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Research Report

Life-long music practice and executive control in older adults: An event-related potential study

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ABSTRACT

Recent research has indicated that music practice can influence cognitive processing across the lifespan. Although extensive musical experience may have a mitigating effect on cognitive decline in older adults, the nature of changes to brain functions underlying performance benefits remains underexplored. The present study was designed to investigate the underlying neural mechanisms that may support apparent beneficial effects of life-long musical practice on cognition. We recorded event-related potentials (ERPs) in older musicians ($N=17$; average age=69.2) and non-musicians ($N=17$; average age=69.9), matched for age and education, while they completed an executive control task (visual go/no-go). Whereas both groups showed similar response speed and accuracy on go trials, older musicians showed fewer no-go errors. ERP recordings revealed the typical N2/P3 complex, but the nature of these responses differed between groups in that (1) older musicians showed larger N2 and P3 effects ('no-go minus go' amplitude), with the N2 amplitude being correlated with behavioral accuracy for no-go trials and (2) the topography of the P3 response was more anterior in musicians. Moreover, P3 amplitude was correlated with measures of musical experience in musicians. In our discussion of these results, we propose that music practice may have conferred an executive control advantage for musicians in later life.

1. Introduction

The regulation of thought and action has been shown to depend highly on executive functions, a system that includes subcomponents such as goal planning, self-monitoring, decision making, attention, mental flexibility and inhibition (Miyake et al., 2000; Stuss and Alexander, 2000). These functions are vital to regulating other cognitive processes and are important predictors of life outcomes (Miller and Cohen, 2001; Salthouse, 2005). They rely on the integrity of an extensive network that includes the prefrontal cortex, superior parietal cortex, supramarginal and angular gyri, anterior cingulate gyrus, putamen, thalamus, parahippocampal gyrus, and cerebellum (see Collette et al. (2006), for review). Critically, a large part of this functional network is underpinned by frontal regions, which are among the brain structures most sensitive to aging (e.g., Hedden and Gabrieli, 2004), which may be related to older adults' deficit in tasks that engage executive function processes such as inhibition, planning, task switching and working memory (Burle et al., 2004).

Among executive functions, inhibitory control shows clear age-related decline (Burle et al., 2004). As a core process involved in many cognitive functions relevant to everyday activities, impairment in inhibitory control can cause significant life challenges (Royall et al., 2004). Yet, importantly, large individual differences can be observed across older adults of similar age (e.g., Rapp and Amaral, 1992), with some individuals maintaining very high levels of cognitive performance well into their later years. This individual variability has given rise to theories such as the cognitive reserve model (Cabeza, 2002; Stern, 2003, 2009), which posits that environmental factors can allow older adults to preserve their cognitive ability or develop compensatory mechanisms, thereby maintaining cognitive proficiency despite age-related brain changes. One of the crucial issues in this field of research is to understand the potential factors that can influence cognitive reserve and the underlying neural mechanisms.

In recent years, evidence has begun to emerge supporting a positive relationship between musical practice and cognitive functioning, and the potential of this form of stimulation to enhance cognitive reserve capacity in advanced age (e.g., Bokura et al., 2001; Hanna-Pladdy and MacKay, 2011; Parbery-Clark et al., 2011; Bokura et al., 2002; Gély-Nargeot et al., 1997; Alain et al., 2014). It is now largely accepted that both short- and long-term musical practice can lead to anatomical and functional brain changes associated with enhanced performance in various perceptual and cognitive domains in children and adults (see for

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example, Herholz and Zatorre, 2012; Jäncke, 2009; Wan and Schlaug, 2010, for reviews). Importantly, superiority of performance in musicians can even be observed when participants are tested on non-musical or even non-auditory tasks, suggesting that benefits from musical practice may extend to non-musical, domain-general activities (e.g., Hanna-Pladdy and Gajewski, 2012; see below for specific examples of such studies). These so-called 'transfer effects', where benefits incurred in the trained domain extend to a distinct domain of cognition, can be explained by the fact that musical and non-musical activities share some degree of overlap in the cognitive processes they recruit (Patel, 2011).

Enhanced performance related to musical practice found in older adults implicates various cognitive domains and tasks. Older musicians show better auditory (Hanna-Pladdy and Gajewski, 2012; Parbery-Clark et al., 2011) and visual (Amer et al., 2013) working memory compared to their non-musician counterparts. They also show enhanced performance in visuospatial processing (Hanna-Pladdy and Gajewski, 2012), as well as verbal and visuospatial executive function tasks such as the phonemic fluency test and the Tower of London (Hanna-Pladdy and Gajewski, 2012). Additionally, Hanna-Pladdy and MacKay (2011) observed linear relationships between the musical background of older adults (years of practice, age of acquisition, type of musical training) and their performance of task switching using the Trail Making Test. In what concerns inhibitory control, improvements have been shown in older musicians compared to non-musicians in both auditory and visual tasks. In the auditory domain, musicians show better perception of speech in noise (requiring the inhibition of background distracting noise; Bokura et al., 2001; Parbery-Clark et al., 2011) and a reduced interference effect in an auditory Stroop task (Amer et al., 2013). In the visual domain, Amer et al. (2013) showed that older musicians were faster in responding to the incongruent condition of the Simon task and were less affected by distractions during a reading task. These findings are consistent with studies in young adults showing advantages for musicians in reaction times and error rates in incongruent/conflicting conditions using similar paradigms, such as an auditory Stroop task (Bialystok and DePape, 2009), a visual Stroop task (Jentzsch et al., 2014), and a visual Simon task (Bialystok and DePape, 2009; Jentzsch et al., 2014).

