Article

MPR

Music Performance Research

Vol. 5, including
CMPCP / PSN Special Issue
2-11
ISSN 1755-9219

Preliminary evidence for reduced cortical activity in experienced guitarists during performance preparation for simple scale playing

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ABSTRACT: Research using neuroscientific techniques has shown that less cortical activity occurs in the brains of experienced musicians and athletes than in the brains of novices when they plan and prepare to perform a motor skill. We used electroencephalography to observe cortical activity in the brains of experienced and novice guitarists preparing to play a scale on the guitar. The results, presented in this research note, confirm the findings of previous research and suggest that the motor preparation of experts is more efficient than that of novices. Cortical activity in music students could therefore, if tracked longitudinally, provide an objective marker of musical skill learning and be used to inform music learning, teaching and assessment practices.

KEY WORDS: Electroencephalography, movement-related cortical potential, motor skills, skill learning, guitar

Motor skill learning is a process that leads to a change, usually an improvement, and normally relatively permanent, in the learner's ability to perform the skill (Schmidt & Lee, 2011). Certain aspects of playing a musical instrument involve the acquisition of motor skills, and it is clear that repetitive practice of these skills, together with the constant monitoring and correction of errors, is likely to bring about improved performance. Further research is needed, however, to ascertain what processes occur in the brain to bring about this improvement in performance.

Experienced musicians have spent many years learning to perform complex motor skills

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(Munte, Altenmueller, & Jancke, 2002). Such individuals therefore provide an ideal participant group for researchers wishing to study both structural and functional adaptations in the human brain resulting from the long-term practice of motor skills. Indeed, many studies have indicated that the brains of experienced musicians are structurally and functionally different to the brains of non-musicians. For example, both Krings et al. (2000) and Jancke, Shah, and Peters (2000) used functional magnetic resonance imaging (fMRI) to compare activity in the brains of experienced pianists and non-musicians as they carried out simple uni-manual and bi-manual finger tapping movements. Both studies reported that the experienced pianists exhibited reduced activity, compared to the non-musicians, in various movement-related brain areas including the motor cortex, the supplementary motor area and the pre-supplementary motor areas. Additionally, in similar studies, reduced activity has also been reported in experienced pianists and keyboard players as compared to non-musicians, in the cerebellum (Haslinger et al., 2004; Koeneke, Lutz, Wustenberg, & Jancke, 2004) and right basal ganglia (Haslinger et al., 2004). Findings such as these support the notion put forward by Krings et al. (2000) that long-term practice of musical skills results in fewer neurons being required to be active in the brains of experienced musicians when they perform.

We used electroencephalography (EEG) to study cortical activity during preparation for movement in experienced and novice guitarists. This technique involves recording the electrical activity generated by the brain from electrodes attached to the scalp (Ward, 2006). In the final seconds prior to a voluntary movement, such as playing a simple musical sequence, there is an increase in the negativity of the low frequency EEG signal (e.g., Kristeva, 1984). This increasing negativity, called the movement-related cortical potential (MRCP), is shown schematically in Figure 1. The MRCP occurs just before voluntary, self-paced movement, distinguishing it from the contingent negative variation (CNV) that is evoked between a warning stimulus and an imperative stimulus in reactive movement tasks. As the MRCP occurs prior to the onset of a voluntary movement, it may reflect the cortical activity involved in movement planning and preparation (Shibasaki & Hallett, 2006). Furthermore, the MRCP is known to vary depending on the physical and psychological characteristics of the movement about to be performed (Birbaumer, Elbert, Canavan, & Rockstroh, 1990). The MRCP may therefore offer an objective marker of human motor performance that could potentially be used to discriminate between different performances (and thereby different levels of ability). The MRCP could also be used for the assessment of skill learning, were this to be tracked longitudinally.

