Abstract
Simple tapping and complex movements (Luria finger apposition task) were performed unimanually and bimanually by two groups of professional guitarists while EEG was recorded from electrodes over the sensorimotor cortex. One group had a task-specific movement disorder (focal dystonia or musicians’ cramp), while the other group did not (controls). There were no significant group interactions in the task-related power (TRPow) within the alpha range of 8–10 Hz (mu1). In contrast, there was a significant group interaction within the alpha range of 10–12 Hz (mu2); these latter frequencies are associated with task-specific sensorimotor integration. The significant group interaction included task (simple and complex) by hand (left, right, and both) by electrodes (10 electrodes over the sensorimotor areas). In the rest conditions, the alpha power (10–12 Hz) was comparable between the groups; during movement, however, compared to the controls, patients demonstrated the greatest TRPow (10–12 Hz) over all conditions. This was particularly evident when patients used their affected hand and suggests that patients with musicians’ cramp have impaired task-specific sensorimotor integration.

Introduction
Precise control of voluntary movement is necessary for the performance of motor tasks, whether they are simple (such as pushing a button for the elevator) or complex (such as playing the guitar). The types and complexity of movement correlate differentially with the degree and loci of cerebral activation. Whether tasks are performed unimanually or bimanually is also important.

During the preparation and execution of such movements, the brain’s oscillatory activity in the alpha band (8–12 Hz) is reduced. Such decreases in oscillations are termed either desynchronizations (ERD) (Pfurtscheller, 1992; Pfurtscheller & Aranibar, 1977) or task-related alpha-power decrease (Gerloff, Richard et al., 1998); and reflects increased cellular excitability in thalamocortical systems (Steriade & Llinas, 1988, also see Ritz & Sejnowski, 1997 for review). Immediately following movement, there are increases in the synchronization of alpha oscillations (ERS) or task-related alpha power increases reflecting either an “idling state” of the brain (Pfurtscheller, 1999) or, alternatively, movement-related somatosensory processing (Cassim et al., 2001).

The alpha band is often divided into two further bands, a lower frequency of 8–10 Hz (mu1) and an upper frequency of 10–12 Hz (mu2). The lower frequency is smaller and more posterior than the upper frequency (Andrew & Pfurtscheller, 1997; Babiloni et al., 1999; Pfurtscheller & da Silva, 1999; Torro et al., 1994). It has been suggested that the two frequency bands have different physiological bases. The lower (8–10 Hz) frequencies reflect general arousal and attention, while the higher (10–12 Hz) alpha frequencies are linked to task-specific sensory processing (Pfurtscheller, Neuper, Krausz, 2000).

It is well established that the contralateral motor and sensory regions are involved in the control of unimanual motor tasks (Fritsch & Hitzig, 1870; cited in Kandel, Schwartz, & Jessell, 1991; Goeres, Samuel, Jenkins, & Brooks, 1998; Hartlage & Gage, 1997; Hoshiyama et al., 1997; Kim et al., 1993; Todor, Kyprie, & Price,
There is also recent evidence suggesting considerable ipsilateral hemispheric involvement in unimanual movements (Kawashima et al., 1998; Kawashima et al., 1993; Tinazzi & Zanette, 1998). In terms of oscillatory activity, unimanual movements are accompanied by a predominately contralateral ERD, and less pronounced ERD over the ipsilateral sensorimotor areas (Andres & Gerloff, 1999; Gerloff, Cohen et al., 1998; Pulvermüller, Lutzenberger, Preissl, & Birbaumer, 1995; Toro et al., 1994).

The contributions of the supplementary motor area (SMA) for bimanual and complex voluntary movement have also been well established (Brinkman, 1984; Luppio, Matelli, Camarda, & Rizzolatti, 1993; Rao et al., 1993; Toyokura, Muro, Komiyay, & Obara, 1999). More recently, research has highlighted the role of the primary motor area in both bilateral (Donchin, Gribova, Steinberg, Bergman, & Vaadia, 1998) and complex sequential movements (Gerloff, Corwell, Chen, Hallett, & Cohen, 1998; Sadato, Campbell, Ibanez, Deiber, & Hallett, 1996; Shibasaki et al., 1993). Furthermore, increasing complexity of movements increases the degree of bilateral activation (Cui et al., 2000). For bimanual and complex movements (such as the Luria finger apposition task; Luria, 1980), the ERD has a bilateral distribution (Andres & Gerloff, 1999; Deiber, Caldara, Ibanez, & Hauert, 2001; Pulvermüller et al., 1995).

