


Our reference: HUMOV 1380

P-authorquery-v8

AUTHOR QUERY FORM

	Journal: HUMOV Article Number: 1380	Please e-mail or fax your responses and any corrections to: E-mail: corrections.esch@elsevier.sps.co.in Fax: +31 2048 52799
---	--	---

Dear Author,

Please check your proof carefully and mark all corrections at the appropriate place in the proof (e.g., by using on-screen annotation in the PDF file) or compile them in a separate list. To ensure fast publication of your paper please return your corrections within 48 hours.

For correction or revision of any artwork, please consult <http://www.elsevier.com/artworkinstructions>.


Any queries or remarks that have arisen during the processing of your manuscript are listed below and highlighted by flags in the proof. Click on the 'Q' link to go to the location in the proof.

Location in article	Query / Remark: click on the Q link to go Please insert your reply or correction at the corresponding line in the proof
<u>Q1</u>	As per journal requirements, PSYCINFO is mandatory. Please provide the same.
<u>Q2</u>	Ref. "Helsinki (2008)" is cited in the text but not provided in the reference list. Please provide it in the reference list or delete this citation from the text.

Thank you for your assistance.

Highlights

► Cortical activity recorded from experts and non-musicians during guitar playing. ► No main effect for Bereitschaftspotential amplitude or onset between groups. ► Negative slope and motor potential components smaller and began later in experts. ► May indicate reduced activity is required during motor preparation by experts. ► Training likely to contribute to this more efficient motor preparation.





ELSEVIER

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov



Differences in cortical activity related to motor planning between experienced guitarists and non-musicians during guitar playing

David J. Wright^{a,*}, Paul S. Holmes^a, Francesco Di Russo^{b,c}, Michela Loporto^a, Dave Smith^a

^aInstitute for Performance Research, Manchester Metropolitan University, UK

^bDept. of Education Sciences for Motor Activity and Sport, University of Rome "Foro Italico", Rome, Italy

^cNeuropsychology Center, Santa Lucia Foundation, IRCCS, Rome, Italy

ARTICLE INFO

Article history:

Available online xxxxx

Keywords:

Electroencephalography
Movement-related cortical potential
Motor skill learning
Ecological validity
Guitar

ABSTRACT

The influence of motor skill learning on movement-related brain activity was investigated using electroencephalography. Previous research has indicated that experienced performers display movement-related cortical potentials (MRCPs) of smaller amplitude and later onset compared to novice participants. Unfortunately, previous studies have lacked ecological validity with experimenters recording the MRCP prior to simple motor tasks and applying the results to more complex motor skills. This study replicated previous research using an ecologically valid motor skill; recording the MRCP from a group of experienced guitarists and a control group of non-musicians whilst they played a simple scale on the guitar. Results indicated no difference between groups in early motor planning. In contrast, the later, negative slope and motor potential components were of smaller amplitude and the negative slope began later in the experienced guitarists. The data may indicate that, for experienced guitarists, a reduced level of effort is required during the motor preparation phase of the task. These findings have implications for musical instrument learning as well as motor skill acquisition in general.

© 2011 Elsevier B.V. All rights reserved.

Q1



* Corresponding author. Address: Institute for Performance Research, Manchester Metropolitan University, Crewe Green Road, Crewe CW1 5DU, UK. Tel.: +44 161 247 5724.

E-mail address: d.j.wright@mmu.ac.uk (D.J. Wright).

1. Introduction

Performance of most motor skills can be improved by accurate, long-term practice. What occurs within the brain to reflect this improved performance is less clear. Electroencephalography (EEG) can be used to examine movement-related cortical activity with high temporal resolution (Luck, 2005) and, as such, is a suitable technique for investigating changes in cortical activity that may be associated with motor skill learning and performance.

In the final seconds prior to voluntary movement production there is an increase in electrical activity in the motor areas of the brain, known as the movement-related cortical potential (MRCP). One component of the MRCP, the Bereitschaftspotential (BP), is a slowly rising negativity that occurs 1–2 s prior to movement onset (Kornhuber & Deecke, 1965; for a review see Shibasaki & Hallett, 2006). The BP is followed by a steeper gradient negativity, the negative slope (NS'), which occurs at 400–500 ms prior to movement onset (Shibasaki, Barrett, Halliday, & Halliday, 1980). These components are followed by the motor potential (MP), the peak negativity occurring concomitantly to movement onset in contralateral central sites. Both the amplitude and onset times of these components vary depending on the physical and psychological characteristics of the forthcoming movement (Birbaumer, Elbert, Canavan, & Rockstroh, 1990). As such, the MRCP may reflect the cortical activity involved in planning and preparing to perform voluntary movements (Shibasaki & Hallett, 2006). A schematic representation of the pre-movement components of the MRCP is displayed in Fig. 1.

