Event-related potentials, reaction time, and response selection of skilled and less-skilled cricket batsmen

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Event-related potentials, reaction time, and response selection of skilled and less-skilled cricket batsmen

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Abstract. The differences in P300 latency, P300 amplitude, response selection, and reaction time between skilled and less-skilled cricket batsmen have been investigated. Eight skilled and ten less-skilled right-handed batsmen each viewed 100 in-swing, 100 out-swing, and 40 slower deliveries displayed in random sequence from projected video footage whilst their responses and electroencephalograms were recorded. Logistic regression was used to derive a discriminative function for the P300 data. This was done to determine whether the skilled batsmen differed from the less-skilled batsmen on the basis of pooled P300 amplitude and latency data. All the batsmen were correctly characterised as being skilled or less-skilled. Logistic regression equations with reaction time and correctness of response data indicated that behavioural data do not correctly classify skilled performance. It is suggested that skilled cricket batsmen have a superior perceptual decision-making ability compared with less-skilled cricket batsmen, as measured by P300 latency and amplitude. This appears to be the first study showing a link between skill and cerebral cortical activity during a perceptual cricket batting task and it could pave the way for future studies on mental processing in cricket batsmen.

1 Introduction

It has been suggested that one of the reasons for the success of one of the greatest cricket batsmen, Sir Donald Bradman, was his ability to ‘see’ the ball earlier than his contemporaries (Bradman 1984). Bradman agreed that earlier recognition of the future trajectory of the delivery allows a player more time to play his strokes (Bradman 1984). Such early recognition and correct response selection would characterise a superior perceptual decision-making ability in a batsman.

Previous studies of the perceptual decision-making ability of cricket batsmen of differing skill levels concentrated on the reaction time specific to the identification of the line and length of the delivered ball (Abernethy and Russell 1984; McLeod 1987; Adams and Gibson 1989; Penrose and Roach 1995). However, the measurement of visual sensory input and visual processing in the brain plays an essential role in evaluating perceptual decision-making processes. Quantifying these sensory visual processes, through the measurement and analysis of brain electrical waves, has the potential to increase our understanding of the perceptual decision-making capacity of batsmen. One of the ways in which this can be done is by the identification and quantification of the brain event related potential (ERP) of the cricket batsmen.

ERPs, which are measured from electrodes applied to the scalp (recorded with an electroencephalogram, EEG), are electrical records of the events related to the activation of the brain during sensory, motor, or cognitive processing (Kutas et al 1977). An example of an ERP is the P300, which represents the first major positive component, occurring at approximately 300 – 600 ms after stimulus onset. Polich (2004) proposed a neural model for the generation of the P300. This model is based on the discrimination between target and standard stimuli in an oddball paradigm. First, visual sensory information of an object travelling in space moves via the ventral 'what' stream for identification of the object, and the dorsal 'where' stream for spatial information about the motion of the object (for review see Goodale and Milner 1992; Creem and Proffitt 2001). The ventral stream projects from the visual cortex to the inferotemporal cortex, while the dorsal stream terminates in the posterior parietal cortex. Second, it is proposed that frontal lobe activity is activated when attention focus is required for task performance. Third, when attention is allocated to discriminate the type of visual stimulus, it results in the stimulation of the hippocampus for memory updating of the stimulus. The interaction of the hippocampus, frontal attention, and the ventral and dorsal streams results in the generation of the P300 or P3b (Polich 2004). This P3b is maximal over the parietal/central electrode sites (Comerchero and Polich 1998; Linden 2005).

The amplitude of the P300 is an index of the brain activity related to attention and working memory needed during the discrimination process (Kok 1997; Kramer and Strayer 1988; Noldy et al 1990). When less attention or effort is expended in the task, ie the more automatic it is, the smaller the P300 amplitude (Kutas et al 1977; Duncan-Johnson and Donchin 1982; Hoffman et al 1983; Herrmann and Knight 2001). On the contrary, better memory performance has been associated with higher P300 amplitudes (Noldy et al 1990; Mecklinger et al 1992). This interplay between attention and memory would affect the P300 amplitude.

P300 latency can be defined as the time required to identify, evaluate, and discriminate between events unrelated to reaction time (Kutas et al 1977; McCarthy and Donchin 1981; Ilan and Polich 1999). This latency time would in turn depend on the memory demand needed for the discrimination process. The higher the memory load, the longer P300 latency (Mecklinger et al 1992).

