Sport expertise: the role of precisetiming of verbal–analytical engagement and the ability to detect visual cues

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Abstract. This study proposed that relative timing of high-alpha (10–12 Hz) left (T3) and right (T4) cortical temporal electroencephalographic (EEG) power levels would differentiate performance groups in a reactive sport such as cricket batting. The time course of EEG event-related alpha synchronisation (ERS) and desynchronisation was investigated in two groups (eight skilled and ten less skilled) of right-handed cricket batsmen whilst viewing projected video footage of a bowler delivering a randomised series of 24 deliveries repeated 10 times (total of 240 deliveries). Ball release from the bowler’s hand was used as the corresponding reaction cue. Participants were instructed to press one of two buttons on a keypad to identify in-swingers or out-swingers. T3 ERS was significantly greater in skilled batsmen from approximately 1500 ms prior to ball release, but differences reduced close to ball release, reaching nonsignificance by 250 ms. There was no significant difference in T4 between the groups. This study uniquely highlights that the relative timing of the T3 high-alpha ERS state appears to differentiate batting skill groups in a reactive task.

Keywords: EEG, left temporal, right temporal, alpha, cricket, reactive sport, batsmen, skill, performance

1 Introduction
Peak sport performance is associated with an optimal mental state (Cox, 2007; Gallucci, 2008; Jennings, 1993; Thellwell & Maynard, 1998). Sport performers have to attain high levels of concentration and be able to clear their minds from distractions (Kane & Engle, 2003) while processing relevant information for decision making (Farrow & Abernethy, 2003; Moore & Müller, 2013) and precision execution of a task (Regan, 1997). Covert verbalisation and analytical reasoning could hinder performance due to competition for attentional resources whilst attending to visuospatial cues (Kane & Engle, 2003; Robazza & Bortoli, 1998) and preparing for task execution. Covert verbalisation and analytical reasoning involve language processing and are typical of left temporal brain function, while visuospatial orientation is typically a right temporal brain function (Clarke, Boutros, & Mendez, 2005; Hatfield, Hauffler, Hung, & Spalding, 2004).

There are numerous studies indicating the importance of advance cue utilisation from the opponent’s action for successful performance in reactive tasks in sports like badminton, tennis, squash, and baseball (Abernethy, 1987, 1990; Farrow & Abernethy, 2003; Moore & Müller, 2013). In these tasks skilled performers were better able to interpret advance body cues from their opponent’s action, resulting in superior sporting performance.

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Similarly, in cricket there is evidence that visual cues relating to the bowler’s action, which may predict the intended ball trajectory, are analysed during this prerresponse period (Müller, Abernethy, & Farrow, 2006; Penrose & Roach, 1995). The most comprehensive of these studies was done by Müller et al. (2006), where the authors used projected video footage of the bowler’s action. They examined the ability of skilled, intermediate-level, and less-skilled cricket batsmen to utilise advance cues to anticipate the direction of swing (curve) and the length (the distance the ball bounces in relation to a batsman) of the delivery. In the first trial the video footage of the bowler was occluded at back foot landing, front foot landing, and ball release. They found that, at front foot landing [refer to figure 1 (subsection 2.5) for a representation of the cricket bowling action] and ball release, skilled batsmen were better at predicting the direction of swing than less-skilled batsmen. Skilled batsmen were also better at predicting the length of the delivery at ball release. In addition, skilled batsmen improved their prediction of the swing and length of the delivery when allowed to view up to front foot landing, whereas less-skilled batsmen improved their prediction only when allowed to view up to ball release. These results indicate that skilled batsmen must have used advance cues from the bowler’s action and that these cues were not utilised or were incorrectly utilised by the less-skilled batsmen. An examination of the mental preparation during the exposure to the visual cues could therefore provide more insight into the reasons for this difference.

Researchers have studied mental preparation prior to a skilled motor task using electroencephalography (EEG). The prerresponse alpha EEG power during self-paced (i.e., there was no external cue to react to) sports such as during the execution of karate blows (Collins, Powell, & Davies, 1991), archery (Salazar et al., 1990), rifle shooting (Deeny, Hillman, Janelle, & Hatfield, 2003; Hatfield, Landers, & Ray, 1984; Kerick, Douglass, & Hatfield, 2004; Kerick et al., 2001), and golf putting (Crews & Landers, 1993) has provided evidence of the reduction of the left temporal (T3) verbal and analytical centre (as indexed by an increase in the alpha power spectrum from a surface EEG electrode placed at T3) in the brain prior to execution of a skilled motor task. This implies a reduction of the prerresponse verbal and analytical processing.

In a reactive sport like cricket batting there is anecdotal evidence for the importance of being in the optimum mental state prior to the ball being released (Bradman, 1958). This has been referred to as the ‘Now’ technique (Australian Cricket Board, 2000). Canaway (2006) suggests a three-step guide in reaching this heightened state of concentration. Firstly, a batsman should ‘clear’ his mind from distractions. This would include reducing the amount of covert verbalisation. Secondly, as the bowler runs up, the batsman should enter a state of ‘fine’ focus. Finally, as the bowler enters the final steps prior to ball release, the batsman should further increase his focus to a state of ‘fierce’ focus. Canaway (2006) suggests that this state of fierce focus will allow the brain to best function in determining the type of delivery bowled.

