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## An electrocortical comparison of executed and rejected shots in skilled marksmen

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### Abstract

Electroencephalographic (EEG) activity during the preshot period was investigated in seven skilled marksmen. Specifically, alpha and beta spectral power were obtained for the 4-s period prior to the execution or rejection of shots. Rejected shots were defined as those that resulted in the marksman's self-initiated decision to withdraw their rifle from the target rather than execute the shot. EEG activity during the preparatory period was contrasted between the executed and rejected shots to better understand the involved attentional processes associated with the preshot state. Results for rejected compared with executed shots revealed a progressive increase in alpha and beta power for rejected compared with executed shots, which increased across the preparatory period. Furthermore, increased spectral power was found in the left compared with the right hemisphere for both executed and rejected shots, and in the different regions of the scalp. Therefore, the decision to reject a shot seems to be characterized by inappropriate allocation of the neural resources associated with task execution. © 2000 Published by Elsevier Science B.V. All rights reserved.

*Keywords:* Alpha power; Beta power; Electroencephalography; Shooting; Marksmen; Preparatory period

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## 1. Introduction

The importance of attentional processes during the preparatory period prior to task execution for self-paced motor performances cannot be overstated. During this time, athletes involved with such tasks must maintain an adaptive focus to perform at peak levels, as even minor disruptions in attentional processes can lead to dramatic variations in performance (Landers, 1980; Druckman and Bjork, 1991). For this reason, marksmen have often been studied by sport scientists, as the maintenance of attentional processes during shooting is paramount to their performance. The time preceding each shot (i.e. 4–24 s) is considered the preparatory period in marksmanship competition, and is characterized as the time in which marksmen focus their attention on the target and attempt to minimize all extraneous movement in an effort to increase steadiness while aiming.

In an earlier investigation, Hatfield et al. (1984) assessed electroencephalographic (EEG) spectral power during the preparatory aiming period in elite marksmen (i.e. the several seconds prior to trigger pull) and found a progressive increase in alpha power in the left hemisphere up to the time of trigger pull. Additionally, this increased alpha power in the left hemisphere was accompanied by relative stability of alpha power in the right hemisphere. This cerebral activation pattern noted in marksmen is fairly robust as it has also been observed during the preparatory period of other closed motor tasks such as golf and archery (Salazar et al., 1990; Crews and Landers, 1993; Lawton et al., 1998).

Importantly, assessment of the cortical activity during self-paced motor performance has been confined to the examination of EEG spectral power prior to successfully executed trials. The rules of international small-bore marksmanship competition state that competitors have 80 min to shoot 40 shots at a static target for each of the three positions (i.e. standing, kneeling, and prone). Consequently, elite shooters have often been observed rejecting shots during the course of their performance. That is, marksmen will physically and mentally ready themselves to execute a shot (i.e. adjust stance, aim rifle, etc.) but will then withdraw from the target (i.e. lower the rifle without executing the shot). The self-made decision to reject a shot suggests that the competitor does not feel that he/she is in the ideal state during the preparatory period to perform optimally. When questioned as to why the shot was rejected, shooters will often vaguely and anecdotally respond that "It just didn't feel right". This experience is typically in contrast to that reported when a shot is executed and tends to be attributed primarily to psychological, rather than physical (e.g. biomechanical, neuromuscular, ventilatory), factors. Accordingly, measurement of the competitor's psychological state during the preparatory period may be predictive of performance outcome.

Unfortunately, most self-reported psychological measures are disruptive to the competitor's preshot routine, making it difficult to unobtrusively gauge their psychological state. For this reason, EEG measures are well suited for investigating the preparatory period for closed motor tasks as a dynamic process measured in real time with little or no disruption to the involved psychological state. Such an assessment can enable inferences regarding the involved psychological processes.

Importantly, previous researchers have neglected to examine EEG activity during the mental state prior to rejected shots; hence, comparisons of electrocortical activity between the preparatory states associated with such different outcomes have yet to be determined.

Since EEG alpha power has traditionally been viewed as inversely related to cortical activation (i.e. increased alpha power reflects decreased cerebral activation) (Adrian and Matthews, 1934), the left hemispheric increase in alpha power observed in elite marksmen has been interpreted as decreased cerebral activation of that hemisphere (Hatfield et al., 1984; Lawton et al., 1998). Consistent with research on the asymmetrical distribution of cognitive function in the cerebral hemispheres (Sperry, 1974), this interpretation suggests that increases in alpha power, as measured at left central, temporal and parietal sites, during the preparatory period, may relate to reductions in verbal-analytic processes such as self-talk (Davidson et al., 1990; Lawton et al., 1998).

In the sport psychology literature, self-talk has been reported to be potentially disruptive to athletic performance (Bunker et al., 1993) and, generally, is not a strategy employed by elite marksmen during shot execution (Lawton et al., 1998). In contrast to the psychological inferences advanced for the mental state prior to executed trials, an assessment of rejected shots may reveal more effortful processing and increased verbalization (i.e. self-talk). Such a state would be inconsistent with the characterization of efficiency that has been applied to skilled performance by Sparrow (1983) and, furthermore, would be inconsistent with the notion of automaticity that accompanies highly skilled motor performance (Fitts and Posner, 1967). According to the traditional view of EEG alpha activity, such a state (i.e. prior to a rejected shot) may be characterized by decreased alpha power in the left hemisphere.