Several studies have investigated differences in the MRCP amplitude and onset times between expert and novice performers to aid our understanding of learning-related changes in brain functioning (e.g., Di Russo, Pitzalis, Aprile, & Spinelli, 2005; Fattapposta et al., 1996; Hatta, Nishihira, Higashiura, Kim, & Kaneda, 2009; Kita, Mori, & Nara, 2001). The main findings from these studies are that expert performers show smaller amplitude and later onset MRCPs than their novice counterparts, prior to task performance. This has been shown in groups of expert and novice clay target (Di Russo, Pitzalis et al., 2005) and pistol shooters (Fattapposta et al., 1996), as well as in elite and novice kendo martial art performers (Hatta et al., 2009; Kita et al., 2001). These authors have generally concluded that experienced performers are able to plan and perform the task with reduced cortical activity compared to novices, attributing these differences to long-term training by the expert group. This body of research is supported by several studies that have used functional magnetic resonance imaging (fMRI) to study skill-related differences in cortical activity in expert and novice musicians. For example, several researchers have reported that expert pianists exhibit reduced activity compared to novices in a variety of movement-related cortical areas when performing actions similar to those used to play the piano (e.g., Haslinger et al., 2004; Jancke,

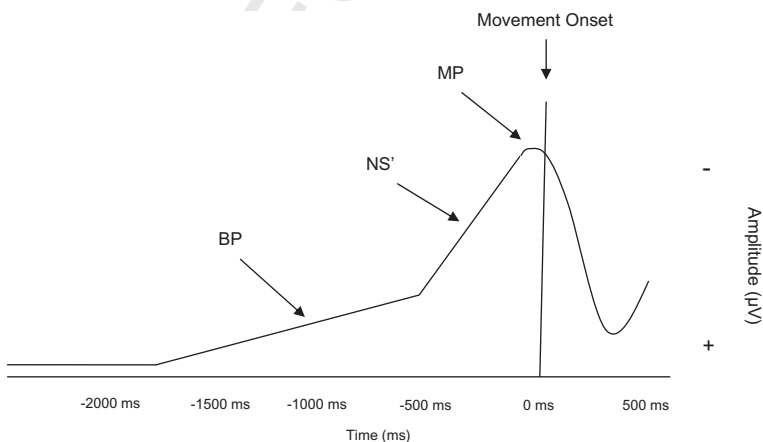


Fig. 1. A schematic representation of the movement-related cortical potential (MRCP). Time 0 ms on the horizontal axis indicates the point of movement onset. The pre-movement components, termed the Bereitschaftspotential (BP), the negative slope (NS') and the motor potential (MP) are thought to reflect the cortical activity involved in planning and preparing to perform voluntary movement.

78 Shah, & Peters, 2000; Koeneke, Lutz, Wustenberg, & Jancke, 2004; Krings et al., 2000). Krings et al. sug-
79 gested that this finding may indicate that following long-term practice in a skill, experienced performers
80 require fewer neurons to be active to plan and perform that skill.

81 Whilst these studies have provided a useful insight into learning-related changes in motor cortex
82 activity, they have tended to employ simple, laboratory-based tasks and applied the results to more
83 complex motor skills. This approach lacks ecological validity as the movement tasks used are far re-
84 moved from the skill being investigated. For example, simple button pressing was used to investigate
85 clay target shooting (Di Russo, Pitzalis et al., 2005) and pistol shooting (Fattapposta et al., 1996), simple
86 finger tapping was used to study piano or keyboard playing (Haslinger et al., 2004; Jancke et al., 2000;
87 Koeneke et al., 2004; Krings et al., 2000), and simple wrist flexion (Kita et al., 2001) and hand-gripping
88 tasks (Hatta et al., 2009) have been used to study kendo. By focusing only on the mechanical actions
89 required to perform a skill, cortical activity involved in other aspects of the skill is not accounted
90 for. Therefore, there is a need to assess differences in the MRCP of expert and novice performers using
91 more ecologically valid motor skills (Nakata, Yoshie, Miura, & Kudo, 2010; Wright, Holmes, & Smith,
92 2011). Ideally, this would be achieved by measuring cortical activity during performance of the skill
93 being investigated, rather than during performance of a task similar to the skill being investigated.
94 For example, if a study were investigating pistol or rifle shooting, then recording the EEG during shoot-
95 ing performance may be more suitable than recording the EEG using a simple button press task. Sim-
96 ilarly, if a study were investigating piano playing, then measuring cortical activity during a piano
97 playing task may provide more meaningful results than recording cortical activity during a simple fin-
98 ger tapping action. Recently, Kristeva, Chakarov, Schulte-Monting, and Spreer (2003) recorded the
99 MRCP from a group of professional violin players prior to both imagery and physical performance of
100 a short musical sequence on the violin. This indicates that it is possible to record the MRCP prior to eco-
101 logically valid motor skills; however, to date, no research has done so in the context of skill learning.

102 This study aimed to address this gap in the literature by comparing MRCP differences in experi-
103 enced guitarists and non-musicians using an ecologically valid guitar-playing task. Based on the pre-
104 viously mentioned literature, we predicted that the experienced guitarists would require less cortical
105 activity to plan and control their hand movements when playing the guitar, compared to the non-
106 musicians. Therefore, we expected that the experienced guitarists may require fewer neurons to be
107 active during motor preparation, and so we hypothesised that the experienced guitarists would exhi-
108 bit smaller amplitude MRCPs that would begin closer to movement onset than the non-musicians,
109 prior to playing a simple scale on the guitar.