Right temporal cortex changes that are associated with visuospatial processing in the preparatory period of a skilled task also appear to differ depending on the sport. In shooting and archery there was no significant change in the right temporal alpha power as the participants approached trigger pull or arrow release (Hatfield et al., 1984; Kerick et al., 2001; Landers, Han, Salazar, & Petruzzello, 1994; Salazar et al., 1990). However, skilled performers also showed a significant decrease in the right temporal alpha power prior to putting in golf (Crews & Landers, 1993). In contrast, in pistol shooting right temporal alpha power increased in pistol shooters prior to trigger pulls (Kerick et al., 2004). A possible reason for these varying results is that different cognitive processes might govern the preparation period in golf, karate, archery, and shooting; therefore, T4 alpha behaviour may be sports specific.
Previous studies that have investigated alpha power in the left and right temporal cortex have used different alpha power bands. Some have used broadband-alpha (between 7 and 13 Hz) power (Collins et al., 1991; Crews & Landers, 1993; Hatfield et al., 1984); others have investigated only high-alpha (between 10 and 13 Hz) power (Kerick et al., 2001, 2004; Kerick, Hatfield, & Allender, 2007), while others have investigated both high-alpha and low-alpha (between 7 and 10 Hz) power (Haufler, Spalding, Santa Maria, & Hatfield, 2000; Rietschel et al., 2012; Salazar et al., 1990). Despite the various alpha bands used, the results all show an increase in left temporal power prior to a skilled action. However, expertise differences or increasing task difficulty are more pronounced in the high-alpha band and not in the lower alpha band (Haufler et al., 2000; Rietschel et al., 2012; Salazar et al., 1990). For this reason and because high alpha is associated with more specific and localised cortical areas (Pfurtscheller & Lopes da Silva, 1999), more of the recent studies involve the investigation of high-alpha power (Kerick et al., 2001, 2004, 2007). We have therefore chosen to investigate high alpha.

These EEG sports studies have generally used power spectral analysis, which has a poor temporal resolution. Power is proportional to the square of the EEG voltage and may be calculated in either the frequency (ie spectral) or time domain. When the power (related to an event) of a particular frequency band is represented as a proportion of its baseline (usually the baseline is a stable EEG period a few seconds prior to the region of interest), it represents the percentage power decrease (event-related desynchronisation—ERD) or increase (event-related synchronisation—ERS) (Pfurtscheller & Lopes da Silva, 1999; Pfurtscheller, Stancak, & Neuper, 1996) calculated in the time domain. ERD occurs when the underlying neuronal populations desynchronise, resulting in suppression of the surface EEG signal in the same frequency band (Klimesch, Doppelmayr, Pachinger, & Russegger, 1997; Pfurtscheller, 1992). ERS occurs when the underlying neuronal populations synchronise, resulting in an increase in the surface EEG signal in the same frequency band (Pfurtscheller, 1992). ERS in the high-alpha band is interpreted as a decrease in activity of the underlying neuronal assemblies since nonactive neuronal populations tend to synchronise in alpha, whereas alpha ERD would indicate an increase in activity (Pfurtscheller, 1992), since active neuronal populations tend to desynchronise in alpha. As the timing of the EEG response as a measure of mental state appears to be important in the case of cricket batting, temporal ERD/ERS in the high-alpha band would be a more appropriate analysis tool to measure cortical activity relating to dynamic visual cues of an opponent or during the preparation for an appropriate motor response. For this reason Kerick et al. (2007) and Del Percio et al. (2007) applied this ERD/ERS technique to enhance the temporal resolution when determining prerespone EEG activity during a skilled task.

In previous EEG sports studies T3 and T4 alpha power were reported for an internally paced task. A sportsperson chooses when to initiate an action in an internally paced sport, whereas the competitor influences the response in a reactive or externally paced sport. The latter creates a scenario where the sportsperson has to react by responding to the action of the opponent. There is evidence that self-paced and reactive motor responses elicit different neural processes (Di Russo, Incoccia, Formisano, Sabatini, & Zoccolotti, 2005a). For example, the Bereitschaftspotential (BP) is a component of movement-related cortical potentials that is known to precede self-paced movement. However, Di Russo et al. (2005a) reported the absence of BP in response to reactive or externally paced versus self-paced movement. Yet, if the timing of the externally paced event is predictable, then a component similar to the BP reappears (Colebatch, 2007). Relative timing, in particular, is hypothesised to be an important factor in reactive sports. Kerick et al. (2007) investigated the event-related cortical dynamics of soldiers during a reactive task. The soldiers were required to react to the stimulus by shooting the correct target whilst EEG data were recorded, thereby converting
shooting into reactive as opposed to a self-paced task. High-alpha event-related spectral perturbation in the left temporal cortex increased as trigger pull occurred, similarly to results of self-paced studies.