Shibasaki, Barrett, Halliday, and Halliday (1980) named the pre-movement components of the MRCP thought to be involved in movement preparation as follows: the Bereitschaftspotential (BP or readiness potential), the negative slope (NS) and the motor potential (MP). The BP is identified by an initial increase in the EEG negativity that occurs about 1500-2000 ms prior to voluntary movement. It is generated in the supplementary motor area, is widely distributed across the scalp, and is of maximal amplitude at centro-parietal locations (Shibasaki & Hallett, 2006). The NS is identified by negativity with a steeper gradient that occurs approximately 500 ms before the onset of movement and is localised to the primary motor cortex and lateral pre-motor cortex (Shibasaki & Hallett, 2006). Finally, the MP is identified by the negative peak occurring immediately prior to movement onset, and is localised to the contralateral primary motor and sensorimotor cortices (Toma & Hallett, 2003). It has been proposed (e.g., Di Russo, Pitzalis, Aprile, & Spinelli, 2005) that the amplitude and onset times of these components may provide an indication as to the level of effort involved in movement preparation. Cross-sectional research from sports sciences has indicated that, in comparison with novice performers, expert performers exhibit pre-movement MRCP components of smaller amplitude, which begin closer to movement onset (e.g., Di Russo et al., 2005; Fattapposta et al., 1996; Hatta, Nishihira, Higashiura, Kim, & Kaneda, 2009; Kita, Mori, & Nara, 2001). These differences have typically been attributed to the long-term training undertaken by experts, and may indicate that the level of effort required for movement preparation is reduced following a period of motor skill learning. In this article, we present preliminary data from our laboratory that indicates reduced cortical activity, similar to that shown in previous research, in experienced guitarists compared to novices when preparing to perform a simple scale on the guitar.

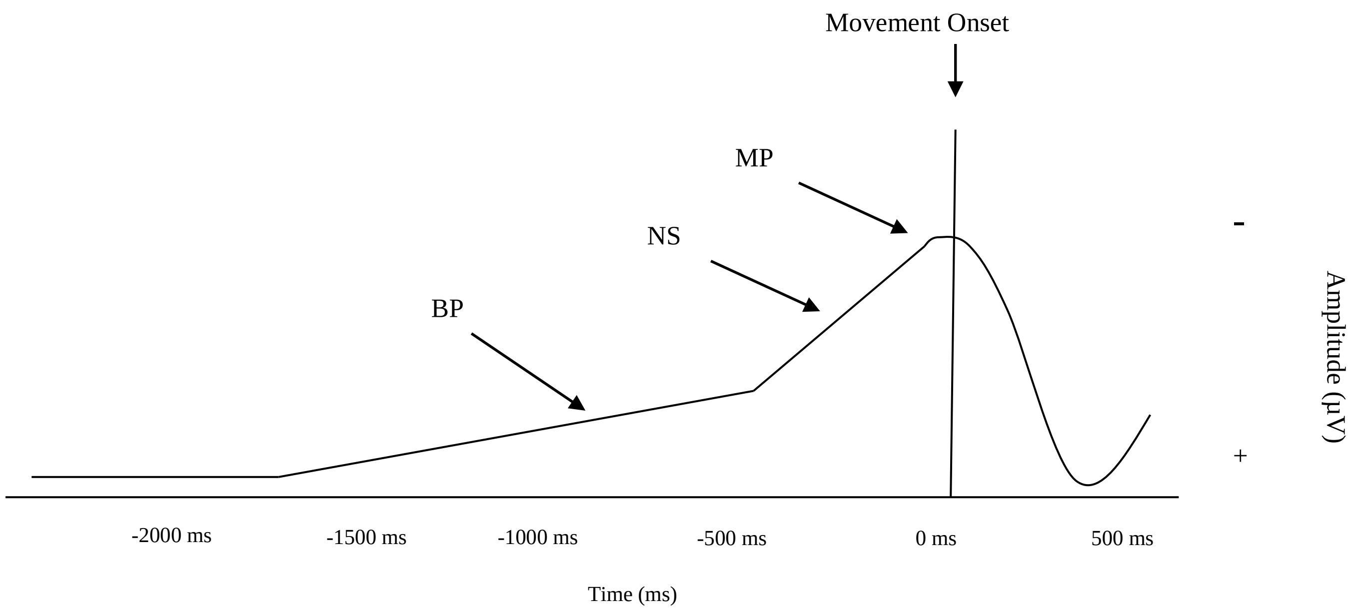

Figure 1. A schematic representation of the movement-related cortical potential (MRCP). On the horizontal axis Time 0 ms indicates the point of movement onset. The pre-movement components, termed the Bereitschaftspotential (BP), the negative slope (NS) and the motor potential (MP), are thought to reflect the cortical activity involved in planning and preparing to perform voluntary movement. The amplitude and onset time of these components may reflect the level of effort involved in movement preparation.

METHOD

Participants

Ten experienced male guitar players (mean age 36.5 years ± 13.73) and ten novice guitarists (5 male, 5 female; mean age 24.1 years ± 6.57) participated in this study. The experienced guitarists had an average of 18.8 years (± 11.23) experience of playing the guitar, whilst the novices had no prior experience of playing the guitar or any other musical instrument. All participants were right handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). All participants gave their written informed consent to take part in the study, which had been granted ethical approval by the host university's departmental ethics committee.