110 2. Methods

111 2.1. Participants

112 Ten male, experienced guitar players (mean age 36.5 yrs. \pm 13.73) and ten non-musicians (5 male, 5
113 female; mean age 24.1 yrs. \pm 6.57) participated in the study. The experienced guitarists had between 8
114 and 40 years (mean 18.8 yrs. \pm 11.23) of guitar playing experience. They all stated that the guitar was
115 their main instrument and reported that they spent approximately 12.8 (\pm 7.35) hours per week prac-
116 ticing the guitar. The majority of the experienced guitarists played the electric guitar as their primary
117 instrument, although one was an acoustic guitarist. Although not professional musicians, all guitarists
118 had received some form of formal tuition on the guitar, and many of them had experience of playing
119 several other musical instruments. The non-musicians had no prior experience of playing the guitar or
120 any other musical instrument. All participants were right-handed, as assessed by the Edinburgh Hand-
121 edness Inventory (Oldfield, 1971). All participants gave their written informed consent to take part in
122 the study which was conducted in accordance with the Declaration of Helsinki (2008). The experi-
123 mental procedures were granted ethical approval by the local institutional ethics committee.

124 2.2. Electrophysiological recording

125 Electroencephalography (EEG) was recorded continuously throughout the testing session from six,
126 6 mm diameter, silver/silver-chloride electrodes positioned over the motor cortex according to the

127 International 10-10 system of electrode placement (Nuwer et al., 1998). Electrodes were placed at
 128 sites overlying the hand representations of the left (FC3 & C3) and right (FC4 & C4) motor cortex, as
 129 well as over the supplementary motor area (FCz & Cz). The electro-oculogram (EOG) was also recorded
 130 from below and adjacent to the left eye to monitor both vertical (VEOG) and horizontal (HEOG) eye
 131 movements. All electrodes were referenced to linked mastoids and a ground electrode was placed
 132 at Fpz. Prior to electrode attachment the recording sites were gently abraded with NuPrep skin prepa-
 133 ration paste (DO Weaver, Aurora, CO, USA). Electrodes were then attached to the scalp using Ten20
 134 conductive EEG paste (DO Weaver, Aurora, CO, USA). Electrode impedances were kept homogenous at,
 135 or below, 5 k Ω throughout the experiment. Testing commenced 45 minutes after the electrodes were
 136 attached to the scalp to minimise signal drift. After this time, the electrode impedances were re-
 137 checked to confirm that the impedance values remained below 5 k Ω . The EEG and EOG were recorded
 138 using a NeuroScan Synamps amplifier and Scan 4.3 software (Compumedics Neuroscan, Charlotte, NC,
 139 USA) with a gain of 1000 and an A/D sampling rate of 1000 Hz. The bandpass filter for the cortical
 140 channels was set at 0–30 Hz, whilst the bandpass filter for the EOG channels was set at 0.15–30 Hz.

141 **2.3. Task description**

142 Participants were required to perform 100 repetitions of the first seven notes of the G Major scale
 143 (see Fig. 2) on a Yamaha Pacifica 112 V electric guitar. The participants were seated and instructed to
 144 play in time with a metronome set at 100 beats per minute (bpm). The G Major scale played at
 145 100 bpm was chosen on the recommendation of an assessor from the 'Rockschool' rock and pop music
 146 examination board. The G Major scale played at this tempo is a 'Rockschool' Grade 2 guitar assessment
 147 piece (Rockschool, 2008). After consultation with the assessor, it was expected that this task would be
 148 easy for the experienced guitarists to play, whilst still being achievable for the non-musicians with
 149 some practice. The metronome ran continuously throughout the experiment and participants were
 150 free to initiate each performance of the scale at their own choosing. They were, however, instructed
 151 to leave approximately ten seconds in between each repetition of the scale. As the non-musician group
 152 had not previously played the scale, they were provided with 15 minutes of instruction on how to play
 153 the scale prior to the testing session. To reduce the number of artefacts in the EEG recording, partic-
 154 ipants were asked to keep as still as possible and to refrain from tapping their feet or nodding their
 155 head in time with the metronome. Similarly, they were also instructed to try to avoid blinking immedi-
 156 ately prior to and during performance of the task.

157 Following the 100 repetitions, the guitar was connected to an Apple Mac Mini computer (Apple,
 158 Cupertino, CA, USA) and participants performed a further 20 repetitions of the scale in time with
 159 the metronome whilst guitar performance was recorded using Logic Express version 9 software (Ap-
 160 ple, Cupertino, CA, USA). This allowed each participant's performance to be assessed offline. It was not
 161 possible to have concurrent EEG recording as connecting the guitar to the computer introduced too
 162 much electrical interference into the EEG trace. Task performance was measured by ability to play
 163 at the correct tempo and variability in performance.



Fig. 2. The G Major scale as played on the guitar, displayed in both the treble clef and tab format. Participants played the first 7 notes, highlighted within the black box, at a tempo of 100 beats per minute. In tab format, the horizontal lines represent each of the six strings on the guitar. The bottom line represents the bottom E string (the thickest string) and the top line represents the top E string (the thinnest string). The numbers depict which fret the string should be pressed down at to successfully play the note.

