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Music training and working memory: An ERP study

Elyse M. George, Donna Coch*

Dartmouth College, Department of Education, 3 Maynard Street, Raven House, HB 6103, Hanover, NH 03755, USA

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ABSTRACT

While previous research has suggested that music training is associated with improvements in various cognitive and linguistic skills, the mechanisms mediating or underlying these associations are mostly unknown. Here, we addressed the hypothesis that previous music training is related to improved working memory. Using event-related potentials (ERPs) and a standardized test of working memory, we investigated both neural and behavioral aspects of working memory in college-aged, non-professional musicians and non-musicians. Behaviorally, musicians outperformed non-musicians on standardized subtests of visual, phonological, and executive memory. ERPs were recorded in standard auditory and visual oddball paradigms (participants responded to infrequent deviant stimuli embedded in lists of standard stimuli). Electrophysiologically, musicians demonstrated faster updating of working memory (shorter latency P300s) in both the auditory and visual domains and musicians allocated more neural resources to auditory stimuli (larger amplitude P300), showing increased sensitivity to the auditory standard/deviant difference and less effortful updating of auditory working memory. These findings demonstrate that long-term music training is related to improvements in working memory, in both the auditory and visual domains and in terms of both behavioral and ERP measures.

1. Introduction

A growing number of studies have reported correlations between music training and improvements on a variety of cognitive skills, including measures of nonverbal reasoning (e.g., Forgeard, Winner, Norton, & Schlaug, 2008), IQ (e.g., Schellenberg, 2004, 2006), verbal memory (e.g., Brandler & Rammsayer, 2003; Chan, Ho, & Cheung, 1998; Ho, Cheung, & Chan, 2003; Jakobson, Cuddy, & Kilgour, 2003; Jakobson, Lewycky, Kilgour, & Stoesz, 2008), arithmetic (e.g., Zafranas, 2004), speech processing (e.g., Moreno & Besson, 2006; Moreno et al., 2009), visual processing (e.g., Helmbold, Rammsayer, & Altenmüller, 2005; Jakobson et al., 2008; Zafranas, 2004), vocabulary (e.g., Forgeard et al., 2008), and reading skills (e.g., Moreno et al., 2009). The mechanisms mediating these associations are unknown. It has been suggested that working memory might play a role (e.g., Chen, Penhune, & Zatorre, 2008; Gunter, Schmidt, & Besson, 2003; Lee, Lu, & Ko, 2007; Williamon & Egner, 2004), but "there is little or no empirical evidence to support this hypothesis" that music training improves aspects of executive function (e.g., Hannon & Trainor, 2007; Schellenberg & Peretz, 2008, p. 46).

Working memory involves the temporary storage and manipulation of information, and functions to integrate incoming information with information in existing memory stores (e.g., Baddeley, 1992, 1998; Brumback, Low, Gratton, & Fabiani, 2005). Evidence from both lesion and neuroimaging studies supports Baddeley's (1992, 1998) model dividing the working memory system into modality based short-term stores (phonological/articulatory loop and visuospatial sketchpad, subsets of working memory with traces lasting only a few seconds without rehearsal) and a modality free, attention-controlling central executive associated with regulation of abilities necessary for goal-directed behavior (e.g., Baddeley, 1992, 2003; Baldo & Dronkers, 2006; Jonides et al., 1998; Koelsch et al., 2009; Postle & D'Esposito, 1999; Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1992). While some have argued for a tonal equivalent to the verbal phonological loop (e.g., Deutsch, 1970), evidence suggests that rehearsal and storage of both tonal and verbal information involves the phonological loop (e.g., Salamé & Baddeley, 1989; Semal, Demany, & Ueda, 1996) and activates overlapping neural networks (e.g., Koelsch et al., 2009; Schulze, Zysset, Mueller, Friederici, & Koelsch, in press). Here, we investigated if prior long-term music training was associated with improved working memory using both standardized behavioral measures and event-related potentials (ERPs).