In the EEG studies previously mentioned there was no dynamic prestimulus information available to affect the participant’s response. Such dynamic prestimuli are typical of most sports where participants are presented with dynamic behaviour that they have to use to predict the intent of opponents. Subsequent reactions are required within a time window determined by the particular sport and context—for example, in cricket and baseball batting, returning a serve in tennis, or saving a penalty kick in soccer. Very little is known about the neurophysiological markers associated with prereaction state in the presence of dynamic visual cues from the opponent’s action or how this differs between skilled and less-skilled performers. For this reason we have chosen to examine the neurophysiological response in a reactive sporting task such as cricket batting, during the prereaction cue or preparatory stage of batting (ie prior to the bowler releasing the ball), and to determine if the extent of covert verbal–analytical engagement and visuospatial activation differentiates skilled and less-skilled performers. The investigation should result in a better scientific understanding of the cognitive processes underlying performance in reactive sports and may also influence future training strategies.

2 Materials and methods

2.1 Ethics approval

The study was approved by the Faculty of Health Sciences Human Research Ethics Committee, where the study was conducted. This was also conducted in accordance with national regulations and legislation and with the World Medical Association Declaration of Helsinki.

2.2 Experimental participants

Eight right-handed (as determined by the direction of their batting stance and hence also their bottom hand whilst holding the bat) skilled and ten right-handed less-skilled male cricket batsmen participated in the study. Skilled batsmen were defined as those currently playing 1st and 2nd grade senior provincial (ie state-level) cricket. Less-skilled batsmen were defined as batsmen currently playing 3rd division senior club cricket, a difference of 13 leagues. Hence, it could confidently be stated that the skilled batsmen were superior in their batting ability compared with the less-skilled batsmen. In addition, none of the less-skilled batsmen had represented a provincial team at any time during their cricket career. Given their current skill, it was unlikely that any of these less-skilled batsmen were talented enough to compete at a much higher level.

2.3 Experimental protocol: video footage

Video footage of a medium-fast swing bowler was recorded from the batsman’s-eye view, in his usual preparatory stance. The bowler was a 1st division club cricketer whom none of the participants were familiar with. The video was projected onto a 1.8 m × 1.4 m white screen. During the trial the participants were seated in a darkened, sound-attenuated room, 3 m from the screen. The projected video footage of the bowler subtended approximately 7 deg at ball release, providing a realistic virtual environment of a bowler delivering the ball.

The footage included 10 in-swing deliveries, 10 out-swing deliveries, and 4 slower deliveries (ie approximately 15–20 km h⁻¹ slower than the normal speed). These 24 delivery clips comprising 3 delivery types were each randomly presented to the participants 10 times so that the participants each viewed a total of 240 deliveries (100 in-swing, 100 out-swing, and 40 slower deliveries). This constitutes 40 overs (1 over equals 6 deliveries) in the game of cricket. The slower delivery was specifically included to prevent the participants from guessing between only two delivery types. Each delivery video clip lasted 12 s followed
by a 5 s rest period before the next delivery clip. Each over was separated by a further 20 s rest period, and the participants were also allowed a 2–5 min break after every 10 overs. The speeds of the in-swing and out-swing deliveries were similar.

Participants were asked to respond as quickly and accurately as possible (by pressing one of two keys) with regard to the identification of an in-swing or out-swing delivery. The participants had to respond by deciding the direction of swing before the ball disappeared from the screen. The viewing time of the delivery (from ball release to the disappearance of the ball) was about 690 ms. Allowing about 200 ms for the finger press button response, any reaction after 890 ms was regarded as incorrect. Pre-ball-release high-alpha ERD/ERS information for correctly identified in-swing and out-swing deliveries, reaction time, and percentage correct response was also recorded.

After the batsmen received instructions and before the start of the experimental protocol, they performed a 6-over familiarisation trial. A different bowler of the same calibre, bowling the same three delivery types, was used in the familiarisation trail. This was done to ensure that none of the participants had prior opportunity to familiarise themselves with anticipatory cues from the bowler’s action that might influence the results.

2.4 EEG preprocessing
EEG signals [Electrical Geodesics Inc (EGI, Oregon)] were sampled at 200 Hz using Netstation 2 software. An online bandpass filter of 0.1–80 Hz and a 50 Hz notch filter were applied, electrode impedance was kept below 50 kΩ, and Cz was the common recording reference. Note that the EGI system has a high-input impedance electrode net as well as a correspondingly high-input impedance amplifier, which tolerates impedances higher than the conventional 5 kΩ.

An automatic artefact detection tool was used to mark bad channels. Channels were marked as bad in a segment if the differential amplitude exceeded 90 μV or the channel had close to zero variance. The outer ring electrodes, which were often bad during the recording, were removed from data processing. A total of 21 bad channel outer ring electrodes were removed. Ignoring the outer electrodes, approximately 107 of the 108 (99.1%) of the remaining electrodes were good for each participant. An automatic bad channel replacement tool corrected for this one bad electrode using interpolation. The data from the 108 good electrodes were then transferred to Matlab for further processing. Further visual inspection of all sweeps was conducted, and bad segments were removed. The EEG signal in the last 2500 ms prior to ball release represented a relatively ‘quiet’ window with minimal movement artefacts, and a relatively small percentage of segments were found to be bad.

EEG signals were then rereferenced to average reference (ie the outputs of all of the active channels were summed and averaged, and this averaged signal was then used as the common reference for each channel) and filtered (using a Finite Impulse Response filter, with Netstation 3.1 software) to a high alpha (10–12 Hz bandpass) with a rolloff of 2 Hz (passband: 99.0%; stop gain: 1%). Data were then segmented into correctly identified in-swing and out-swing deliveries to be used for ERD/ERS analysis.