Please cite this article in press as: Wright, D. J., et al. Differences in cortical activity related to motor planning between experienced guitarists and non-musicians during guitar playing. *Human Movement Science* (2011), doi:10.1016/j.humov.2011.07.001

164 2.4. Data analysis

165 The EEG trials were averaged with reference to movement onset. This was recorded by a thin elec-
166 trode that was attached to the neck of the guitar, underneath the strings on the 3rd fret and plugged
167 into a 'movement onset' electrode channel in the EEG amplifier. When the bottom E string was pressed
168 down at the 3rd fret to play the first note of the scale, the string made contact with the electrode, caus-
169 ing a sharp deflection to occur on the 'movement onset' channel in the EEG trace. Digital markers were
170 inserted in the EEG recording at the points where the sharp deflection caused by the first note being
171 played exceeded 50 μV in amplitude. An offline computerised eye-movement rejection was then run
172 on the raw data to remove any segments of the EEG that contained artefacts in excess of 50 μV
173 in either the VEOG or HEOG channels. On average 15 trials per participant were rejected from the
174 non-musician group and 19 trials per participant were rejected from the experienced guitarist group
175 as they contained eye-movement artefacts. Following the automated EOG rejection, the data was visu-
176 ally scanned and any additional artefacts in the recording were removed. Movement artefacts were
177 very rare as only the pre-movement components of the EEG were analysed. Using Scan 4.3 software,
178 the EEG recording was then filtered offline with a 0–5 Hz bandpass to remove the higher frequency
179 signals. Following this the EEG was split into epochs of 3 seconds around the movement onset marker
180 (2500 ms prior to and 500 ms after movement onset). The epochs were then averaged together to pro-
181 duce the MRCP. Prior to analysis the microvolt values were converted into z-scores, referenced to a
182 baseline period from -2500 ms to -2000 ms. The purpose of this was to normalise the data and re-
183 move any variability in the baseline data between participants.

184 For statistical analysis the mean amplitudes and onset times of the BP and NS', together with the
185 peak amplitude of the MP were extracted from the averaged EEG prior to movement onset at electrode
186 sites FCz, Cz, C3 and C4. MRCPs were not present in all participants at FC3 and FC4 and so these sites
187 were not included in the analysis. The BP amplitude was taken as the mean amplitude from the point
188 of BP onset to the point of NS' onset, and the NS' amplitude was taken as the mean amplitude from the
189 point of NS' onset to the MP peak. The MP was taken as the maximum negative peak immediately prior
190 to movement onset. The BP and NS' onset times were established by visual inspection by the first
191 author. Using Scan 4.3 software, it was possible to place a cursor marker at the points of BP and NS'
192 onset and obtain an exact millisecond value at each cursor placement. These onset times were then
193 subsequently confirmed independently, and under blind conditions by the fourth author using the
194 same procedure. Statistical analysis was performed using the SPSS for Windows 15.0 statistical pack-
195 age. The onset times of the BP and NS' and the mean amplitudes of the BP, NS' and MP components
196 were submitted to separate 2 group (guitarists, non-musicians) \times 4 electrode (FCz, C3, Cz, C4) inde-
197 pendent measures analysis of variance (ANOVA). Bonferroni's post-hoc analysis was used to interpret
198 main effects, whilst the Tukey post-hoc analysis was used to interpret interaction effects.

199 Ability to play at the correct tempo was measured using Logic Express software. By measuring
200 the millisecond timing error between the beat of the metronome and the notes being played, it
201 was possible to establish synchronicity with the metronome. Variability in performance was
202 calculated using intra-individual coefficients of variation for each participant. This was done by
203 dividing the standard deviation of the performance timing errors by the mean performance timing
204 errors. These two performance measures were then submitted to the appropriate parametric or
205 non-parametric test. All significant effects were reported at an alpha level of .05 and adjusted
206 where necessary.

207 **3. Results**

208 3.1. Electrophysiological data

209 A clear MRCP, in which the BP, NS' and MP components were evident was found in both groups,
210 peaking at electrode site Cz. MRCP components were slightly larger on left, compared to right
211 hemisphere electrodes, confirming the contralateral topography of these components (relative to
212 the participants handedness). Waveforms of the MRCP recorded from both groups at all electrode sites

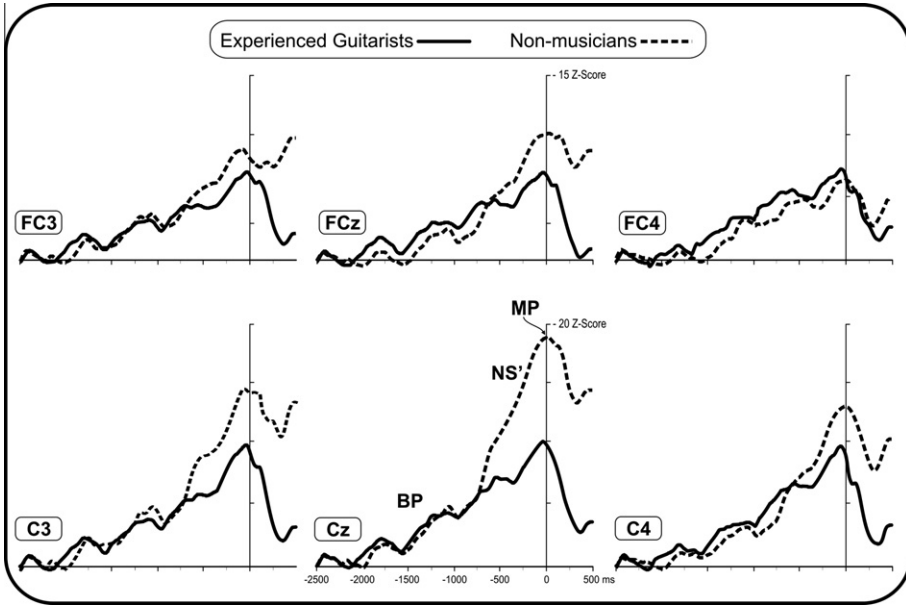


Fig. 3. Movement-related cortical potential (MRCP) waveforms, recorded from the motor cortex, for experienced guitarists (black) and non-musicians (red), whilst performing the G Major scale on the guitar at a tempo of 100 beats per minute.