In the present paper, we investigated changes in the alpha band oscillatory activity (lower and upper frequency bands) during execution of unimanual and bimanual sequences of finger movements in a group of patients with known impairments when performing particular tasks (focal dystonia). Patients with focal dystonia are characterized by impairments in voluntary movement, and excessive co-contraction of agonist and antagonist muscles, which frequently causes twisting and repetitive movements, or abnormal postures (Berardelli et al., 1998; Hallett, 1998a, 1998b; Tempel & Perlmutter, 1993). It was expected that any changes in the sensorimotor integration and imbalances in the basal ganglia-thalamocortical network accompanying focal dystonia would be reflected in differences in the upper alpha frequencies (10–12 Hz) and not the lower alpha frequencies (8–10 Hz).

### Method

#### Participants

All participants played the guitar professionally. There were five patients (41 ± 6 years) with involuntary flexion in the fingers of the right hand while playing. The average duration of the dystonic symptoms was 7 ± 8 years and an average severity of 82 ± 84% (Fahn, 1989). Five of the patients had previous injections of Botulinum toxin A (Dysport). However, the last injection was approximately 3–4 months prior to the study. None of the five patients had any family members with any movement disorders. Six controls (37 ± 8 years) were matched as closely as possible for age and length of playing guitar.

#### Electrophysiology: Oscillations

Continuous EEG was recorded with 10 scalp electrodes (Fz, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, and CP4) mounted on an elastic cap (Electrocap International, Eaton). Electrode impedance was kept below 5 kOhms for EEG and 10 kOhms for electromyogram (EMG). EEG signals were amplified (Synamps amplifiers, Neuroscan Table 1 Patient demographics of this study are shown.

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Years playing</th>
<th>Entrance into music</th>
<th>Duration of problem</th>
<th>Handedness</th>
<th>Type of previous medication</th>
<th>Type of music played</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>46</td>
<td>24</td>
<td>20</td>
<td>1</td>
<td>Right</td>
<td>Yes</td>
<td>Yes * (75 U)</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>22</td>
<td>27</td>
<td>10</td>
<td>Right</td>
<td>Yes * (75 U)</td>
<td>Classical</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>28</td>
<td>21</td>
<td>11.5</td>
<td>Right</td>
<td>No (writing)</td>
<td>Jazz &amp; Rock/Pop</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>38</td>
<td>17</td>
<td>15</td>
<td>Right</td>
<td>Yes * (150 U)</td>
<td>Classical</td>
</tr>
<tr>
<td>5</td>
<td>34</td>
<td>25</td>
<td>23</td>
<td>4</td>
<td>Right</td>
<td>No (computer)</td>
<td>Jazz &amp; Rock/Pop</td>
</tr>
</tbody>
</table>

* Botulinum toxin A (Dysport; U = Units); 1 = Classical; 2 = Jazz; 3 = Jazz & Rock/Pop; 4 = Classical, Jazz, & Rock/Pop
Inc.) between DC (high pass) and 200 Hz (low pass), and were digitized with a sampling frequency of 1000 Hz. Linked mastoid electrodes were utilized as reference electrodes.

Four bipolar EMG channels were recorded from surface electrodes. The electrodes were positioned along the forearm extensors (extensor digitorum) with 2.5 cm distance between the centers of the electrodes. For the EMG, the high-pass filter was 30 Hz and the low-pass filter was 2000 Hz.

In order to monitor eye movements, vertical electrooculogram (VEOG) was recorded with electrodes placed 1.5 cm above and below the edge of the right orbit. This was subsequently employed for off-line artifact rejection.