Procedure

During a single testing session, participants performed 100 repetitions of the first seven notes of the G Major scale on a Yamaha Pacifica 112 V electric guitar. During their performance, the participants were instructed to attempt to keep their playing in time with a metronome, set at 100 bpm. Cortical activity was recorded continuously throughout this time, using electroencephalography, from four electrodes placed over areas of the supplementary motor area and motor cortex (FCz, C3, Cz, C4), according to the 10% system of electrode placement (Nuwer et al., 1998). To reduce the number of artefacts in the EEG recording, the participants were asked to try to avoid blinking immediately prior to and during the performance, and to refrain from tapping their feet or nodding their head in time with the metronome.

The EEG recording was carried out using a NeuroScan Synamps amplifier and Scan 4.3 software (Compumedics Neuroscan, Charlotte, NC, USA), with a gain of 1000, an A/D sampling rate of 1000 Hz, and a bandpass filter of 0 – 30 Hz. Horizontal and vertical eye-movements were monitored using electro-oculography (EOG), recorded with a 0.15 – 30 Hz bandpass. Any trials containing eye-movement artefacts were rejected from the recording before analysis. Electrodes were referenced to linked mastoids and a ground electrode was placed on the forehead. Electrode impedances were kept homogenous at or below 5kΩ. After the testing session, the recording was filtered offline (0 – 5 Hz) to remove the higher frequency components from the recording. The filtered data were then split into individual epochs of 3 seconds around the movement onset marker (2500 ms prior to movement onset to 500 ms post movement onset). Finally, the epochs were averaged to produce the MRCP.

Movement onset was measured by a thin electrode placed on the neck of the guitar, underneath the strings, at the third fret. When the bottom E string was pressed to play the first note of the scale, the string made contact with this electrode and sent a digital marker on to the EEG recording to identify the first meaningful movement on the EEG trace.

For the purpose of statistical analysis, the microvolt amplitude values were converted into *z*-scores, referenced to a baseline period of -2500 to -2000 ms, so as to normalise the data and remove any variability in participants' baseline values. The amplitude and onset time values for the BP, NS and MP at each electrode site were then averaged together to provide a mean amplitude or onset time value. These data were then analysed using independent samples *t*-tests.

RESULTS

Figure 2 shows the grand average MRCP of the experienced and novice guitarists recorded from electrode sites FCz, C3, Cz and C4. In both groups, the initial rise of the BP started approximately 2000 ms prior to movement onset. The amplitude of the BP was similar for the two groups. The amplitudes of the NS and MP, however, were much larger for the novices than the experienced guitarists and the NS also appeared to start closer to movement onset for the experienced players.