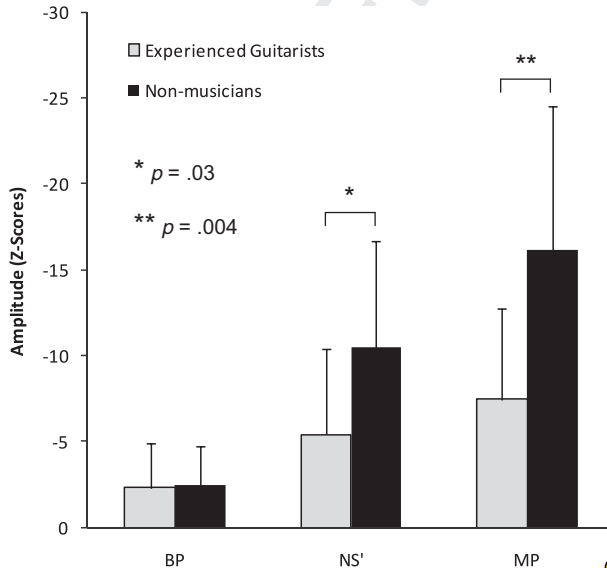


Fig. 4. Mean amplitude values of the BP, NS' and MP components of the MRCP for experienced (grey) and novice (black) guitarists. Data was recorded from electrode sites FCz, Cz, C3 and C4, prior to performance of the G Major scale on the guitar. Significant differences between the groups are indicated by stars (*).

Table 1

Mean (\pm SD) onset times (ms) for BP and NS' components of the MRCP in experienced and novice guitarists, together with p values from the ANOVA analysis. A separate ANOVA was conducted for each component of the MRCP.

	Experienced guitarists	Novice guitarists	Significance
BP Onset (ms)	-1917 (\pm 226)	-1794 (\pm 281)	$p = .22$
NS' Onset (ms)	-462 (\pm 168)	-721 (\pm 209)	$p = .006$

215 3.1.1. *Bereitschaftspotential (BP)*

216 The BP initiated around 1900 ms prior movement onset and was of similar amplitude in both
 217 groups until around -700 ms, when the waveform became more negative in the non-musicians.
 218 The onset times of the BP component in both groups are shown in Table 1. The ANOVA for BP onset
 219 time revealed no significant differences between groups, $F(1, 18) = 1.63, p = .22$, or between electrodes,
 220 $F(2.4, 43.1) = 0.82, p = .46$. However, there was a significant group \times electrode interaction effect for BP
 221 onset, $F(2.4, 43.1) = 3.77, p = .02$. Tukey's HSD post-hoc analysis indicated that the BP onset at Cz and
 222 C4 occurred later in the non-musicians than in the experienced guitarists.

223 The amplitude of the BP was taken as the mean amplitude from the point of BP onset to the point of
 224 NS' onset. The mean z-score BP amplitude in the experienced guitarist group was $-2.34 (\pm 2.56)$ com-
 225 pared to $-2.44 (\pm 2.29)$ in the non-musicians. The ANOVA revealed no significant difference in terms of
 226 BP amplitude between groups, $F(1, 18) = 0.01, p = .92$, or between electrodes, $F(3, 54) = 2.64, p = .06$.
 227 Similarly, there was no Group \times Electrode interaction effect, $F(3, 54) = 1.45, p = .24$.

228 3.1.2. *Negative slope (NS')*

229 The onset times of the NS' component in both groups are shown in Table 1. The ANOVA revealed a
 230 significant main effect for group, with a significantly later NS' onset in the experienced guitarists com-
 231 pared to the non-musicians, $F(1, 18) = 9.78, p = .006$. No significant main effect was found for NS' onset
 232 time between electrodes, $F(1.9, 34.3) = 1.18, p = .32$, and there was no group \times electrode interaction
 233 effect, $F(1.9, 34.3) = 1.54, p = .23$.

234 The amplitude of the NS' was taken as the mean amplitude from the point of NS' onset to the MP
 235 peak. The mean z-score amplitude for the NS' was $-5.41 (\pm 5.02)$ in the experienced guitarists, com-
 236 pared to $-10.45 (\pm 6.22)$ in the non-musicians. The ANOVA revealed a significant main effect for group,
 237 with a significantly lower amplitude NS' component in the experienced guitarists compared to the
 238 non-musicians, $F(1, 18) = 5.43, p = .03$. There was also a significant difference in the amplitude of
 239 the NS' between electrodes, $F(3, 54) = 6.26, p = .001$. Bonferroni's post-hoc analysis indicated that
 240 the NS' amplitude at Cz was significantly larger than at FCz. Finally, there was no group \times electrode
 241 interaction effect, $F(3, 54) = 2.2, p = .10$.

