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Research paper

Musical experience shapes top-down auditory mechanisms: Evidence from masking and auditory attention performance

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ABSTRACT

A growing body of research suggests that cognitive functions, such as attention and memory, drive perception by tuning sensory mechanisms to relevant acoustic features. Long-term musical experience also modulates lower-level auditory function, although the mechanisms by which this occurs remain uncertain. In order to tease apart the mechanisms that drive perceptual enhancements in musicians, we posed the question: do well-developed cognitive abilities fine-tune auditory perception in a top-down fashion? We administered a standardized battery of perceptual and cognitive tests to adult musicians and non-musicians, including tasks either more or less susceptible to cognitive control (e.g., backward versus simultaneous masking) and more or less dependent on auditory or visual processing (e.g., auditory versus visual attention). Outcomes indicate lower perceptual thresholds in musicians specifically for auditory tasks that relate with cognitive abilities, such as backward masking and auditory attention. These enhancements were observed in the absence of group differences for the simultaneous masking and visual attention tasks. Our results suggest that long-term musical practice strengthens cognitive functions and that these functions benefit auditory skills. Musical training bolsters higher-level mechanisms that, when impaired, relate to language and literacy deficits. Thus, musical training may serve to lessen the impact of these deficits by strengthening the corticofugal system for hearing.

1. Introduction

Deficits in auditory perception contribute to language and literacy disorders, affecting over 10% of children in developed countries (Torgeson, 1991). These deficits impact perceptual abilities that are particularly subject to cognitive control (Hartley et al., 2003; Moore et al., 2008; Wright et al., 1997). For example, temporal auditory processing can be impaired in children with language and literacy disorders (Benasich and Tallal, 2002; Gaab et al., 2007; Montgomery et al., 2005; Temple et al., 2000). This impairment manifests itself as an inability to separate brief sounds presented one after the other. Backward masking thresholds provide a metric for temporal auditory processing and are determined by measuring how loud a tone must be for it to be perceived when immediately followed by a competing signal that is longer in duration than the tone, such as broadband noise. The noise results in reduced sensitivity to the preceding tone even in unimpaired listeners, but children with temporal processing deficits show more debilitating effects of the masker on the tone (Hartley and Moore, 2002; Hartley et al., 2003; Rosen and Manganari, 2001; Tallal et al., 1993; Wright, 1998, 2001; Wright et al., 1997). In speech, deficits in backward masking may impair the perception of syllables in which vowels produce a masking effect on the preceding consonants (Johnson et al., 2007; Rosen and Manganari, 2001). Backward masking performance appears to relate to cognitive performance (Tallal et al., 1993; Wright, 1998).

Abbreviations: Mus, musicians; NonMus, non-musicians; IMAP, IHR Multicentre Battery for Auditory Processing; FD, frequency discrimination; BM, backward masking; BMgap, backward masking with a delay gap; SM, simultaneous masking; SMnotch, simultaneous masking with a notched filter; AAtt, auditory attention; VAtt, visual attention; AWM, auditory working memory; WASI, Wechsler abbreviated scale of intelligence; IQ, intelligence quotient; SNR, signal-to-noise ratio; SLI, Specific Language Impairment; APD, Auditory Processing Disorder

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A growing body of research suggests that high-level cognitive functions can drive auditory perception by tuning lower-level sensory mechanisms to increase neural signal-to-noise ratios (SNR). This interaction between cognitive and sensory mechanisms has been observed in both the visual (Ahissar and Hochstein, 2004; Dosher and Lu, 1998, 1999, 2006; Gold et al., 1999) and auditory domains (Allen et al., 2000; Kauramaki et al., 2007), with higher SNRs being associated with better perception and a more efficient system (Hartley and Moore, 2002; Hartley et al., 2003). By strengthening cognitive functions related to the task at hand (such as auditory attention for backward masking perception), deficits in sensory processing may be ameliorated (Moore, 2002).

Considerable effort has gone toward the development of language-based auditory training programs to improve auditory processing at sensory and cognitive levels (Marler et al., 2001; Merzenich et al., 1996; Moore et al., 2009). Music provides a potentially powerful alternative to traditional language-based programs because its practice requires interactive participation with complex sounds and occurs regularly, with those undergoing musical training required to spend many hours weekly with their instruments. Although other structural auditory training programs might accomplish similar feats, the frequency with which musicians must spend time manipulating and attending to complex sounds may provide a distinct advantage for engendering neural plasticity and learning. By activating the neural reward circuit, musical practice and performance promotes engagement and plasticity (Blood and Zatorre, 2001; Menon and Levitin, 2005). Furthermore, musical practice not only enhances the processing of music-related sounds but also affects processing in other domains, such as language (Marques et al., 2007; Moreno et al., 2009; Parbery-Clark et al., 2009a; Schon et al., 2004, 2008). Specifically, cognitive mechanisms pertaining to verbal abilities (Forgeard et al., 2008), working memory (Brandler and Rammsayer, 2003; Chan et al., 1998; Franklin et al., 2008; Ho et al., 2003; Jakobson et al., 2008; Ohnishi et al., 2001; Parbery-Clark et al., 2009) and auditory attention (Burns and Ward, 1978; Locke and Kellar, 1973; Siegel and Siegel, 1977) may be strengthened in musicians.