2.5 EEG time window of interest
A 1 kHz auditory beep was recorded on the videotape to coincide with the start of the bowler’s run-up. The participants did not hear the auditory signal that was merely used to place a synchronous ‘event’ marker on the EEG recording. This event marker was placed on the EEG recording, 8 s prior to ball release, and coincided with the start of the bowler’s run-up. This allowed for time-locking of the EEG signal to ball release. To incorporate all the phases of the bowling action (figure 1) and to include sufficient video run-up footage prior to the exposure of the important visual cues of the bowler (in the last 1200 ms prior to ball release),
Precise timing of verbal–analytical engagement and ability to detect visual cues

2.6 Movement and eye-movement or blink artefact
In order to reduce the influence of movement-related artefacts in the psychophysiological recordings, participants remained seated and were asked to refrain from any gross movements. The removal of eye blink artefact was carried out 2500 ms prior to ball release. Baseline artefacts were minimised by alpha filtering and averaging. This process is valid because these blinks were not time-locked to any stimulus or event in the run-up—hence the effectiveness of the averaging process, particularly given the relatively large number of epochs averaged (Luck, 2005, page 133).

2.7 ERD/ERS calculation
Using Matlab®, a reduced set of 108 ‘clean’ (ie 20 ‘noisy’ channels with poor electrode contact were removed) EEG channels were first high-alpha filtered (10–12 Hz), then squared to obtain power estimates (µV²) and averaged across trials. A moving-average filter of 16 samples was then applied to the waveforms. Finally, the ERD/ERS waveform was represented as a percentage of the mean activity in the selected baseline period. Topographical maps were generated using the EEGLAB toolbox (Delorme & Makeig, 2004).

The percentage values for ERD/ERS for the high-alpha band were obtained from the classical ERD/ERS power method formula proposed by Pfurtscheller and Lopes da Silva (1999):

\[
\%\text{ERD (or } \%\text{ERS)} = \frac{A - R}{R} \times 100, \tag{1}
\]

where \(A\) is an estimate of the ‘instantaneous’ (ie within 5 ms, given the 200 Hz sample rate) band power for the EEG time window of interest, and \(R\) is the average power in the preceding baseline—that is, 5000 ms—beginning at the start of the bowler’s run-up (figures 1–2).
The 2500 ms EEG with window of interest was divided into ten 250 ms epochs to provide a reduced time-course resolution for statistical calculations. The area of each 250 ms epoch was then calculated. Area calculations were used because they are less sensitive to higher frequency waveform fluctuations (Luck, 2005).

2.8 Statistical analysis
Age, reaction time, percentage-correct response selections, and average baseline alpha power were compared between skilled and less-skilled batsmen using a two-tailed Mann–Whitney test. Where Mann–Whitney tests were used, the populations had the same shape, and data were reported as median and 95% confidence interval (CI) for the difference in the medians. Alpha ERD/ERS data from electrodes T3 and T4 were then initially subjected to a 10 (time epoch) × 2 (swing type) repeated-measures ANOVA. Since the corresponding ERD/ERS values were not significantly different between in-swing and out-swing deliveries, swing-type data were then averaged and compared between the skill groups. Where significant differences were found, a posteriori Bonferroni tests were conducted with the alpha level adjusted for multiple comparisons. Correlation analysis between the behavioural data (reaction time and response selection) and ERD/ERS in the 1500 ms prior to ball release was computed.

3 Results
There were no significant differences in the median age between the skilled and less-skilled batsmen (21.5 vs 21.5 years, 95% CI = −3.0–3.0, p = 0.98). There was a tendency for reaction times to be shorter for the skilled batsmen for both in-swing (416 vs 495 ms, p = 0.083) and out-swing deliveries (421 vs 483 ms, p = 0.083) (table 1). There was no significant difference in the percentage-correct responses between groups (table 1). There were no significant differences in the baseline between the skilled and less-skilled batsmen (table 2). There was also no significant difference between in-swing and out-swing deliveries for T3 and T4 for both skilled and less-skilled batsmen (table 3).

Table 1. Comparison of the median reaction times and percentage-correct responses for the different deliveries, and 95% confidence intervals (CIs) for the difference in medians. p-values are for the Mann–Whitney test for equality of medians (Taliep et al., 2008).

<table>
<thead>
<tr>
<th></th>
<th>Skilled</th>
<th>Less skilled</th>
<th>Sum of ranks</th>
<th>Mann–Whitney U</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction time in</td>
<td>416</td>
<td>495</td>
<td>56 116</td>
<td>19.5</td>
<td>−150–11</td>
<td>0.083</td>
</tr>
<tr>
<td>Reaction time out</td>
<td>421</td>
<td>483</td>
<td>56 115</td>
<td>20.0</td>
<td>−210–23</td>
<td>0.083</td>
</tr>
<tr>
<td>% correct response in</td>
<td>89.5</td>
<td>90.0</td>
<td>70 102</td>
<td>33.5</td>
<td>−22–6.0</td>
<td>0.593</td>
</tr>
<tr>
<td>% correct response out</td>
<td>94.5</td>
<td>89.5</td>
<td>56 111</td>
<td>20.0</td>
<td>−2–9.0</td>
<td>0.326</td>
</tr>
</tbody>
</table>

Table 2. Comparison of the average power (μV²) in the 5000 ms baseline between skilled and less-skilled batsmen for electrodes T3 and T4 for both the in-swing and out-swing deliveries, and 95% confidence intervals (CIs) for the difference in medians. p-values are for the Mann–Whitney test for equality of medians.