1.1. Working memory and music training: behavioral studies

A handful of behavioral studies have explored which subsystems within the working memory system might be affected by

* Corresponding author at: Department of Education, Reading Brains Lab, Dartmouth College, 3 Maynard Street, Raven House, HB 6103, Hanover, NH 03755, USA. Tel.: +1 603 646 3282; fax: +1 603 646 3968.
E-mail address: donna.coch@dartmouth.edu (D. Coch).

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music training, providing evidence of associations between working memory and music training. For example, children and adults who have received music training have been shown to outperform non-musician controls on measures of auditory and visual working memory such as forward and backward digit span (e.g., Fujioka, Ross, Kakigi, Pantev, & Trainor, 2006; Lee et al., 2007; Parbery-Clark, Skoe, Lam, & Kraus, 2009), nonword span (e.g., Lee et al., 2007), operation span (e.g., Franklin, Moore, Yip, & Jonides, 2008; Lee et al., 2007), spatial span (e.g., Lee et al., 2007), and verbal working memory span (e.g., Franklin et al., 2008; Parbery-Clark et al., 2009) tasks. However, Lee et al. (2007) reported that musically trained adults scored higher than their control counterparts only on tasks related to phonological storage (forward digit and nonword span), while musically trained children scored higher than their control counterparts on these tasks as well as on tasks related to central executive functions (backward digit and operation span) and visuospatial storage (object and location span).

Consistent with this evidence for better phonological working memory in musically trained adults, Berti, Münzer, Schröger, and Pechmann (2006) reported that adult musicians outperformed non-musicians on a pitch comparison task, demonstrating advantages in storing auditory information that the authors suggested were due to improved working memory operations. Similarly, Pechmann and Mohr (1992) interpreted superior performance on their behavioral pitch discrimination task to improved working memory in musicians as compared to non-musicians. Williamson and colleagues have also reported differences in pitch memory for musicians and non-musicians, such that musical training was associated with use of multiple strategies for encoding pitch information (Williamson, Baddeley, & Hitch, 2010). Others have reported enhanced pitch processing in musically trained children and adults, as compared to their untrained counterparts, but have not directly connected this finding to changes in working memory with music training (e.g., Brattico et al., 2009; Fujioka et al., 2006; Hantz, Crummer, Wayman, Walton, & Frisina, 1992; Hantz, Kreilick, Braveman, & Swartz, 1995; Kishon-Rabin, Amir, Vexler, & Zaltz, 2001; Kuriki, Kanda, & Hirata, 2006; Lappe, Herholz, Trainor, & Pantev, 2008; Magne, Schön, & Besson, 2006; Marques, Moreno, Castro, & Besson, 2007; Moreno & Besson, 2006; Moreno et al., 2009; Nikjeh, Lister, & Frisch, 2008; Schneider et al., 2002; Schön, Magne, & Besson, 2004; Shahin, Bosnyak, Trainor, & Roberts, 2003; Shahin, Roberts, Pantev, Aziz, & Picton, 2007; Shahin, Roberts, & Trainor, 2004; Strait, Kraus, Parbery-Clark, & Ashley, 2010; Strait, Kraus, Skoe, & Ashley, 2009; Tervaniemi, Castaneda, Knoll, & Uther, 2006; Trainor, Desjardins, & Rockel, 1999; Wayman, Frisina, Walton, Hantz, & Crummer, 1992). While a recent study using a backward digit span task as a measure of auditory working memory failed to find differences between adult musicians and non-musicians, results from auditory attention and masking tasks were consistent with the interpretation that "musicians' sensory enhancements result from strengthened cognitive modulation of auditory processing" (Strait et al., 2010, p. 26).