242 3.1.3. *Motor potential (MP)*

243 The amplitude of the MP was taken as the maximum negative peak immediately prior to move-
 244 ment onset. The mean z-score amplitude for the MP peak was $-7.48 (\pm 5.28)$ in the experienced gui-
 245 tarists, compared to $-16.17 (\pm 8.36)$ in the non-musicians. The ANOVA confirmed that this was a
 246 significantly lower amplitude in the experienced guitarists compared to the non-musicians,
 247 $F(1, 18) = 10.85, p = .004$. There was also a significant difference in MP peak amplitude between elec-
 248 trodes, $F(3, 54) = 7.02, p < .001$. Bonferroni's post-hoc analysis indicated that, as with the NS',
 249 the amplitude of the MP peak was significantly larger at Cz than at FCz. Finally, there was also a significant
 250 group \times electrode interaction, $F(3, 54) = 2.97, p = .04$. Tukey's post-hoc test indicated that the MP
 251 amplitude was smaller in experienced guitarists, compared to non-musicians at all electrode sites.

252 3.2. *Performance data*

253 3.2.1. *Ability to play at the correct tempo*

254 The experienced guitarists were able to play the scale in time with the metronome with an average
 255 of 46 ms (± 77) error between the beat of the metronome and the note being played, compared to

573 ms (± 1084) error in the non-musician group. Due to the large variability in performance by the non-musician group (see the high standard deviation value), the assumption of homogeneity of variance was violated. Given this violation, it was deemed more appropriate to analyse these data using a non-parametric Mann–Whitney U test. The results of this test indicated that the experienced guitarists were able to play the scale more closely in time with the metronome than the non-musicians ($U = 11, p = .002$).

3.2.2. Variability in performance

The mean intra-individual coefficient of variation for the experienced guitarists was 0.73 (± 0.1), compared to 1.09 (± 0.41) in the non-musicians. An independent t test confirmed that the experienced guitarists were significantly less variable in their performance errors compared to the non-musicians ($t = -2.67, df = 9.97, p = .02$).

4. Discussion

The aim of this study was to investigate possible differences in the pre-movement components of the MRCP between experienced guitarists and non-musicians in an ecologically valid guitar-playing task. To the best of our knowledge, this study provides the first account of differences in the MRCP between two groups of differing skill levels, prior to performance of an ecologically valid motor skill. We found no group differences in the amplitude of the BP component, although the BP was found to start earlier in the non-musicians at Cz and C4. The amplitude of the NS' component was significantly smaller and began significantly later in the experienced guitarists compared to the non-musicians. In addition, the amplitude of the MP peak was significantly smaller in the experienced guitarists compared to the non-musicians. Previous research has reported the BP, NS' and MP components of the MRCP to be of smaller amplitude and later onset in elite performers compared to novices (Di Russo, Pitzalis et al., 2005; Fattapposta et al., 1996; Hatta et al., 2009; Kita et al., 2001). Therefore, only the NS' and MP findings in this study support those of previous research. Deecke (1996) suggested that negativity in the EEG indicates increased activity in the area of the cortex. Based on this suggestion, we propose that the lower negativity prior to movement preparation in the experienced guitarists, compared to the non-musicians, indicates less activity, and possibly a reduced effort involved in cortical motor preparation. Furthermore, the later onset of this activity for the NS' provides evidence to support the idea of a greater efficiency during motor preparation in experts.

It is interesting to highlight that, as predicted, the reduced cortical activity during motor preparation in the experienced guitarists was also accompanied by superior performance in the task. The experienced guitarists were able to play the scale more closely in time with the metronome than the non-musicians and the significantly smaller variability coefficient in the experienced guitarists suggests that their performance was more stable than the non-musicians were. This finding is consistent with the study by Fattapposta et al. (1996), who reported that expert pistol shooters produced smaller amplitude MRCPs than a novice control group, and also performed better in a shooting-based task. We believe that this performance data strengthens the claim that lower amplitude MRCPs in expert performers are skill-related. Where possible, to corroborate this claim, we encourage other cross-sectional MRCP comparison studies to include a performance measure. Also of interest is the finding that the NS' and MP values were significantly larger at Cz than at FCz. This finding was to be expected, as the MRCP is typically maximal at the vertex (Shibasaki & Hallett, 2006).

Previous research in this area has tended to use relatively simple motor tasks and then extrapolated the findings to more complex motor skills. For example, simple button pressing has been used to study clay target or pistol shooting tasks (Di Russo, Pitzalis et al., 2005; Fattapposta et al., 1996), finger-tapping has been used to study piano playing (Haslinger et al., 2004; Jancke et al., 2000; Koeneke et al., 2004; Krings et al., 2000), and hand gripping or wrist flexion tasks have been used to study kendo (Hatta et al., 2009; Kita et al., 2001). Recently, there has been a call for more ecologically valid motor skills to be used when studying skill- and learning-related changes in the motor areas of the brain (Nakata et al., 2010; Wright et al., 2011). This study addressed this need as it investigated the MRCP prior to an ecologically valid motor skill on a guitar, as opposed to a more simple motor task.

306 The smaller amplitude and later onset of the NS', together with the smaller amplitude MP in the exper-
307 ienced guitarists compared to the non-musicians indicates that the experienced guitarists required
308 less cortical activity, and possibly less effort, to plan and perform the task. This finding is consistent
309 with the research that indicates experienced athletes (Di Russo, Pitzalis et al., 2005; Fattapposta et
310 al., 1996; Hatta et al., 2009; Kita et al., 2001) and musicians (Haslinger et al., 2004; Jancke et al.,
311 2000; Koeneke et al., 2004; Krings et al., 2000) require reduced cortical activity during motor planning
312 and preparation. The fact that we replicated these findings using a more ecologically valid motor skill
313 extends the current literature base and adds support to the claims made in earlier studies that the re-
314 ported differences are due to training in a particular skill.