<table>
<thead>
<tr>
<th></th>
<th>Skilled</th>
<th>Less skilled</th>
<th>Sum of ranks</th>
<th>Mann–Whitney U</th>
<th>95% CI</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In-swing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>2.6</td>
<td>2.4</td>
<td>90 81</td>
<td>35</td>
<td>−1.2–1.2</td>
<td>0.697</td>
</tr>
<tr>
<td>T4</td>
<td>2.3</td>
<td>2.3</td>
<td>95 76</td>
<td>40</td>
<td>−1.1–1.5</td>
<td>0.965</td>
</tr>
<tr>
<td><strong>Out-swing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>2.5</td>
<td>2.4</td>
<td>99 72</td>
<td>36</td>
<td>−1.0–1.6</td>
<td>0.762</td>
</tr>
<tr>
<td>T4</td>
<td>2.2</td>
<td>2.1</td>
<td>93 78</td>
<td>38</td>
<td>−1.2–0.9</td>
<td>0.897</td>
</tr>
</tbody>
</table>
Table 3. A representation of the differences (mean) in event-related desynchronisation (ERD) and event-related synchronisation (ERS) between the in-swing and out-swing deliveries at electrode locations T3 and T4 across the 1500 ms prior to ball release.

<table>
<thead>
<tr>
<th></th>
<th>In-swing</th>
<th>Out-swing</th>
<th>df</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skilled T3</td>
<td>13.8</td>
<td>17.4</td>
<td>1, 32</td>
<td>0.12</td>
<td>0.734</td>
</tr>
<tr>
<td>Less-skilled T3</td>
<td>1.1</td>
<td>-4.8</td>
<td>1, 32</td>
<td>0.39</td>
<td>0.539</td>
</tr>
<tr>
<td>Skilled T4</td>
<td>-11.0</td>
<td>-11.4</td>
<td>1, 32</td>
<td>0.00</td>
<td>0.961</td>
</tr>
<tr>
<td>Less-skilled T4</td>
<td>-5.0</td>
<td>-7.0</td>
<td>1, 32</td>
<td>0.10</td>
<td>0.749</td>
</tr>
</tbody>
</table>

*Significant differences, p < 0.05.
Note: df = degrees of freedom.

Table 4. A representation of the differences (mean) in event-related desynchronisation (ERD) and event-related synchronisation (ERS) between skilled and less-skilled batsmen for T3 and for both in-swing and out-swing deliveries (pooled).

<table>
<thead>
<tr>
<th>Prestimulus time period/ms</th>
<th>Skilled ERD/ERS</th>
<th>Less-skilled ERD/ERS</th>
<th>df</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500–2250</td>
<td>-2.251</td>
<td>0.68</td>
<td>1, 32</td>
<td>0.23</td>
<td>0.633</td>
</tr>
<tr>
<td>2250–2000</td>
<td>7.655</td>
<td>0.93</td>
<td>1, 32</td>
<td>0.65</td>
<td>0.427</td>
</tr>
<tr>
<td>2000–1750</td>
<td>4.650</td>
<td>-7.20</td>
<td>1, 32</td>
<td>1.54</td>
<td>0.224</td>
</tr>
<tr>
<td>1750–1500</td>
<td>-5.156</td>
<td>-11.77</td>
<td>1, 32</td>
<td>0.73</td>
<td>0.398</td>
</tr>
<tr>
<td>1500–1250</td>
<td>9.967</td>
<td>-11.82</td>
<td>1, 32</td>
<td>6.12</td>
<td>0.019*</td>
</tr>
<tr>
<td>1250–1000</td>
<td>15.931</td>
<td>-3.84</td>
<td>1, 32</td>
<td>4.27</td>
<td>0.047*</td>
</tr>
<tr>
<td>1000–750</td>
<td>36.105</td>
<td>-9.39</td>
<td>1, 32</td>
<td>11.00</td>
<td>0.002*</td>
</tr>
<tr>
<td>750–500</td>
<td>43.159</td>
<td>-5.21</td>
<td>1, 32</td>
<td>15.49</td>
<td>0.000*</td>
</tr>
<tr>
<td>500–250</td>
<td>30.106</td>
<td>5.72</td>
<td>1, 32</td>
<td>6.19</td>
<td>0.018*</td>
</tr>
<tr>
<td>250–0</td>
<td>15.805</td>
<td>23.31</td>
<td>1, 32</td>
<td>0.40</td>
<td>0.530</td>
</tr>
</tbody>
</table>

*Significant differences, p < 0.05.
Note: df = degrees of freedom.

