper slope of the learning curve will be paralleled by dynamically altered brain signatures, reflecting an amelioration of perceptual encoding mechanisms (i.e., early AEPs in response to the first and second stimulus, N1/P2 complex), echoic memory (i.e., N400 and P600 waveforms), as well as working memory functions (i.e., P600 responses).

2. Methods

2.1. Participants

Forty-five healthy volunteers (29 non-musicians and 16 musicians) were recruited for the study. Due to EEG artefacts (i.e., movement and muscle artefacts), seven participants had to be excluded from further analyses. After the exclusion of one additional participant who was not able to conclude the experiment, the data of 25 non-musicians (15 female, mean age = 24.68 years, SD = 2.93) and 12 musicians (9 female, mean age = 23.75 years, SD = 4.20; five pianists, two flautists, two cellists, one violinist, one violoncellist, and one double-bass player) entered data analysis. None of the subjects reported present or past neurological, psychiatric or audiological problems, all participants had an unremarkable audiological status as revealed by pure tone audiometry (MAICO ST 20, MAICO Diagnostic, GmbH, Berlin), and all subjects were consistently right-handed (Annett, 1970) native Swiss-German or German speakers. Non-musicians have never undergone professional music training nor regularly played a musical instrument in the last five years. By contrast, all musicians commenced music training before the age of ten years (mean age of commencement = 6.92 years, SD = 1.31 years), and at the time point of EEG measurements they still practiced their musical instrument for at least two hours a day (mean hours/day during the last year = 3.25 h, SD = 0.81 h). Participants were paid for participation, the local ethic committee approved the study (in accordance with the declaration of Helsinki), and written consent was obtained from all participants.

2.2. History of music training and musical aptitudes

History of music training was assessed by an in-house questionnaire previously used by our group (Elmer et al., 2012). The questionnaire was specifically designed to evaluate the age of onset of music training, the instruments played, the number of years of music training, and the estimated number of training hours per day/week during every three-year period of life. Furthermore, musical aptitudes were quantified by using the “Advanced Measure of Music Audiation” (AMMA) test (Gordon, 1989). During this procedure, participants listened to 30 pairs of piano melodies and had to decide whether these were either rhythmically or tonally different, or identical.

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