**Procedure**

Movements were either simple or complex (Luria finger apposition task, Luria, 1980); and the order of presentation was counterbalanced. The simple procedure involved the repeated touching of the index finger tip and thumb of the same hand. The complex procedure involved sequential touching of the thumb with all fingers, starting with the index and ending with the small finger, then in reverse order. Apart from the first thumb to index contact, participants were required to touch the small and the index finger twice before proceeding to touch the other fingers in the opposite direction. (Numbering the fingers 1 through 4, starting with the index, the sequence would be: 12344321123... etc.)

A block of trials began with one hand (for example, left), followed by both hands, and finally the other hand (for example, right). Each block was performed twice with a 1 min pause in between. Subsequently, the next condition began (e.g., from complex to simple or vice versa). One block took approximately 1 min, with the entire experiment taking no longer than 10 min. Participants were also instructed to keep their eyes closed at all times, even during the pauses.

All participants had the order of trials demonstrated to them by the same experimenter and particular care was taken with the complex task. The speed of all movements was set at approximately 5 movements per second. Because guitarists perform fast movements regularly during practice and performances, neither task was too demanding and both were mastered. Patients with musicians’ cramp had no dystonic postures or cramps during either of the tasks, further demonstrating the nature of the task-specific disorder. Once the participants understood the procedure, the experiment was initiated. The on-line counter of the EEG recording software was used to determine the time of the movement intervals. The trials were verbally started and stopped.

**Data Analyses**

Each “movement” condition was approximately 21 seconds and for the data analyses, the first second of all “movement” conditions was disregarded. Subsequently, the conditions were divided into a series of nonoverlapping 2 s epochs. Thus, for each “movement” condition, 10 epochs per trial were created. As the “rest” condition was three times longer than the “movement conditions,” the 10 epochs were taken from the middle of the rest period (i.e., 20 s into the rest period). Therefore, there were 20 epochs for all conditions which were then averaged together in the following manner.

The task-related power approach was employed in this study because of the continuous task nature of the study (Gerloff, Richard et al., 1998). For the spectral power analyses, a discrete Fourier transform was computed for all the electrodes. Spectral power was calculated for all frequency bins between 1 and 50 Hz (0.5 Hz bin width). Following previous research (Gerloff, Richard et al., 1998) the following equation was employed to calculate task-related power (TRPow).

\[
\text{TRPow}_x = \text{Pow}_{x, \text{activation}} - \text{Pow}_{x, \text{rest}}
\]

The mean power (µV²) during rest was subtracted from the movement conditions in the alpha frequencies of 8–10 Hz and 10–12 Hz. For the statistical analyses, a logarithmic (log) transformation of the power values was necessary to stabilize the variances (Halliday et al., 1995). As recommended by Gerloff, Richard et al. (1998), Equation 2 was used for statistical analyses.*

\[
\text{logTRPow}_x = \log(\text{Pow}_{x, \text{activation}}) - \log(\text{Pow}_{x, \text{rest}})
\]

Greenhouse-Geisser correction was used for all EEG analyses (Greenhouse & Geisser, 1959). Separate analyses were performed for the two alpha band ranges (8–10 Hz and 10–12 Hz) with the following conditions: tasks (simple and complex) by hands (left, both, right), by electrodes (10) by group (dystonic and controls). While the statistical analyses were performed on the log values, the following topographical maps show the TRPow(10–12 Hz) of each condition (Figures 1 to 3).

EMG signals were rectified and averaged for each task (simple and complex) and hand condition (unaffected, unaffected, dystonic)

* Although this transformation equates mathematically to \(\log(\text{Pow}_{x, \text{activation}}/\text{Pow}_{x, \text{rest}})\), this has been used extensively in scalp, spectral power, and statistical analyses (e.g., Deiber et al., 2001; Gerloff, Richard et al., 1998; Hummel, Andres, Altenmüller, Dichgans, & Gerloff, 2002).
both, affected). EMG activity during the rest period was also analyzed.