3.1 Grand average ERD/ERS topographical maps
The grand average topographical maps for high-alpha ERD/ERS for the in-swing and out-swing deliveries are presented in figures 3 and 4. A distinct developing left temporal ERS is evident particularly for the skilled batsmen. This ERS appears to increase in magnitude towards ball release for both skilled and less-skilled batsmen for both delivery types. However, it is also evident that this ERS occurs earlier in the skilled batsmen. These changes in ERS are also graphically depicted in the grand averages (figure 5). At T3 there were no significant differences in ERD/ERS between groups for both delivery types early in the bowler’s run-up (between time 2500 ms and 1500 ms prior to ball release) (table 4). Skilled batsmen had significantly higher ERS between 1500 ms and 250 ms prior to ball release compared with the less-skilled batsmen for both delivery types (table 4). However, during the last 250 ms prior to ball release there was no significant difference in the ERS between skilled and less-skilled batsmen.

In the right temporal cortex there appears to be slight ERD for both groups throughout the 10 time periods (figure 5). There was no significant difference in the ERD in the right temporal cortex between groups at all 10 time points (table 5).

There was a significant positive correlation between response selection and ERS in the 1500 ms prior to ball release ($r = 0.356$, $p = 0.033$, figure 6) at T3. There was, however, no significant correlation between the reaction time and ERD/ERS at T3 and T4, nor any significant correlation for response selection at T4 (figure 6).
Figure 3. [In colour online, see http://dx.doi.org/10.1068/p7530] Grand average topographical maps of high-alpha event-related desynchronisation (ERD) and event-related synchronisation (ERS) for the in-swing deliveries.

Table 5. A representation of the differences (mean) in event-related desynchronisation (ERD) and event-related synchronisation (ERS) between skilled and less-skilled batsmen for T4 and for both in-swing and out-swing deliveries (pooled).

<table>
<thead>
<tr>
<th>Prestimulus time period/ ms</th>
<th>Skilled ERD/ERS</th>
<th>Less-skilled ERD/ERS</th>
<th>df</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2500–2250</td>
<td>−7.680</td>
<td>−10.377</td>
<td>1, 32</td>
<td>0.13</td>
<td>0.718</td>
</tr>
<tr>
<td>2250–2000</td>
<td>−11.877</td>
<td>−8.460</td>
<td>1, 32</td>
<td>0.33</td>
<td>0.572</td>
</tr>
<tr>
<td>2000–1750</td>
<td>−9.601</td>
<td>−4.609</td>
<td>1, 32</td>
<td>0.56</td>
<td>0.458</td>
</tr>
<tr>
<td>1750–1500</td>
<td>−11.181</td>
<td>−8.927</td>
<td>1, 32</td>
<td>0.08</td>
<td>0.779</td>
</tr>
<tr>
<td>1500–1250</td>
<td>−8.331</td>
<td>−8.521</td>
<td>1, 32</td>
<td>0.00</td>
<td>0.978</td>
</tr>
<tr>
<td>1250–1000</td>
<td>−7.327</td>
<td>−5.367</td>
<td>1, 32</td>
<td>0.05</td>
<td>0.820</td>
</tr>
<tr>
<td>1000–750</td>
<td>−11.373</td>
<td>−9.774</td>
<td>1, 32</td>
<td>0.06</td>
<td>0.810</td>
</tr>
<tr>
<td>750–500</td>
<td>−17.580</td>
<td>−10.334</td>
<td>1, 32</td>
<td>1.21</td>
<td>0.280</td>
</tr>
<tr>
<td>500–250</td>
<td>−12.396</td>
<td>2.742</td>
<td>1, 32</td>
<td>3.01</td>
<td>0.089</td>
</tr>
<tr>
<td>250–0</td>
<td>−14.625</td>
<td>3.505</td>
<td>1, 32</td>
<td>2.73</td>
<td>0.108</td>
</tr>
</tbody>
</table>

Note: df = degrees of freedom.
Figure 4. [In colour online.] Grand average topographical maps of high-alpha event-related desynchronisation (ERD) and event-related synchronisation (ERS) for the out-swing deliveries.

Figure 5. Grand average high-alpha event-related desynchronisation (ERD) and event-related synchronisation (ERS) at T3 and T4 for the in-swing and out-swing deliveries. The 2500 ms period prior to ball release is represented. Baseline is presented on the y-axis as 0%. Refer to tables 4–5 for 250 ms epoch statistical comparisons for pooled in-swing and out-swing data.
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Figure 6. Regression analysis between the behavioural data and event-related desynchronisation (ERD) and event-related synchronisation (ERS) in the last 1500 ms prior to ball release at (a) T3 and (b) T4.

4 Discussion

The aim of the study was to determine if the extent of covert verbal–analytical engagement and visuospatial activation differentiated skilled and less-skilled cricket batsmen during the preparatory stage of batting. Surprisingly, the behavioural data did not separate the groups. In the context of cricket, we would have expected skilled batsmen to have faster reaction times and higher percentage-correct responses. There are many possible reasons for this result. Firstly, the behavioural response (button press) is not sensitive enough to detect skilled differences. The absence of a skilled motor response could have contributed to this outcome. Secondly, the less-skilled batsmen’s ability to quickly process early ball flight information could have been as advanced as the skilled group. However, this is unlikely considering the large skill difference between groups. Further, the less-skilled batsmen’s ability to discriminate between deliveries as measured by their P300 latencies was significantly slower than the skilled group (Taliep et al., 2008). Finally, reactions times tended to be significant for both in-swing and out-swing deliveries. Perhaps a larger sample size would provide more conclusive behavioural responses.