315 One unexpected finding in this study was that there were no differences between the two groups in
316 the amplitude of the BP component, and the onset time of the BP occurred later in the non-musicians
317 than the experienced guitarists at sites Cz and C4. This finding is in contrast with previous research
318 that has reported smaller amplitude and later onset BP components in expert, compared to novice per-
319 formers (Di Russo, Pitzalis et al., 2005; Fattapposta et al., 1996; Kita et al., 2001). It is possible that the
320 contradictory BP evidence presented in our study could be due to the sound generated by the metro-
321 nome, which ran continuously throughout the experiment at 100 bpm. Although participants were
322 free to initiate each repetition of the scale at their own choosing, they were also instructed to try to
323 keep their playing in time with the metronome. The result of this may have been that the decision
324 to begin each repetition was governed by the metronome, rather than being self-initiated. A study
325 by Di Russo, Incoccia, Formisano, Sabatini, and Zocolotti (2005) compared components of the MRCP
326 prior to index finger flexion actions that were either self-initiated or externally triggered by a tone.
327 The authors reported that the BP component was present prior to self-initiated movements but absent
328 prior to the externally triggered movements. It could be argued that the presence of the metronome in
329 our experiment acted as an external trigger for the participants to begin playing the scale. Therefore, in
330 this experiment, the decision to begin a repetition of the scale may have been partially internally trig-
331 gered and partially externally triggered. The external trigger element may have reduced the BP ampli-
332 tude and had a confounding effect on our results. As such, it is not possible to speculate as to the cause
333 of the later BP onset at Cz and C4 in the non-musician group. Removing the metronome would have
334 made measuring performance differences between the groups difficult and more subjective, and so it
335 was important to include the metronome in this study. However, had the metronome not been pres-
336 ent we would have anticipated that, consistent with previous research, the amplitude of the BP would
337 have been smaller and may have begun later in the experienced players, compared to the non-
338 musicians.

339 Alternative explanations for the NS' differences reported in this study could be the result of age and
340 sex differences between the groups, rather than being skill-related. The non-musicians sample con-
341 tained five males and five females with a mean age of 24.1 (± 6.57) years. The sample of experienced
342 guitarists contained ten males with a mean age of 36.5 years (± 13.73). However, regarding age differ-
343 ences, a study by Singh, Knight, Woods, Beckley, and Clayworth (1990) compared amplitude and onset
344 time differences in the MRCP between young (20–40 years) or old (54–78 years) participants, prior to
345 unimanual and bimanual button pressing tasks. The authors reported that there were no differences
346 between the groups in either the amplitude or the onset times of any components of the MRCP. Fur-
347 thermore, and of relevance to our study, the younger group was sub-divided into two further groups;
348 one with an age range of 20–29 years, and one with an age range of 30–40 years. Again, no differences
349 were reported between these groups in any components of the MRCP. It is therefore unlikely that the
350 differences reported here are age-related.

351 There is no published data regarding sex differences in the MRCP. However, comparison of the
352 MRCP of the five male non-musicians with the five female non-musicians in this study revealed that
353 there was no difference in the MRCP in terms of sex¹. Therefore, whilst we acknowledge that not match-

¹ Sex differences in the MRCP of the non-musicians were compared using separate 2 sex (male, female) \times 4 electrode (FCz, C3, Cz, C4) independent measures ANOVAs. No differences were found between sex for the onset times of the BP ($p = .10$) or NS' ($p = .89$) components. Similarly, no differences were found between sex for the amplitudes of the BP ($p = .08$), NS' ($p = .67$) or MP ($p = .93$) components.

ing participants for age and sex is a limitation to the study, we do not think that these factors had a confounding effect on the results.

The differences reported in this study indicate that less cortical activity, and possibly less effort, is required during movement preparation in a group of experienced guitarists compared to a group of non-musicians. It is possible that these differences are brought about by training in the experienced guitarists. However, the cross-sectional design of this study does not allow us to verify this claim or speculate as to the time course of these changes. It is possible that short-term practice lasting only a few hours could bring about a change in the MRCP, whilst it is equally possible that such changes could take many months to develop. To better establish if the differences that have been reported using cross-sectional designs are due to training in the expert group, future studies should investigate MRCP changes within the same participant group (Nakata et al., 2010; Wright et al., 2011). Research should focus on studying changes in the MRCP over both a short-term practice period and a longitudinal learning period of weeks or months. A reduction in cortical activity after either a short-term practice period or a longer learning period would provide a stronger indication that the differences reported here are due to training. Research is currently in progress in our laboratory in an attempt to address these issues.

Acknowledgments

The authors would like to thank Dr Martin Blain for his advice regarding how to assess participants' performance, and Grant Rockley for designing the method of marking movement onset through the guitar fret. We would also like to thank two anonymous reviewers for their helpful and constructive comments to improve an earlier version of this paper.

