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The effects of musical training on movement pre-programming and re-programming abilities: An event-related potential investigation

Melis Anatürk, Ines Jentzsch*

School of Psychology & Neuroscience, University of St Andrews, St Andrews KY16 9JP, UK

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ABSTRACT

Two response precuing experiments were conducted to investigate effects of musical skill level on the ability to pre- and re-programme simple movements. Participants successfully used advance information to prepare forthcoming responses and showed response slowing when precue information was invalid rather than valid. This slowing was, however, only observed for partially invalid but not fully invalid precues. Musicians were generally faster than non-musicians, but no group differences in the efficiency of movement pre-programming or re-programming were observed. Interestingly, only musicians exhibited a significant foreperiod lateralized readiness potential (LRP) when response hand was pre-specified or full advance information was provided. These LRP findings suggest increased effector-specific motor preparation in musicians than non-musicians. However, here the levels of effector-specific preparation did not predict preparatory advantages observed in behaviour. In sum, combining the response precuing and ERP paradigms serves a valuable tool to examine influences of musical training on movement pre- or re-programming processes.

1. Introduction

Instrumental music performance frequently involves the rapid execution of well-practiced and sequential uni- or bi-manual movements (Jerde, Santello, Flanders, & Soechting, 2006; Palmer, 2006). For example, a top-level pianist is able to produce up to 1800 note/min (Münte, Altenmüller, & Jäncke, 2002). In order to achieve such advanced-level musical ability, individuals need to engage in a significant amount of deliberate practice that is usually gained over a period of many years (often initiated in early childhood; Sloboda & Davidson, 1996; Williamon & Valentine, 2000). During these rehearsals, instrumentalists repeatedly perform finger movements required to produce each musical note, for example by pressing successive piano keys (Watson, 2006). This extensive training leads to the development of fine motor skill (Willingham, 1999; Jabusch, 2006) as demonstrated by the superior performance of musicians, compared to non-musicians, on finger tapping (e.g. Franěk, Mates, Radil, Beck, & Pöppel, 1991; Repp & Doggett, 2007) and motor sequence learning tasks (e.g. Landau & D'Esposito, 2006).

A widely distributed brain network is recruited during instrument playing (Baumann et al., 2007) and the high motor and auditory demands placed on the developing brain by intensive musical practice seem to lead to structural and functional neural adaptations (Pascual-Leone, Amedi, Fregni, & Merabet, 2005). For example, children who received music lessons over a 15-month period exhibited enlargements in the right precentral gyrus, right primary auditory cortex and corpus callosum compared to controls (Hyde et al., 2009). Neuroanatomical and neurophysiological differences are also frequently reported between adult musician and non-musicians (for a review, see Wan & Schlaug, 2010), particularly within the motor network (Herholz & Zatorre, 2012). Indeed, neuroimaging studies indicate that professional musicians exhibit larger grey matter volume in the primary motor cortex (Amunts et al., 1997; Gaser & Schlaug, 2003; Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995) and cerebellum (Hutchinson, Lee, Gaab, & Schlaug, 2003), relative to non-musicians. Furthermore, structural enlargements in the primary motor cortex (M1) appear to correspond to the type of instrument that an individual specializes in (Elbert et al., 1995; Bangert & Schlaug, 2006). For example, Bangert and Schlaug (2006) reported that professional string-players exhibited pronounced cortical representations of their left hand (i.e. the hand predominantly used to play their instrument) in the right M1. These enlarged M1 representations may enable musicians to execute their movements more

* Corresponding author.
E-mail address: ij7@st-andrews.ac.uk (I. Jentzsch).

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efficiently (Jäncke, Shah, & Peters, 2000; Jentzsch, Mkrtchian, & Kansal, 2014).

As the ability to prepare movements slows with age (Stelmach, Goggin, & Amrhein, 1988; Seidler et al., 2010), musical practice could serve as a potential intervention to delay or prevent such aging-related decline (Hanna-Pladdy & MacKay, 2011; Jentzsch et al., 2014). Moreover, novel therapies that improve the efficiency of movements are necessary and musical training forms a viable treatment option (e.g. in post-stroke rehabilitation; Schneider, Schönle, Altenmüller, & Münte, 2007; Altenmüller, Marco-Pallares, Münte, & Schneider, 2009). Thus, the present study aims to examine whether musical training even at an amateur levels improves the ability to pre-programme (Experiment 1) and re-programme (Experiment 2) simple finger movements in a non-musical task. To investigate this, the study combined two response precuing tasks with an event-related potential (ERP) paradigm. The next section describes these experimental paradigms and outlines the rationale of each experiment.