Skilled and less-skilled batsmen have similar left temporal cortical responses to in-swing and out-swing deliveries (table 3). This indicates that, even if the batsmen were able to detect slight differences in the body cues of the bowler for the different delivery types, it did not change their responses at T3 and T4.

The most significant finding of this study is that the amplitude of alpha ERS in the left temporal cortex is higher relative to the less-skilled batsmen. Alpha ERS results from a decrease in the activity of the underlying neural networks of the left temporal cortex (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Foxe, Simpson, & Ahlfors, 1998; Kelly, Lalor, Reilly, & Foxe, 2006; Pfurtscheller, 1992; Pfurtscheller & Lopes da Silva, 1999; Smith, 1994). Using the method of cognitive inference, one may infer that the increase in the left temporal alpha ERS in skilled cricket batsmen is similarly associated with an increased suppression of the verbal and analytical centre (Hatfield et al., 1984; Haufler et al., 2000). Suppression of the
verbal and analytical centre does not only refer to suppression of overt speech, as the batsmen were not talking during the run-up and delivery of the ball. Suppression of the verbal centre in this case may rather refer to the ability of batsmen to suppress their covert verbalisation and analytical reasoning. This is consistent with a theoretical explanation that the analytical and motor processes compete for cognitive resources, so one has to be reduced or switched off in order for the other to be at its most effective. This results in a more energy-efficient mechanism that is typical of skilled sport performers (Hatfield et al., 2004; Kerick et al., 2007; Smith, McEvoy, & Gevins, 1999; Taliep et al., 2008). Irrelevant verbal and analytical processing could disrupt the task-relevant processing from occurring. The verbal and analytical centres are therefore suppressed to allow neural resources to be more appropriately allocated to the task. Skilled batsmen were therefore able to better suppress irrelevant verbal and analytical processing, resulting in a more efficient neural processing of the task. Masters and Maxwell (2008) also discuss this in the context of the reinvestment hypothesis. In the hypothesis the introduction of conscious control of the task results in a reduction in automation which hinders performance (Kinrade, Jackson, & Ashford, 2010; Maxwell, Masters, & Poolton, 2006). Perhaps the less-skilled batsmen were consciously trying to identify and focus on specific cues from the bowler’s action. Similar utilisation of cost-effective neural processes were found during a self-paced movement task in skilled rifle Shooters (Di Russo, Pitzalis, Aprile, & Spenelli, 2005b). Skilled rifle shooters’ BPs and negative slopes were found to occur later compared with nonshooters. Although these neurophysiological markers appear later in the skilled shooters, it has also been interpreted as representing energy-efficient mechanisms associated with skilled performance.

In the right temporal cortex ERD was evident for both skilled and less-skilled batsmen. This represents an increase in the activity of the underlying neuronal network (Pfurtscheller & Aranibar, 1977). In this case we infer that it could represent an increase in visuospatial processing of cues from the opponents action. Visuospatial processing of cues of the opponents during the motor preparatory period prior results in high-alpha ERD. This was not evident in a number of self-paced tasks like shooting and archery, where there was no significant change in the right temporal alpha power as the participants approached arrow release or trigger pull (Hatfield et al., 1984; Kerick et al., 2001; Landers et al., 1994; Salazar et al., 1990). Kerick et al. (2004) even found an increase in right temporal alpha power in novice shooters prior to trigger pull.

There was no significant difference in the ERD between skilled and less-skilled batsmen, suggesting that visuospatial processing as measured by high-alpha ERD at T4 is not a determinant of skill during the preparatory period. A reason for this could be that visuospatial processing is necessary for the task. Both skilled and less-skilled performers attend to visual cues from the opponent (McRobert, Williams, Ward, & Eccles, 2009; Savelsergh, Van der Kamp, William, & Ward, 2005); however, the interpretation of these cues may vary, and that is possibly not indexed by high-alpha ERD at T4. The processing efficiency and correct interpretation of the visual cues are dependent on the skill of the performer. Evidence for this can be found in visual tracking (Mann, Williams, Ward, & Janelle, 2007), temporal occlusion (Penrose & Roach, 1995), and spatial occlusion studies (Müller et al., 2006). The results of the present study are similar to self-paced tasks in pistol shooting and archery, where right temporal alpha does not separate skilled from less-skilled performers (Hatfield et al., 1984; Haufler et al., 2000; Kerick et al., 2001; Landers et al., 1994; Salazar et al., 1990). Furthermore, right temporal power also do not change following neurofeedback training in archery or in pistol shooting training (Kerick et al., 2004; Landers et al., 1994). This suggests that the visuospatial centre as measured from a high-alpha ERD perspective at T4 does not play an important role in distinguishing skill in both self-paced and reactive-type tasks, and the task requires visuospatial processing irrespective of the skill level.
The timing of the suppression of the verbal–analytical and visuospatial centre in the skilled batsmen is of particular importance. In the left temporal cortex it was estimated that ERS begins from approximately 1500 ms prior to ball release in the skilled and from only 250 ms prior to ball release in the less-skilled batsmen. If the timeline of the bowling action is considered at approximately 1500 ms prior to ball release, the bowler is still running towards the crease during the run-up phase, with no apparent change in the body action (figure 1). Soon afterwards, as the bowler approaches front foot take-off, the bowler’s body action changes significantly. It is possible that high-alpha ERS of the skilled batsmen increases in preparation for the important visual cues presented in the final phases of the bowler’s action. Contrarily, these ERS levels are reached only late in the left temporal cortex of the less-skilled batsmen, suggesting that less-skilled batsmen were preparing later for motor response and possibly also missing some visual cues. Their processes appear to be timed closer to ball release, similar to the findings of Müller et al. (2006). It is apparent that, for reactive sports, the timing of left temporal alpha ERS is an additional indicator of skill difference. This is especially important since the absolute differences reduce away from statistical significance within –250 ms from the stimulus (ie ball release).