References

- Birbaumer, N., Elbert, T., Canavan, A. G., & Rockstroh, B. (1990). Slow potentials of the cerebral cortex and behavior. *Physiological Reviews*, 70, 1–41.
- Deecke, L. (1996). Planning, preparation, execution, and imagery of volitional action. *Cognitive Brain Research*, 3, 59–64. doi:10.1016/0926-6410(95)00046-1.
- Di Russo, F., Incoccia, C., Formisano, R., Sabatini, U., & Zoccolotti, P. (2005). Abnormal motor preparation in severe traumatic brain injury with good recovery. *Journal of Neurotrauma*, 22, 297–312. doi:10.1089/neu.2005.22.297.
- Di Russo, F., Pitzalis, S., Aprile, T., & Spinelli, D. (2005). Effect of practice on brain activity: An investigation in top-level rifle shooters. *Medicine & Science in Sports & Exercise*, 37, 1586–1593. doi:10.1249/01.mss.0000177458.71676.0d.
- Fattapposta, F., Amabile, G., Cordischi, M. V., Di Venanzio, D., Foti, A., Pierelli, F., & Morrocutti, C. (1996). Long-term practice effects on a new skilled motor learning: an electrophysiological study. *Electroencephalography and clinical Neurophysiology*, 99, 495–507. doi:10.1016/S0921-884X(96)96560-1.
- Haslinger, B., Erhard, P., Altenmuller, E., Hennenlotter, A., Schwaiger, M., Graf von Einsiedel, H., & Ceballos-Baumann, A. O. (2004). Reduced recruitment of motor association areas during bimanual coordination in concert pianists. *Human Brain Mapping*, 22, 206–215. doi:10.1002/hbm.20028.
- Hatta, A., Nishihira, Y., Higashiura, T., Kim, S. R., & Kaneda, T. (2009). Long-term motor practice induces practice-dependent modulation of movement-related cortical potentials (MRCP) preceding a self-paced non-dominant handgrip movement in kendo players. *Neuroscience Letters*, 459, 105–108. doi:10.1016/j.neulet.2009.05.005.
- Jancke, L., Shah, N. J., & Peters, M. (2000). Cortical activations in primary and secondary motor areas for complex bimanual movements in professional pianists. *Cognitive Brain Research*, 10, 177–183. doi:10.1016/S0926-6410(00)00028-8.
- Kita, Y., Mori, A., & Nara, M. (2001). Two types of movement-related cortical potentials preceding wrist extension in humans. *Neuroreport*, 12, 2221–2225. doi:10.1097/00001756-200107200-00035.
- Koeneke, S., Lutz, K., Wustenberg, T., & Jancke, L. (2004). Long-term training affects cerebellar processing in skilled keyboard players. *Neuroreport*, 15, 1279–1282.
- Kornhuber, H. H., & Deecke, L. (1965). Changes in the brain potential in voluntary movements and passive movements in man: Readiness potential and reafferent potentials. *Pflügers Archiv für die gesamte Physiologie des Menschen und der Tiere*, 284, 1–17.
- Krings, T., Topper, R., Foltys, H., Erberich, S., Sparing, R., Willmes, K., et al (2000). Cortical activation patterns during complex motor tasks in piano players and control subjects. A functional magnetic resonance imaging study. *Neuroscience Letters*, 278, 189–193. doi:10.1016/S0304-3940(99)00930-1.
- Kristeva, R., Chakarov, V., Schulte-Monting, J., & Spreer, J. (2003). Activation of cortical areas in music execution and imagining: A high-resolution EEG study. *NeuroImage*, 20, 1872–1883. doi:10.1016/S1053-8119(03)00422-1.
- Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: The MIT Press.
- Nakata, H., Yoshie, M., Miura, A., & Kudo, K. (2010). Characteristics of athletes' brain: Evidence from neurophysiology and neuroimaging. *Brain Research Reviews*, 62, 197–211. doi:10.1016/j.brainresrev.2009.11.006.

- 410 Nuwer, M. R., Comi, G., Emerson, R., Fuglsang-Frederiksen, A., Guerit, J. M., Hinrichs, H., & Rappelsburger, P. (1998). IFCN
411 standards for digital recording of clinical EEG. International Federation of Clinical Neurophysiology. *Electroencephalography*
412 *and clinical Neurophysiology*, 106, 259–261. doi:10.1016/S0013-4694(97)00106-5.
- 413 Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9, 97–113.
414 doi:10.1016/0028-3932(71)90067-4.
- 415 Rockschool (2008). *Guitar Grade 2*. Twickenham, UK: Rockschool.
- 416 Shibasaki, H., Barrett, G., Halliday, E., & Halliday, A. M. (1980). Components of the movement-related cortical potential and their
417 scalp topography. *Electroencephalography and clinical Neurophysiology*, 49, 213–226. doi:10.1016/0013-4694(80)90216-3.
- 418 Shibasaki, H., & Hallett, M. (2006). What is the Bereitschaftspotential? *Clinical Neurophysiology*, 117, 2341–2356. doi:10.1016/
419 j.clinph.2006.04.025.
- 420 Singh, J., Knight, R. T., Woods, D. L., Beckley, D. J., & Clayworth, C. (1990). Lack of age effects on human brain potentials preceding
421 voluntary movements. *Neuroscience Letters*, 119, 27–31. doi:10.1016/0304-3940(90)90747-W.
- 422 Wright, D. J., Holmes, P. S., & Smith, D. (2011). Using the movement-related cortical potential to study motor skill learning.
423 *Journal of Motor Behavior*, 43, 193–201. doi:10.1080/00222895.2011.557751.
- 424