Cricket batsmen often have to discriminate between the types of delivery being bowled in order to play the correct stroke. During this discrimination process, we propose that a similar P300 (P3b) would be elicited in the brain of the batsmen, with a maximum at Pz. Therefore, the aim of the study was to measure P300, reaction time, and correctness of response of skilled and less-skilled batsmen whilst they watched filmed deliveries of medium to fast bowling in a realistic cricket-specific situation to evaluate their abilities for information processing. It can be hypothesised that the skilled batsmen will be able to discriminate between delivery types more quickly, thus reporting shorter P300 latencies. This discrimination process would be more automatic, requiring less attention, and hence resulting in smaller P300 amplitudes.

This quantification of the P300 activity underlying the perceptual decision-making in skilled and less-skilled cricket batsmen could provide a basis for understanding the visual sensory cortical processing of expertise in cricket batsmen. The results could be used as a benchmark for training studies, talent-identification studies, and the improvement of cricket batting performance.

2 Methods

Eight right-handed, skilled batsmen (who were currently playing provincial/county cricket) and ten right-handed, less-skilled batsmen (who were playing 3rd division club cricket) were recruited for the study. All subjects were briefed on the trial procedures and each provided written informed consent before entering the trial. The Ethics and Research Committee of the Faculty of Health Sciences at the University of Cape Town approved the study.

2.1 *Subjects*

The subjects' age and oral temperatures were recorded before the start of the trial. As far as possible, subjects were selected with similar social backgrounds and current occupations.

They were instructed to refrain from eating for 2 – 3 h before the trial, and not to consume any alcohol, caffeine-containing beverages, or any pharmaceutical agents which might affect the central nervous system on the day of the trial. Subjects were only selected if they had not been on any medication for a period of at least 2 weeks prior to the start of the trial. They were non-smokers, were not addicted to alcohol, and had no history of neurological disorders. All testing took place in the afternoons during the same time of the year. All subjects had normal or corrected-to-normal vision.

2.2 *Preparation of video*

Video footage of a medium-fast swing bowler was filmed from the viewpoint as if one was standing at the batting crease in the usual preparatory stance. The bowler filmed was a 1st division club cricketer from the Western Province League, South Africa. None of the subjects had previously batted against this bowler. This was done to ensure that none of the participants would have had prior opportunity to familiarise himself with anticipatory cues from the bowler's action that might influence the results.

10 in-swing deliveries (where the ball curves from right to left when the right-handed batsman is viewing the bowler from front on), 10 out-swing deliveries (where the ball curves from left to right when the right-handed batsman is viewing the bowler from front on), and 4 slower deliveries (approximately 15 – 20 km h^{-1} slower than the normal speed of delivery) were displayed. These 24 deliveries comprising three delivery types were each shown to the subjects ten times in different random orders so that each subject viewed a total of 240 deliveries (100 in-swing, 100 out-swing, and 40 slower balls).

2.3 *Trial procedure*

On arrival in the laboratory the subjects were fitted with a 128 Channel Electrical Geodesic™ System (Electrical Geodesics, Inc. 2001). The video sequence of cricket deliveries was projected onto a 1.8 m × 1.4 m white screen. Subjects were seated in an armchair 3.0 m from the screen in a darkened, sound-attenuated room. The subjects were instructed to press one of two keys on a finger-response pad, the one that corresponded to identification of either an in-swing or out-swing delivery, as soon as they recognised which delivery had been bowled, while maintaining a high level of accuracy. Whenever a slower ball was identified, the subject was required to refrain from pressing any buttons. The slower ball was included to prevent the subjects from guessing between only two delivery types and to ensure that concentration was maintained throughout the trial.

Before the start of the experimental protocol, the subjects performed a 6-over familiarisation trial. A different bowler of the same calibre, bowling the same 3 deliveries was used in the familiarisation trial.

2.4 *EEG testing*

EEG signals were sampled at 200 Hz and the electrode impedance was kept below 50 kΩ during the recording in line with the manufacturer's specifications (Electrical Geodesics, Inc. 2001). Data were filtered offline at 0.1 to 15 Hz bandpass. All segments containing eye blink and other artifacts were removed. Land and McLeod (2000) demonstrated that anticipatory eye movements do differentiate cricketing-skill levels. Despite this, eye movements were not different between groups in our study. Therefore eye-movement 'artifact' does contain potential information that is not presented here. All bad channels were removed from the analysis and an averaged reference was used on the remaining good channels. A 200 ms pre-stimulus baseline was set. The maximum P300 amplitude occurred over the parietal area, and electrode site Pz was therefore used for statistical analysis of the P300 amplitude and latency values. Only correct responses were analysed.