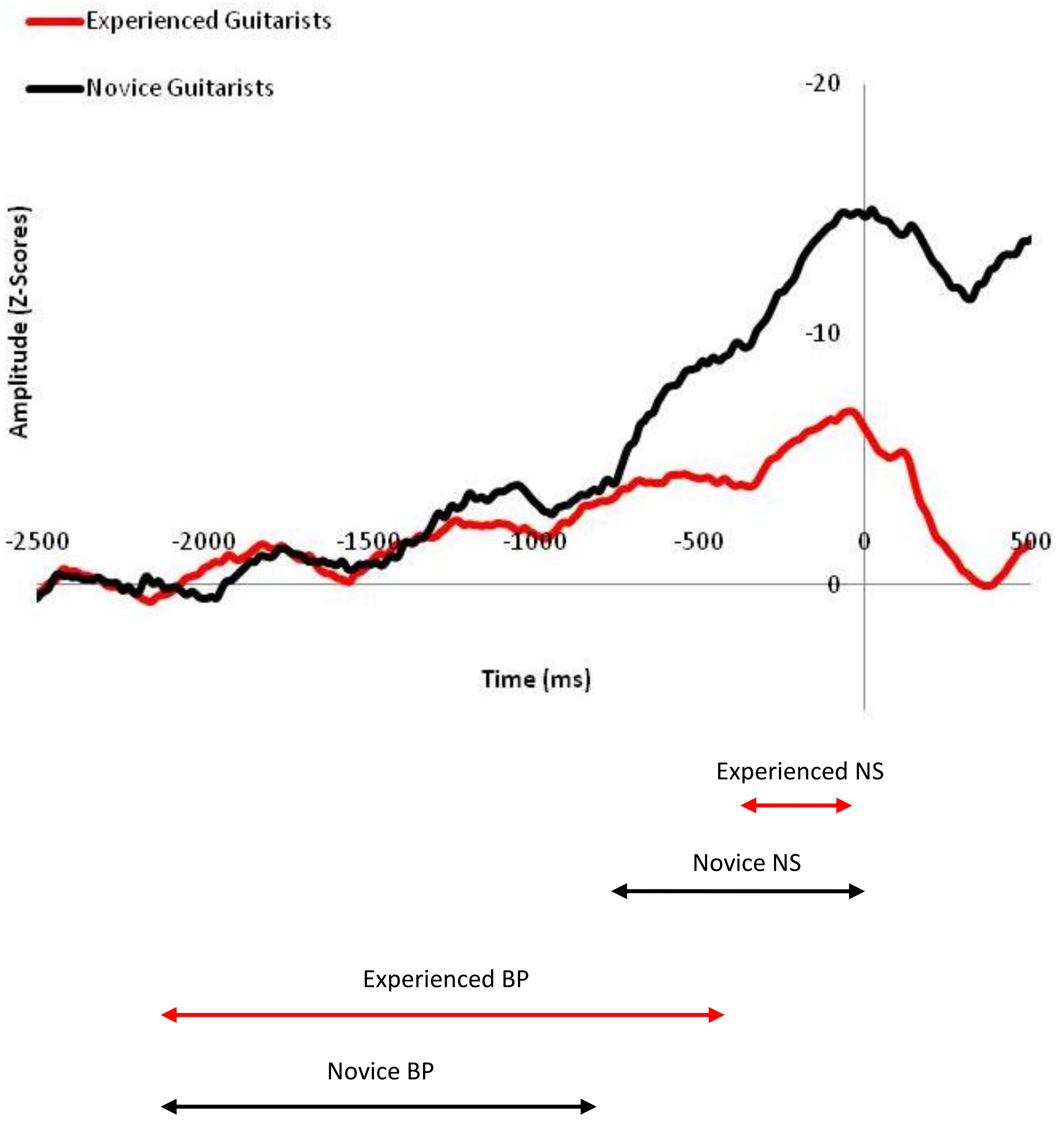

Figure 2. The grand average MRCP of the experienced and novice guitarists, recorded from electrode sites FCz, C3, Cz and C4. The BP component was of similar amplitude in both groups of participants and began at around 2 seconds prior to movement onset (Time 0 ms). Both the NS and MP were of smaller amplitude in the experienced guitarists, and the NS also began later, compared to the novices. This may indicate that for the experienced guitarists less effort was required for movement preparation.

Bereitschaftspotential

The mean *z*-score amplitude of the BP was -2.34 (± 2.29) for the experienced guitarists compared to -2.44 (± 1.72) for the novices. An independent samples *t*-test yielded no significant difference in BP amplitude between the groups (t = .11, df = 18, p = .92). The mean onset time of the BP was -1917 ms (± 195) for the experienced guitarists, not significantly earlier than the mean onset time of -1779 ms (± 240) for the novice group (t = 1.41, df = 18, p = .18).

Negative Slope

The mean *z*-score amplitude of the NS was -5.41 (± 4.66) for the experienced guitarists, significantly smaller than the mean *z*-score amplitude of the NS of -10.45 (± 5.02) for the novice guitarists (t = 2.33, df = 18, p = .03). The mean onset time of the NS was -462 ms (± 157) for the experienced guitarists, significantly later (closer to movement onset) than the mean onset time of the NS of -721 ms (± 210) for the novices (t = 3.13, df = 18, p = .006).

Motor Potential

The mean *z*-score amplitude of the MP, taken at the negative peak immediately prior to movement onset, was -7.48 (± 4.73) for the experienced guitarists, significantly smaller than the mean *z*-score amplitude of the MP of -16.17 (± 6.87) for the novices (t = 3.3, df = 18, p = .004).

DISCUSSION

The amplitudes of the negative slope and motor potential components of the MRCP were smaller for experienced guitarists, compared to novices, prior to playing a simple scale on the guitar. Additionally, the NS component began closer to movement onset for the experienced guitarists compared to the novices. The NS and MP are generated within the primary motor cortex, the pre-motor cortex and the sensorimotor cortices, and so the results are likely to reflect reduced activity within these areas of the brain for the experienced guitarists compared to the novices. These results therefore indicate that the experienced performers were able to devote fewer cortical resources to planning and preparing to play the scale than were the novices. In short, their motor preparation was more efficient. Long-term training may bring about a process of long-term potentiation in the brain, resulting in an increase in synaptic strength and enhanced communication between neurons (Martinez & Derrick, 1996), possibly narrowing the amplitude of the experienced guitarists' MRCP. We could also speculate that this reduced activity in motor preparation may 'free up' neurons, allowing the performer to devote more cortical activity to other aspects of performance that could be described as more advanced, relating to creativity, artistic expressivity, or improvisation (Gruber, Jansen, Marienhagen, & Altenmueller, 2010).