Some form of inhibition appears to operate at various cerebral levels, from the lateral inhibition in the visual and auditory cortices that contribute to perceptual acuity to the inhibition required for selective attention (Hampshire and Sharp, 2015). Many forms are likely exercised by the practice of music. When playing an instrument, for instance, inhibitory processes are necessary in the perception of sound, the correct selection of a motor program from among many possible ones at any given moment of instrumental execution, and the selective attention to a particular sound stream over others in the music. This latter example is somewhat similar to the demands of focusing on our interlocutor during a conversation in a noisy environment, which may be why musicians show a better ability to perceive speech in noise in laboratory tasks (Parbery-Clark et al., 2011; Zendel and Alain, 2012).

Despite behavioral evidence for better abilities in executive control in older musicians, the neural mechanisms underlying enhanced processing in musicians have not been investigated in an older adult population. Previous research, however, has examined brain effects related to music training in young adult musicians during tasks requiring conflict monitoring, but it has yielded somewhat inconsistent results. Jentzsch et al. (2014) investigated ERPs in young musicians and non-musicians in two tasks involving cognitive control (the Simon task and the Stroop task). Musicians showed increased amplitude for the Error Related Negativity (ERN), an electrophysiological brain correlate associated with the detection of incorrect responses. They also found a stronger N2 effect (difference in wave amplitudes between the N2 for no-interference vs. interference conditions) in musicians. This was interpreted as reflecting an improved ability to monitor behavior in 'conflict' conditions giving rise to incorrect responses. In contrast, using a visual go/no-go task, Moreno and colleagues observed larger P2 amplitudes (for both go and no-go trials together) followed by a reduced N2 effect (no-go minus go), driven by a reduced amplitude of the N2 for no-go trials in young musicians relative to non-musician controls (Moreno et al., 2014; See also Moreno et al. (2011), for similar results in young children after 4 weeks of music training). This was interpreted to mean that benefits observed in musicians might be mediated by alterations in the early stages of information processing, such that early enhanced processing of relevant stimulus features reduces the need for subsequent inhibitory control at the stage of the N2 response. The apparent contradiction between these two studies may come in part from the fact that, although both tested an aspect of conflict monitoring, they used different tasks which seem to range in complexity of instructions and type of response being suppressed/inhibited. The simplicity of the go/no-go task used in the work presented here may allow better isolation of the underlying neural processes involved in the inhibitory control of an inappropriate response.

In non-musicians, previous studies measuring ERPs during a go/no-go task have typically focused on N2 and P3 waves. Although the functional roles of these ERP deflections remain a matter of debate (e.g., Bokura et al., 2001; Kok et al., 2004; Yeung et al., 2004), both waves are generally associated with cognitive control processes. Studies manipulating the parameters of go/no-go tasks have consistently led to the view that N2 increases (no-go vs. go trials) reflect additional processing associated with conflict monitoring (Burle et al., 2004; Donkers and Van Boxtel, 2004; Nieuwenhuis et al., 2003). In some studies, a modulation of the P3 wave has been observed when overt inhibition of a response or when the monitoring of inhibitory outcome is required to successfully complete the task (response suppression; e.g., Hämmerer et al., 2010; Liotti et al., 2005). In older adults, both waves are affected by the aging process, making them ideal candidates to investigate our question. Research typically reports a reduction of N2 and P3 amplitudes with aging, which accompany a reduction in no-go accuracy (Bokura et al., 2002; Hämmerer et al., 2010).

Given findings suggesting benefits in cognitive and brain processing with music practice in younger adults, it is of great interest to examine whether similar benefits from music practice might extend to older adults. The current study involves 17 older musicians and 17 older non-musicians, matched in age and education level, and with comparable scores in basic background neuropsychological measures (see Section 4). Our objective is to investigate both behavioral and electrophysiological differences in inhibitory processing associated with life-long music practice as evoked by a go/no-go task. We expect that a lifetime of musical practice is associated with a better ability to withhold the prepotent response tendencies evoked by rare no-go trials, which should be reflected in reduced error rates on no-go trials for older musicians relative to their non-musician counterparts. Existing findings in young musicians from a 2014 study by Moreno and colleagues suggest that older musicians may show enhanced early stimulus processing, manifested as a larger P2, and a consequently reduced need for inhibitory control, resulting in a reduced N2. However, we must take into account that older musicians may have an age-related diminishment of this music-related early processing advantage, so we may not, in fact, observe the P2 enhancement. In that case, we might expect increased amplitude of the N2 and a larger no-go versus go N2 effect as a sign of better engagement of cognitive control processes, as in the study of