P300 was determined as the maximum peak occurring at Pz between 300 and 800 ms after stimulus onset. The designated stimulus was the video frame showing the release of the ball from the bowler's hand. The grand average of skilled batsmen and less-skilled batsmen for both correctly identified in-swing and out-swing deliveries was then determined by averaging the grouped P300 waveforms across subjects. Geodesic Sensor Net electrodes 62, 129, and 11 (Electrical Geodesics, Inc. 2001), which correspond to parietal (Pz), central (Cz), and frontal (Fz) electrode sites on the 10/20 system were used for P300 grand-average representation (Jasper 1958), although only the Pz electrode was analysed.

2.5 *Statistical methods*

Mann-Whitney tests were used to compare the medians of all the variables of the skilled and the less-skilled batsmen. Kruskal–Wallis rank sum tests were employed to simultaneously compare the medians of more than two variables, such as the median percentage-correct response between the in-swing, out-swing, and slower ball deliveries. Logistic regression analysis was used to derive discriminant functions (performance factors) to classify skilled and less-skilled batsmen.

3 Results

One less-skilled batsmen who did not have a clear P300 wave was removed from subsequent EEG analysis. Therefore, EEG analysis was carried out on nine less-skilled batsmen and eight skilled batsmen, while reaction time and percentage-correct responses were analysed for ten less-skilled batsmen and eight skilled batsmen.

There was no significant difference in median age (21.5 versus 21.5 years, $p = 0.96$) and oral temperature (36.3 versus 36.4 °C, $p = 0.37$) between the two groups of batsmen.

3.1 *P300 data*

Skilled batsmen had a significantly shorter median P300 latency compared to the less-skilled batsmen for both the in-swing (452 versus 520 ms, $p < 0.001$, table 1) and out-swing delivery (413 versus 465 ms, $p = 0.014$). Within-group comparison indicates that the less-skilled batsmen had longer P300 latency for the in-swing compared to the out-swing (465 versus 520 ms, $p = 0.003$). There was a tendency for the skilled batsmen amplitude for the in-swing delivery to be lower than that for the less-skilled batsmen (6.9 versus 8 μV, $p = 0.06$), whilst there was no significant difference between the groups for the P300 amplitude of the out-swing delivery (7.4 versus 7.8 μV, $p = 0.773$, table 1). The grand average EEG data for both in-swing and out-swing deliveries illustrate a parietal maximum (Pz) but a frontal negativity at Fz (see figures 1 and 2).

Table 1. Comparison of the median P300 latency, P300 amplitude, reaction times, and percentage-correct responses for the different deliveries, and 95% confidence intervals for the difference in medians. p-Values are for the Mann–Whitney test for equality of medians. Note: * indicates weak significance, $0.05 < p < 0.10$; ** indicates significant difference, $p < 0.05$.

Variable	Skilled batsmen ($n = 8$)	Less-skilled batsmen ($n = 10$)	95% confidence intervals		p-value
P300 latency: in-swing/ms	452	520	−45	−105	< 0.001
P300 latency: out-swing/ms	413	465	−10	−85	0.014**
P300 amplitude: in-swing/μV	6.9	8.0	−1.0	6.1	0.060*
P300 amplitude: out-swing/μV	7.4	7.8	−2.0	2.7	0.773
Reaction time: correct in-swing/ms	416	495	−150	11	0.083*
Reaction time: correct out-swing/ms	421	483	−210	23	0.083*
Reaction time: incorrect response/ms	401	458	−191	45	0.203
Correct in-swing/%	89.5	90.0	−22.0	6.0	0.593
Correct out-swing/%	94.5	89.5	−2.0	9.0	0.326
Correct slower delivery/%	83.0	69.5	2.0	25.0	0.018**