1.1. Movement pre-programming

Voluntary movements are prepared before they are performed (Keele, 1968; Churchland, Yu, Ryu, Santhanam, & Shenoy, 2006) and the response precuing paradigm (Rosenbaum, 1980, 1983) is frequently utilized to investigate these processes. In such tasks, a precue appears before target onset and conveys advance partial information about a forthcoming response (i.e. 'foreperiod'). Precues can indicate, for example, the hand (left or right), type of finger (i.e. index or middle) or direction of movement. Subsequently, a target provides complete information about the required response. If participants utilize precue information to prepare their responses in advance, their reaction times (RT) are significantly faster in informative precue trials compared to non-informative trials (for a review, see Leuthold, Sommer, & Ulrich, 2004). This suggests that even incomplete information about forthcoming movements can activate the necessary motor programs, which enable faster responses (Ulrich, Leuthold, & Sommer, 1998; Shojaei & VaezMousavi, 2007; but see Goodman & Kelso, 1980). However, response precuing tasks are restricted to overt measures of movement preparation, hence, are frequently combined with the ERP method (for a review, see Leuthold et al., 2004). ERP studies examine the neural correlates of action preparation: the foreperiod lateralized readiness potential (LRP; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988) and foreperiod contingent negative variation (CNV; Walter, Cooper, Aldridge, McCallum, & Winter, 1964), extracted from electrophysiological recordings of neural activity with high temporal accuracy (Coles, Smid, Scheffers, & Otten, 1995; Friedman, 2000).

The foreperiod CNV is a slow negative potential often triggered by a warning stimulus (e.g. a precue) and develops during the interval between the precue and target onset. The foreperiod CNV consists of early and late activity arising from the frontoparietal and centroparietal regions, respectively. The earlier component indexes non-motoric processing such as sensory preparation, anticipatory attention and orienting towards the warning stimulus (e.g. Brunia & van Boxtel, 2001; Gomez et al., 2004; Loveless & Sanford, 1974; Rohrbaugh & Gaillard, 1983), whereas the late component corresponds to muscle-unspecific motor preparation (Rohrbaugh, Syndulko, & Lindsley, 1976; for a review, see Leuthold et al., 2004). This study focuses on the late foreperiod CNV, which has been suggested to reflect the combined activity of lateral premotor and supplementary/cingulate motor areas (Leuthold & Jentzsch, 2001). In response precuing tasks, the late foreperiod CNV is detected during all trials, although its amplitude increases with the amount of advance information provided by the precue (MacKay & Bonnet, 1990; Leuthold et al., 2004). The foreperiod LRP, an index of selective motor activation of the specific effector representation and originates most likely from the primary motor cortex (Deecke, Grozinger, & Kornhuber, 1976; Leuthold & Jentzsch, 2001; Leuthold & Jentzsch, 2002a; Jentzsch & Leuthold, 2002). It can therefore only be detected when the specific effector (e.g. left or right hand) is known in advance. This ERP component is recorded over the C3′ and C4′ electrode sites and calculated by subtracting the activity from the electrode site (i.e. C3/C4) ipsilateral to each response hand from the activity in the contralateral recording site (Osman, Moore, & Ulrich, 2003). Moreover, the foreperiod LRP seems to index later stages of movement preparation (i.e. the conversion of motor programs into muscle-specific commands; Leuthold et al., 2004). As the foreperiod LRP and foreperiod CNV provide markers of different stages of motoric preparation, combining the two can be used as a powerful tool to investigate covert movement preparation processes (Leuthold et al., 2004).

As mentioned earlier, musicians have been reported to show structural enlargements in motoric areas of the brain. Musicians may therefore be more efficient at preparing their actions compared to non-musicians (Jäncke et al., 2000). For example, professional instrumentalists have been shown to anticipate their forthcoming movements when performing musical compositions (Engel, Flanders, & Soechting, 1997) and more musically experienced individuals exhibit more anticipatory behaviour (Palmer & Pfordresher, 2003; Palmer & Dalla Bella, 2004). Indeed, RT latencies generally seem to decrease as musical experience increases (e.g. Jentzsch et al., 2014). Moreover, young adults with musical training respond faster on uni-manual and bi-manual RT tasks compared to musically-naïve individuals (Hughes & Franz, 2007). Overall, musical practice may accelerate motor preparation processes, thus reducing their contribution to RT. Thus, the first experiment reported here aimed to directly examine the influence of musical practice on selective movement preparation.

1.2. Movement re-programming

Prepared movements must occasionally be modified before they are executed, such as when an unforeseen change occurs in the environment. This process of response re-programming enables humans to flexibly engage with their surroundings (Larish & Frekany, 1985; Stelmach et al., 1988). Response precuing tasks can also be used to investigate this form of movement preparation (Leuthold & Jentzsch, 2002b), by including invalid precues that encourage participants to prepare the incorrect motor parameters, which they must change after target onset (Leuthold, 2003). If responses are prepared according to invalid precue information, RTs are significantly slower compared to trials with valid precues (Leuthold & Jentzsch, 2002b). The resulting RT costs may reflect additional, inhibitory as well as motoric re-programming processes involved in invalid trials (Larish & Frekany, 1985; Lépine, Glencross, & Requin, 1989). Again, to our knowledge no previous study has addressed the influence of musical practice on the ability to re-programme an incorrectly pre-specified motor programme. A recent study by Jentzsch et al. (2014) suggested that musicians even at an amateur level might have a better ability to detect conflicts and errors compared to non-musicians. Thus, from this evidence one could predict musicians to be more efficient at re-programming their movements. This would also fit with brain imaging data suggesting an involvement of the ACC not only in error and conflict detection in general, but also specifically detecting conflict between existing and newly activated motor plans (Leuthold & Jentzsch, 2002b). Thus, Experiment 2 investigates whether amateur musicians show a better ability for motor re-programming compared to non-musical control participants.