Results

Rest

In Figure 1, the rest conditions for the two groups appear to be different; however, this difference was not significant, $F_{(1, 9)} = 2.90$, n.s. The focus of power within the alpha frequency (10–12 Hz) appears over the posterior sites for the controls, while the power distributions for the patients appear to be more central and front. There was also no significant electrode by group interaction, $F_{(3.01, 27.11)} = 1.54$, n.s.

Mu 1: 8–10 Hz

There was no overall main effect of group, $F_{(1, 9)} = 3.93$, n.s; however, there were two significant main effects. First, there was a significant main effect of hand, $F_{(1.75, 15.70)} = 6.51$, $P < .05$, with the right hand having the greatest difference ($-0.12 \mu V^2$) compared to using either the left or both hands ($0 \mu V^2$ for both). Second, there was also a main effect of electrodes, $F_{(2.13, 19.15)} = 4.33$, $P < 0.05$.

Mu 2: 10–12 Hz

There was no overall main group effect, $F_{(1, 9)} = 2.14$, n.s, but there was a main effect of task, $F_{(1, 9)} = 5.00$, $P = .052$. 

Figure 1 Grand average spectrum maps for controls and patients (respectively) during the rest-phase are shown. Electrode positions used in this study are presented on the right schematic ($Fz$ is closest to the front of the head).

Figure 2 Grand average spectrum maps [10–12 Hz] of the simple task shown separately by group with the controls on the upper panel and patients on the lower panel. The columns are spectrum maps for the groups and represent the TRPow when the simple task was performed with the left, right, and both hands. Note the difference in scale [controls have much less TRPow compared to the patients]. For electrode positions see schematic in Figure 1.
marginal. Complex movements (−0.16 µV²) had greater TRPow (10–12 Hz) decreases than simple movements (0 µV²). There was also a significant task by electrodes interaction, $F_{(2.61, 23.50)} = 6.25, P < .01$.

Finally, there was a significant group interaction with task by hands by electrodes, $F_{(3.33, 29.96)} = 3.07, P < .05$.* This interaction can be seen in Figures 2 and 3. Overall, the patients had a much larger amount of TRPow (10–12 Hz); this remained irrespective of task and hand used and despite having similar amounts of alpha power during rest (Figure 1). In Figure 2, the TRPow (10–12 Hz) for the controls was decreased over the right side. For the patients, the TRPow (10–12 Hz) was relatively uniform, with larger decreases when the right (affected) hand performed the task. In Figure 3, as expected, the controls had larger decreases when the complex task was performed compared to the simple task. The patients also demonstrated a similar pattern across tasks. In addition, the greatest difference in TRPow (10–12 Hz) occurred when the patients used their right (affected) hand.

**EMG Analyses**

There were no significant group differences in any of the movement or rest conditions for the EMG signals, all $F_{(1,9)} < 2.44$, n.s. The EMG signals from one control participant were not included in the analysis because of the bad signal to noise ratio. This was despite the fact that all EMG signals were under 10 kOhms.

**Discussion**

In the lower alpha frequencies (8–10 Hz), there were no group interactions, only an overall main effect of hands and electrodes (separately). In the case of the hand main effect, the right hand (also the dominant hand) had the greatest decrease for both groups, suggesting that the overall arousal when using the right hand was greater than when using the left or both hands. This result may reflect the special training of guitarists, which usually focuses on the refinement of sensory-motor representations of the right hand, which contribute more to musical (e.g., timing) and emotional (sound) qualities of guitar playing (Fletcher & Rossing, 1991).

Consistent with previous studies (Andres & Gerloff, 1999; Deiber et al., 2001; Pulvermuller et al., 1995), complex movements for both groups produced greater decreases in TRPow (10–12 Hz) compared to simple movements. This suggests that as the complexity of move-
ments increases the cortical networks that are necessary for movement become more active.