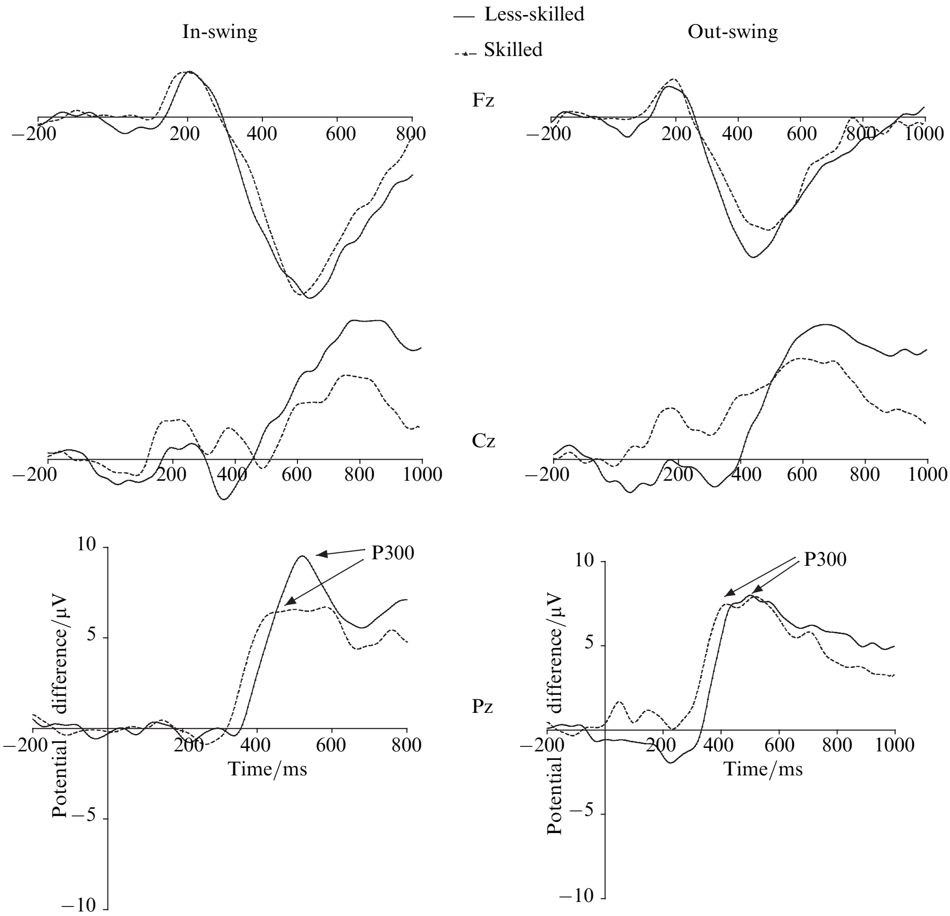

Figure 1. Grand average P300 data at electrodes 62, 129, and 11 (corresponding to Pz, Cz, and Fz on the 10/20 system) for the in-swing and out-swing deliveries.

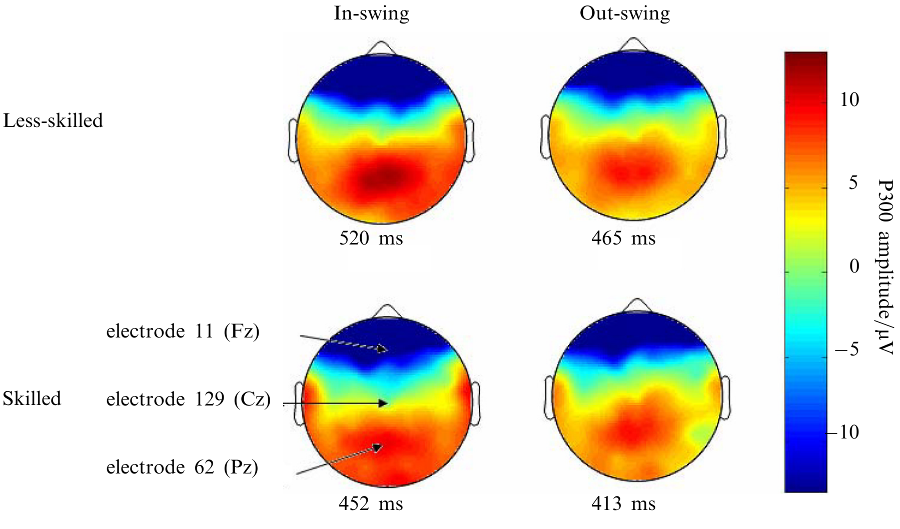

Figure 2. [In colour online, see http://dx.doi.org/10.1068/p5620] Grand average topographical head plots of P300 at a maximum peak, Pz, for the in-swing and out-swing deliveries. The corresponding P300 latency is shown below each topographical head plot.

3.2 *EEG data as a function of performance*

We wished to determine if the analysis of P300 data would allow separation of the two groups of batsmen. Using a stepwise selection procedure for logistic regression, we derived a function which classified our batsmen perfectly into skilled and less-skilled:

$$\text{Score} = (23.6 \times \text{amplitude out-swing}) + (4.4 \times \text{latency in-swing})\,.$$

High values of this function indicate less skill. It is interesting to note that the other two P300 variables were not needed in the equation, as their inclusion would separate the groups even further.