Overall, these findings are consistent with previous research reporting differences in the MRCP between elite and novice athletes (e.g., Di Russo et al., 2005; Fattapposta et al., 1996; Hatta et al., 2009; Kita et al., 2001) and with fMRI research, which has indicated reduced activity in a variety of cortical motor areas in musicians, compared to non-musicians

(Haslinger et al., 2004; Jancke et al., 2000; Koeneke et al., 2004; Krings et al., 2000). The present study represents an advance on the previous literature in that the EEG recordings were obtained while participants performed an ecologically valid motor skill. In the past cortical activity has been recorded while participants undertook simple motor tasks, and the findings were then extrapolated to more complex motor skills. For example, cortical activity associated with playing the piano was inferred from fMRI studies in which participants tapped with their fingers. Similarly, sports science studies investigated trigger pulling in shooting sports by requiring participants to carry out simpler actions such as pressing a button. The rationale for this approach is that simple movements require the performance of motor actions similar to those used in more complex activities such as music-making and sport. We have provided a valuable addition to the literature on the cortical processes involved in motor skill learning by recording the MRCP while participants demonstrated an ecologically valid motor skill, namely a scale-playing task, undertaken regularly by guitar players.

This finding has potential implications for both learning and teaching the guitar and for assessing the learning of musical skills. Assessment of musical performance is often measured subjectively by just one individual, who attempts to balance and synthesize multiple aspects of the performance, before ranking or providing a judgment as to the quality of the performance (McPherson & Thompson, 1998). McPherson and Thompson explain that this method of assessment is flawed as assessor biases often influence the results, and reliability between assessors (when more than one is used) is sometimes low. More objective markers of changes in skill are therefore warranted. Based on the preliminary findings presented here, we suggest that by using neuroscientific techniques it may be possible to provide objective markers of musical skill learning that could be used in addition to subjective performance assessments to give a more valid overall assessment. Future research is planned in our laboratory to establish whether a reduction in the MRCP amplitude can be observed when novice guitar players have undergone a period of intensive training. If this is the case, we believe that it may be possible to use changes in the MRCP as an objective marker of music skill learning. For example, musical assessors could collaborate with researchers in psychophysiology and plot changes in the MRCP amplitude and onset times over a learning period of weeks or months. A reduced amplitude or earlier-onset MRCP at the end of the learning period compared to the start could provide a marker or indication that some instrument-specific learning had occurred, resulting in reduced effort when preparing for the physical and psychological elements of the musical performance. It would not, of course, be possible to infer solely from a reduction in MRCP amplitude that the standard of performance was higher. Changes in performance would still need to be measured alongside any changes in the EEG signal in order to provide a more complete picture of the learning process. Interestingly, however, research from sports sciences using EEG has shown distinguishable alpha power activity reflecting high and low scoring shots in air-pistol shooting (Loze, Collins, & Holmes, 2001). It may therefore be possible for future research to study trial-by-trial changes in alpha activity during musical performance and attempt to identify similar psychophysiological markers of musical performances deemed to be of high and low quality.

Additionally, it could be possible to plot changes in the MRCP associated with different types of musical training. Research is planned in our laboratory to compare changes in the

MRCP associated with different learning techniques. For example, we plan to compare observational learning or modelling techniques, where a student learns by observing and repeating the actions of an instructor, with discovery learning techniques, where a student learns a musical piece by him- or herself through a process of trial and error. If one technique were found to produce greater changes in the MRCP, or bring about such changes more quickly than the other technique, this could inform learning and teaching practices, and potentially indicate the most beneficial teaching practices for bringing about changes at a cortical level. Whilst it is recognised that the bi-manual nature of guitar playing is a complex skill, our initial work has produced some significant findings. To complement this work, it is suggested that future studies could explore these training study proposals with a focus on a uni-manual musical skill – for example, separate hand activities related to a piano keyboard.

The music-related research in this area is at an early stage. Nevertheless, we would encourage other laboratories to replicate our findings and explore other musical skills to see if the phenomenon we have reported generalizes across instruments and for different types of musical activity.

ACKNOWLEDGEMENTS: The authors would like to thank two anonymous reviewers and the editors for their helpful and constructive comments to improve an earlier version of this paper.

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