We are just now beginning to explore relationships between musicians' cognitive and perceptual enhancements and the underlying processes that drive them. It has recently been proposed that perceptual enhancements in musicians can be attributed, at least in part, to top-down modulation of cochlear (Perrot et al., 1999) and brainstem function (Kraus et al., 2009; Lee et al., 2009; Musacchia et al., 2008, 2007; Parbery–Clark et al., 2009b; Strait et al., 2009a,b; Tzounopoulos and Kraus, 2009; Wong et al., 2007). This top-down control may be mediated by the corticofugal pathway for hearing, which consists of an extensive tract of efferent fibers (Suga, 2008; Suga et al., 2000). We now ask: does sophisticated interaction with musical sound strengthen cognitive mechanisms that fine-tune auditory perception in a top-down fashion?

In order to define relationships between musicians' cognitive and perceptual enhancements, we tested adult musicians and non-musicians on a standardized battery of cognitive and perceptual tasks. We hypothesized that musicians demonstrate greater perceptual advantages for tasks that rely on cognitive abilities—especially in the auditory modality. Specifically, we anticipated a musician advantage for frequency discrimination and temporal processing, assessed by backward masking, and no advantage for simultaneous masking, which is thought to be less dependent on cognitive abilities and more dependent on physiological properties of peripheral hearing structures. We also expected musical experience to affect auditory but not visual attention. Lastly, auditory-related cognitive abilities, such as auditory attention and working memory, were only expected to correlate with performance on perceptual measures at which musicians excel, such as frequency discrimination and backward masking.

2. Methods

We collected cognitive and perceptual data using the IHR Multicentre Battery for Auditory Processing (IMAP, developed by the Medical Research Council Institute of Hearing Research, Nottingham, UK) from 33 adults between the ages of 18–40 years. Participants provided informed consent according to Northwestern University's Institutional Review Board. All participants completed an extensive questionnaire addressing family history, musical experience and educational history and demonstrated normal audiometric thresholds (<20 dB pure tone thresholds at octave frequencies from 125 to 8000 Hz) and non-verbal IQ (>40th percentile achieved on the Wechsler Abbreviated Scale of Intelligence Matrix Reasoning subtest) (Harcourt Assessment, San Antonio, TX). Musicians (Mus, $N = 18$) were self-categorized, began musical training at <9 years of age and had consistently practiced for >10 years (consistency defined as practicing at least 3 days weekly for >1 h per session). Non-musicians (NonMus, $N = 15$) were self-categorized and had <4 years of formal musical experience throughout their lifespan.

A subset of IMAP measures were administered in a sound attenuated booth using a laptop computer that was placed 60 cm from the participant. Responses were recorded using a 3-button response box. Stimuli were presented diotically through Sennheiser HD 25–1 headphones and were accompanied by animated visual stimuli. Testing sessions lasted ~1.5 h, including questionnaire completion and audiometric testing.

IMAP tasks addressed auditory working memory (memory for reversed digits, AWM), auditory attention (AAtt), visual attention (VAtt), frequency discrimination (FD), frequency selectivity (simultaneous masking with and without notched filters—SM and SMnotch), temporal resolution (backward masking with and without a temporal gap between the target and masker—BM and BMgap), and non-verbal IQ (Wechsler Abbreviated Scale of Intelligence matrix reasoning subtest—WASI). All subtests except for the WASI, which was administered according to its required protocol, used an identical response paradigm, visual cues and response feedback. Perceptual subtests were initiated by a practice session of easy trials, consisting of the same stimuli used for initial trials in each subtest (a 90 dB SPL target tone for backward masking and a 50% frequency difference between the target and standard tones for frequency discrimination). Correct responses on 4 out of 5 practice trials were required to continue. All subjects achieved a minimum of 4 out of 5 correct responses for all practice sessions.

2.1. Auditory working memory

Participants listened to a sequence of numbers presented at 70 dB SPL and were asked to repeat them in reverse order. Initial sequences were two digits in length and increased in difficulty (more digits) with subsequent correct responses, to a maximum of nine digits. All digits had to be repeated in the appropriate sequence to be considered correct. Participants were given unlimited time to respond.

2.2. Auditory and visual attention

Attention tasks were similar to the Test of Attentional Performance (Zimmerman and Fimm, 2002) and measured phasic alertness by comparing reaction times induced by the presence or absence of a cue that occurred with a variable delay (0.5–1.0 s) before a target stimulus. For both visual and auditory attention tasks, participants attended to a computer screen displaying of a single cartoon character that was standing in an open space. For the visual attention task (VAtt), participants were instructed to monitor