Others have reported similar findings in the visual domain: musically trained adults outperformed non-musicians on psychometric tasks requiring quick visual processing (Helmbold et al., 2005) and delayed visual recall and recognition (Jakobson et al., 2008), while children who received piano training for one year showed improvement on a visual short-term memory task (Zafranas, 2004). Musically trained adults also recalled sequentially visually presented note patterns better than non-musicians, particularly well-formed patterns, even when gestalt properties, verbal rehearsal, and familiarity were controlled (Kalakoski, 2007). Finally, older adults who took piano lessons showed gains on measures of visual working memory such as the Trail Making Test and Digit Symbol task, while controls who did not receive piano instruction did not (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007). However, others have reported no advantages for musicians as compared to non-musicians on measures of visual memory or attention (Chan et al., 1998; Ho et al., 2003; Strait et al., 2010).

1.2. Working memory and music training: neuroscientific studies

1.2.1. fMRI studies

In addition to these behavioral findings, there is tenuous fMRI evidence suggesting a relation between music training and working memory at the neural level. In one study, Janata, Tillmann, and Bharucha (2002) found that attentive listening to one instrument in polyphonic music activated regions also involved in working memory processes, including the superior temporal gyrus, intraparietal sulcus, precentral sulcus, inferior frontal sulcus and gyrus, and the frontal operculum. However, this study only included trained musicians as participants and lacked a non-musician control group, precluding conclusions about the neural effects of music training. In another study, Chen et al. (2008) found that musicians behaviorally performed a rhythmic task better than non-musicians, and recruited the prefrontal cortex to a greater extent than non-musicians during performance of the task. They argued that the superior ability of musicians to organize and maintain a rhythm's temporal structure was related to the greater involvement of the prefrontal cortex mediating working memory. Previously, Gaab and Schlaug (2003) reported that musicians relied more on short-term memory (with greater activation in right temporal cortex and supramarginal gyrus) than non-musicians (with greater right primary and left secondary auditory cortex activation) to perform a difficult pitch memory task, and Schulze et al. (in press) have reported recently differences in sensorimotor coding of verbal and tonal information in a working memory task in musicians as compared to non-musicians. Absent musical training or expertise, lesion and neuroimaging studies have associated specific neural regions with specific aspects of working memory (e.g., see Baddeley, 2003, for a review).

1.2.2. ERP studies: the P300 component

Given these disparate findings, further research targeting the subsystems of working memory at both the behavioral and neural levels is important to understanding a possible link between music training and working memory. In order to measure working memory processes at the neural level, particularly considering the relatively brief timing of processing within the short-term stores (e.g., Baddeley, 1998), it would be useful to employ a technique that allowed for real-time processing of information such as the recording of ERPs (e.g., Morgan, Klein, Boehm, Shapiro, & Linden, 2008, p. 989). There have been numerous studies investigating a link between the P300 ERP component and the working memory system (e.g., Brumback et al., 2005; Grune, Metz, Hagendorf, & Fischer, 1996; Guo, Lawson, Zhang, & Jiang, 2008; Kiss, Pazderka-Robinson, & Floden, 2001; Klein, Coles, & Donchin, 1984; Lefebvre, Marchand, Eskes, & Connolly, 2005; Morgan et al., 2008; Murphy & Segalowitz, 2004; Ruchkin et al., 1992; SanMiguel, Corral, & Escera, 2008; Talsma, Wijers, Klavier, & Mulder, 2001). The classic task used to measure working memory processing in a P300 paradigm is the traditional oddball task (e.g., Brumback et al., 2005; Croft, Gonsalvez, Gabriel, & Barry, 2003; Frisina, Walton, & Crummer, 1988; Klein et al., 1984; Murphy & Segalowitz, 2004; Polich, 1995, 2007). A two-stimulus oddball paradigm presents infrequent (deviant) target stimuli within a train of frequent (standard) stimuli, and the participant is asked to respond only to the deviant stimuli. The deviant stimuli in oddball tasks consistently elicit a marked P300 component in the ERP waveform (e.g., Brumback et al., 2005; Croft et al., 2003; Gonsalvez, Barry, Rushby, & Polich, 2007; Gonsalvez & Polich, 2002; Klein et al., 1984; Murphy & Segalowitz, 2004; Polich, 1995, 1997, 2007; SanMiguel et al., 2008), and this P300 is con-