If the reason for the suppression of the verbal–analytical centre at –1500 ms for skilled batsmen is that they are beginning to focus on detection of visuospatial cues, then the visuospatial centre (T4) would activate at the same time or slightly later. Therefore, one would expect to see significantly different T4 ERD, also starting around –1500 ms. However, this does not happen, and there is only close to significant difference, just before ball release. So there are a number of possibilities for this. Firstly, high-alpha T3 ERS (language centre suppression) could be in preparation for motor action. Secondly, high-alpha T4 ERD (visuospatial activation) does not fully tag the activation of the visuospatial centre during a complex dynamic action (eg perhaps other EEG features would better tag this, or perhaps no EEG feature represents this adequately). Finally, high-alpha T4 ERD does not provide insight into the skill element of visuospatial activation.

A significant positive correlation between ERS in the left temporal cortex and response selection suggests that those players who were able to suppress their verbal and analytic centre more were more likely to predict the type of delivery bowled. However, there was no significant correlation between reaction time and suppression of the verbal and analytical centre or activation of the visuospatial processing. This suggests that the highest ERS does not correlate to the fastest reaction times. Two possible reasons exist. Firstly, it is possible that there is an optimal range of ERD/ERS above and below which will result in poor performances. This is supported by studies in marksmen, where the increase in shooting percentage accuracy was associated with increases in the alpha power of the left temporal cortex up to an optimal level, beyond which the performance of the participants either remained constant or decreased (Kerick et al., 2004). Similarly, heightened alpha power in the temporal region was associated with worst scores in archers and marksmen (Landers et al., 1994; Salazar et al., 1990) and failure to execute shots in marksmen (Hillman, Apparies, Janelle, & Hatfield, 2000). Secondly, perhaps the neurophysiological signatures are more sensitive to skill differences than the behavioural measure recorded, as shown in earlier studies (Deeny et al., 2003; Taliep et al., 2008).

4.1 Training
High-alpha ERS may be used by coaches to train batsmen in suppression of the covert verbal and analytical activity of the left temporal cortex, prior to ball release, with a hypothesised improvement in performance. This is a feasible future research direction, given the large timing differences of approximately 1500 ms between the groups. In reactive or externally paced tasks where importance is placed on attending to visual cues of the opposition, training
should focus on the timing of the ERS. The performer should reach an optimal level prior to the opponent revealing critical visual cues. This timing would obviously change depending on the task or opponent but has been previously identified in archery and shooting (Kerrick et al., 2004; Landers et al., 1994).

There is also partial evidence suggesting that neurofeedback increases left alpha power and archery performance (Landers et al., 1994). An external alpha (10 Hz) audiovisual flickering stimulus, which has also been used to enhance alpha power in certain brain areas, was associated with improved sensorimotor performance in athletes (karate and fencing) and in nonathletes (Del Percio et al., 2007). Similar training techniques may be investigated to improve performance in a reactive sporting task.

4.2 Limitations of the study
The behavioural response (ie button press) is not an adequate indicator of cricket batting performance or expertise. Further, the danger of the batsmen being struck by the ball is removed in a laboratory trial. This is particularly true for less-skilled batsmen, who might be more ‘afraid’ of being struck by the ball. This ‘fear’ could further affect the neuronal processing prior to ball release. So an experiment with increased motor response demands—for example, real batting strokes—would be preferable; however, the subsequent movement and muscle artefact may render EEG recordings invalid. Sport EEG researchers have therefore often used simulated sport scenarios (Melnikov & Singer, 1998; Radlo, Janelle, Barba, & Frehlich, 2001; Taliep et al., 2008). Another limitation is that the participants were seated when viewing the video footage, which meant that participants slightly look upwards towards the screen. We were also limited by the number of available skilled right-handed batsmen, resulting in a small sample size.

5 Conclusion
This study shows that the higher levels of skill are associated with the ability to reduce task-irrelevant activity—that is, verbal–analytical processes—whereas the right temporal activation similarities are likely due to visuospatial processing being necessary for the task regardless of skill level. Further, the timing of the suppression of verbal–analytical processes is important. This finding may be applicable to reactive or externally paced sports in general. This is differentiated from earlier neurophysiological results in the literature that do not consider timing differences and were applicable to only self-paced sports.

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