The patients showed a different distribution of TRPow (10–12 Hz) compared to controls during tasks involving movement. Irrespective of task complexity, patients had greater TRPow (10–12 Hz) decreases over the areas contralateral to their affected hand, particularly evident when they performed the complex (Luria) task (Figure 3). Furthermore, in both tasks, the TRPow (10–12 Hz) decreases appears graded, with the greatest decrease occurring when the right (affected) hand was used in isolation, and the smallest decrease occurring when only the left (unaffected) hand was used. This suggests that the hemisphere ipsilateral to the symptoms was relatively unimpaired, and may have exerted some influence when voluntary movements were performed with both hands. Thus, it appears that the hand, the symptoms, and performance of tasks are important, and is in contrast to previous literature involving patients with writers’ cramp, which did not find differences between unaffected and affected hands (Deuschl et al., 1995; Hamano et al., 1999; Toro, Deuschl, & Hallett, 2000; Yazawa et al., 1997).

Differences between the current study and previous results may be due to differences in patient populations (disorders). This is unlikely because both writers’ and musicians’ cramp are classified within the same movement disorder. The most likely explanation for the differences between the hand conditions in this study, compared to previous studies, is in fact, the nature of the task. In the earlier studies, movement was based on flexion of the fingers with no extra sensory feedback. In the current study, the patients had to touch their fingers, and thus, the completion of movement was coupled with sensory feedback. Although dystonia is affected by sensory information, none of the patients developed dystonic symptoms during this task. It has also been suggested that dystonia may be a result of disturbed control of motor outputs in response to sensory inputs (Chen & Hallett, 1998). Indeed, symptoms of dystonia can often be temporarily relieved by tactile input (geste antagoniste, sensory trick). Altenmüller (1998) describes two pianists who expressed dystonic symptoms almost exclusively when playing on ivory – but not plastic – keys. Furthermore, patients who play with latex gloves usually have a temporary relief of their symptoms, but this effect is unstable and only lasts a few minutes. Therefore, for the patients, it is possible that the TRPow (10–12 Hz) decreases that were different between the hand conditions are a result of a deficiency in task-related sensorimotor integration of the affected hand.

In addition, the inability to inhibit movement and to integrate sensory information may also contribute to the results of the current study. Using transcranial magnetic stimulation (TMS), patients with writers’ cramp have demonstrated decreases in the excitability of intracortical inhibition (Chen, Wassermann, & Hallett, 1996; Riding, Sheean, Rothwell, Inzelberg, & Kujirai, 1995); an absence of task-related alpha power increases over the sensorimotor areas during inhibition of movement (Hummel et al., 2002); and patients with musicians’ cramp also have problems in integrating vibratory stimuli (Rosenkranz, Altenmüller, Siggelkow, & Dengler, 2000). These results combined with the current study would suggest that sensory input during a motor task is an important aspect in the pathophysiology of focal dystonia and are reflected in the group difference found in the current study in the 10–12 Hz frequency range.

There are, of course, several limitations to this study. The electrode coverage was limited to 10 electrodes; a larger montage would allow for a more detailed description of these task-related power effects. Although the current montage was the same as the “regions of interest” used in previous research (Gerloff, Richard et al., 1998; Hummel et al., 2002), a larger coverage of the scalp may reveal the extent of the group differences between the dystonic and controls that were found in this study. Thus, further studies should consider the employment of a larger montage. The relative rarity of the disorder limited the number of patients who were tested. However, even with a small number of participants, which generally makes the detection of real effects more difficult due to lower statistical power, there was clear evidence of group differences. Moreover, investigations involving patients with other forms of focal dystonia, such as patients with writer’s cramp, may allow for larger groups to be tested and for comparisons between forms of focal dystonia to be examined.

In conclusion, patients with musicians’ cramp demonstrated greater TRPow (10–12 Hz) reduction across task and hand conditions compared to controls. The affected hand showed the greatest TRPow (10–12 Hz) reduction compared to either the unaffected hand or both hands, and irrespective of the complexity of the movement task. These findings suggest that patients with musicians’ cramp are affected by sensory information from the affected hand. The current study provides evidence for the disruption in the sensorimotor cortices, possibly reflecting abnormal excitability or deficient inhibition in the basal-ganglia-thalamic-cortical network.

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