3.3 *Behavioural data*

There was a tendency for the median reaction time to be shorter in the skilled batsmen for both in-swing (416 versus 495 ms, $p = 0.083$) and out-swing (421 versus 483 ms, $p = 0.083$) deliveries. There was no significant difference between groups in median percentage-correct responses for either the in-swing or the out-swing deliveries (table 1). However, the skilled batsmen had a significantly higher percentage of correct responses to the slower deliveries (83% versus 69.5%, $p = 0.018$, table 1). Their median percentage-correct response was highest for out-swings and lowest for the slower balls for both the skilled ($p = 0.092$) and less-skilled ($p < 0.001$, table 2) batsmen. The percentage-correct responses for in-swing and out-swing deliveries were similar for the skilled batsmen ($p = 0.141$) whilst the less-skilled ($p = 0.003$) batsmen had significantly shorter out-swing compared to in-swing P300 latencies (table 2).

Table 2. Comparison of medians of variables within groups (Kruskal–Wallis test, p-values). Note: * indicates weak significance, $0.05 < p < 0.10$; ** indicates highly significant difference, $p < 0.01$.

Comparison variables	p-Value	
	skilled batsmen	less-skilled batsmen
Latency of in-swings and out-swings	0.141	0.003**
Amplitude of in-swings and out-swings	0.429	0.289
Reaction times for correctly identified in-swings, correctly identified out-swings, and incorrect responses	(0.872)	(0.635)
Percentage correct for in-swings, out-swings, and slower deliveries	(0.092*)	(< 0.001**)

3.4 *Reaction time and correctness of response data as a function of performance*

We wished to determine if the performance of the skilled batsmen separated them from the less-skilled batsmen on the basis of their reaction time and correctness of response data. The following function of the reaction time (in ms) and correctness of response data was formed:

$$\begin{aligned}\text{Score} = {} & -54.445 - 129 \times (\text{\% correct in-swing}) + 177.8 \times (\text{\% correct out-swing}) \\ & + 0.532 \times (\text{\% correct slower ball}) - 0.218 \times (\text{reaction time for correct in-swing}) \\ & + 0.124 \times (\text{reaction time for correct out-swing}) + 0.019 \times (\text{reaction time for incorrect} \\ & \text{responses}).\end{aligned}$$

The results of the logistic regression analysis mathematically separates the groups. However, the equation produced indicates that the skilled batsmen should have lower percentage-correct responses for the in-swing deliveries and higher reaction times for the out-swing deliveries. This is not typical of skilled performance. Thus, the behavioural data, although they separate the groups mathematically, do not separate the groups correctly in terms of their cricketing skill.

4 Discussion

Once the ball has been released by the bowler, an important cortical process that occurs in batsmen is the processing of visual information about the flight trajectories. In particular, the parietal area of the brain shows a large positive peak approximately 350–450 ms after ball release in both skilled and less-skilled batsmen (figure 1). This is consistent with a visual P300 waveform.

In this trial, subjects were required to discriminate between the types of delivery bowled. It can be suggested that the shorter P300 latency in the skilled batsmen is most probably associated with a faster evaluation and discrimination of the type of delivery bowled. Thus, faster P300 latencies could be the result of faster processing of the two visual streams, faster updating of memory, or faster integration of the hippocampus, frontal lobe, and ventral and dorsal visual streams. Shorter P300 latency has been associated with superior cognitive performance when attention is allocated for memory processing (Polich et al 1990; Reinvang 1999). Evidence for faster updating of working memory associated with shorter P300 latency has also been reported (Mecklinger et al 1992). It could be argued that the less-skilled batsmen had increasing difficulty in updating memory when attending to the relevant body cues of the bowler and flight information of the ball. The skilled batsmen on the other hand could perhaps attend to the important visual cues and integrate the relevant visual information more quickly, resulting in less memory demand and easier and faster recall of the working memory, thus having a shorter P300 latency.

It was also hypothesised that, coupled with the ability to recognise the nature of the delivery and its future trajectory earlier, the skilled batsmen would make this early decision more automatically and with less attention. Smaller P300 amplitudes would indicate that the skilled players have a tendency to make the decision with less attention than the less-skilled batsmen for the in-swing deliveries. It is believed that one of the reasons elite sports players are better able to perform is because they select and process the most relevant information (Abernethy and Russell 1984; Abernethy 1987, 1990a, 1990b; Renshaw and Fairweather 2000). As a result, less 'effort' is wasted on the processing of irrelevant information, which results in smaller P300 amplitudes. P300 amplitude has also been shown to decrease with an increase in memory load (Mecklinger et al 1992). It is possible that the less-skilled batsmen increased their memory demand at the time of ball release in an attempt to attend to the different visual cues given by the bowler. This would, however, lead to a decrease in the P300 amplitude. Although there might be this contribution of memory load, P300 amplitude is possibly more sensitive to change in attention in this cricket-related perceptual task. The attentional resources needed to make this decision could be the main cause of differences in P300 amplitude between skilled and less-skilled batsmen.

An interesting finding of this study is that the P300 latency for the out-swing delivery was significantly shorter than for the in-swing delivery for the less-skilled batsmen (table 2). The out-swing delivery is probably the most frequent delivery bowled by swing bowlers in cricket because of the potential of a batsman edging the ball for a catch to the wicket keeper or slip fielders. Less-skilled batsmen might be forming a pre-cue of the out-swing delivery because of its potential danger of dismissing the batsmen. If this pre-cue is correct, the latency of the P300 is shorter (Radlo et al 2001). The larger P300 amplitude of the less-skilled batsmen for the in-swing delivery could also suggest that they were attending harder during the discrimination process. However, skilled batsmen were equally able at detecting the swinging deliveries.

The grand average data indicate large negative amplitudes in the frontal area (Fz) of the cortex (see figures 1 and 2). Traditionally, P300 would have a positive peak at Fz. However, in this study, Fz is negative. The positive P300 is most probably overlapping with the large frontal negative component. Independent component analysis (ICA) or principal component analysis (PCA) might be able to separate the positive P300 from the large frontal negative component. Further investigation is, however, necessary. Previous baseball studies in which a video sequence for a batter was used to discriminate between throws never reported any P300 data from the frontal electrodes (Melnikov and Singer 1998; Radlo et al 2001). This large frontal negativity could result from this complex video stimulus and the applied nature of the protocol.

The skilled batsmen were also more likely to correctly identify the slower delivery (table 2). Skilled batsmen may interpret advanced cues based on the bowler's action and early trajectory of the delivery more effectively than less-skilled batsmen, resulting in better identification of the slower ball. Both skilled and less-skilled batsmen were less able to detect slower deliveries than those that swung (table 2). The most probable reason is that the slower balls are rarely presented in the video sequence. Also, batsmen face slower deliveries less frequently during cricket matches than in-swing or out-swing deliveries. Others have shown that batsmen have greater difficulty detecting deliveries that are bowled infrequently (Renshaw and Fairweather 2000).

Logistic regression used to derive a discriminative function for the P300 data indicates that P300 latency and amplitude as measured in this trial perfectly predict skilled performance. This is the first evidence relating cerebral cortical processing of a cricketing perceptual task and cricket batting skill. P300 could thus be used as a good indication of testing skill in cricket batsmen. However, the behavioural data did not correctly group the skilled and less-skilled batsmen according to the apparent cricketing skill. Previous researchers, all using projected video images similar to our trial, investigated the respective abilities of skilled and unskilled players to detect the line and length of the delivery (Abernethy and Russell 1984; McLeod 1987; Penrose and Roach 1995). These studies also failed to find significant difference in the percentage-correct response when they viewed more than 240 ms of the ball-flight delivery. Abernethy and Russell (1984) also found that skilled batsmen had quicker (although not significantly) reaction times for shot selection than did amateurs. The use of projected video images, mimicking match conditions, might not require separation of the groups according to reaction time and response selection.

4.1 *Limitations of the study*

The absence of a cricket stroke as a response under the time constraints of batting might not give a true reflection of expertise. It has been shown in other fast-ball sports like tennis that when the usual coupling of perception is retained, this results in superior prediction accuracy compared with an uncoupled or visual perception task, which only shows limited differences in expertise (Farrow and Abernethy 2003). Given a larger sample size under ecologically valid settings, trends in differences shown between skilled and less-skilled cricket batsmen in this study could be enhanced further. This needs further investigation. However, the use of EEG in the field is extremely difficult because of movement artifact when playing a stroke. For this reason the use of filmed action in realistic sports situations with an uncoupled response becomes the most appropriate method to evaluate EEG in cricket players. There is currently no way of overcoming this problem because of the constraints EEG recording places on the testing protocol. However, valuable information can still be obtained from this type of EEG testing.

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