Additionally, activation in right hemisphere central, temporal and parietal regions has been associated with visual-spatial processing (Sperry, 1974). Investigations of skilled motor performance have revealed that alpha power remains relatively stable or actually decreases in the right hemisphere during the preparatory period, suggesting that these regions may be increasingly active during the preparatory period for skill execution in superior performers (Crews and Landers, 1993; Hatfield et al., 1984). As such, one could speculate that a preparatory period culminating in a decision to reject or terminate a performance would be marked by a failure to adaptively allocate visual-spatial processes and a coincident increase in right hemispheric EEG alpha power relative to those preparatory periods associated with successful shot execution.

Therefore, it was hypothesized that increased alpha power would be evident in the left hemisphere during the aiming period prior to successful shot execution, when compared with that prior to shot rejection. We also predicted decreased alpha power in the right hemisphere prior to successful shots when compared with that observed in the right hemisphere during the same time period preceding rejected shots. Furthermore, it was hypothesized that the magnitude of these differences would increase across the successive time periods prior to shot execution or rejection. EEG beta (14–20 Hz) spectral power was also examined during the

preparatory period. As guided by traditional views of EEG activity (Adrian and Matthews, 1934), we predicted that beta activation would show the opposite trends to those observed for alpha activation.

## 2. Method

### 2.1. Participants

Initially, data from 12 skilled marksmen were collected. However, in an attempt to maximize external validity, participants were not instructed to reject trials. Hence, only eight of the 12 participants rejected trials, of which seven rejected enough trials (i.e. 10 or more) to be included in analyses. Therefore, seven right-handed (as determined using the Chapman and Chapman (1987) scale) and ipsilateral eye dominant skilled marksmen participated in this study. The participants consisted of six males and one female with a mean age of 34 years, an average of 12.2 years of shooting experience, and 7.4 years of competitive experience. Participants were identified by the Director of Education and Training at the National Rifle Association (NRA) and consisted of two junior Olympians and one Olympic trials finalist, and all participants held expert ranking by the NRA, meaning that they are able to shoot with 90–95% accuracy. Finally, participants were given up to 80 min to execute 40 shots from a standing position using a small-bore rifle.

### 2.2. Procedure

Testing occurred in a sound-attenuated room. Upon arrival, the participants were informed as to the general purpose of the study, given a tour of the testing area, and encouraged to ask questions regarding the testing procedure. Participants then read an informed consent form and were again given the opportunity to ask questions prior to signing the form.

After providing informed consent, participants outfitted themselves in regulation shooting attire (i.e. leather jacket, pants, and glove). They were then seated and prepared for electrocortical measurement in accordance with the guidelines set by the Society for Psychophysiological Research (Pivik et al., 1993). This preparation included fitting participants with a lycra electrode cap manufactured by Electrode-Cap International, Inc. (ECI), which housed tin electrodes. Omni-prep cleansing solution and ECI electrode gel were used to prepare the left and right frontal (F3, F4), central (C3, C4), temporal (T3, T4), and parietal (P3, P4) sites in accordance with the international 10–20 system (Jasper, 1958). All sites were referenced to the vertex (Cz), and the mid-frontal (FPz) site served as the ground. Four 10-mm Grass E5GH, gold-plated sensors located superior and inferior to the right eye, and to the right and left of the orbital fossi were placed to record bipolar electro-oculographic activity (EOG). Impedance values for all electrodes were  $\leq 5 \text{ k}\Omega$ , homologous sites (e.g. C3, C4) were within 1 k $\Omega$  of each other, and all channels were calibrated with

a 12-Hz 50- $\mu$ V signal prior to each testing session. When EEG calibration was completed, the Noptel ST-2000 (version 2.33) optical simulation system was attached to the barrel of the rifle in order to record the location of shots executed on the target so that live fire was not necessary.

Upon calibration of all instruments, participants were instructed to shoot 40 shots from a standing position in accordance with International Shooting Union rules. Over the course of 40 shots, participants were permitted to rest their rifles on a stand and were given the opportunity to sit briefly after each block of 10 shots. To maximize external and ecological validity, investigators did not instruct participants to reject shots and, therefore, participants rejected shots only when they deemed it necessary. Across all participants, there was an increased number of executed compared with rejected shots. Specifically, participants varied in the number of shot executed and rejected with a range of 22–40 shots executed ( $M = 36.6$ ,  $S.D. = 6.6$ ) and 10–29 shots rejected ( $M = 16.6$ ,  $S.D. = 6.3$ ). After the 40 shots were completed, all equipment was removed from the participants and they were further debriefed as to the purpose of the study and given the opportunity to ask any further questions.

### 2.3. EEG recording and data reduction

EEG and EOG data were collected and amplified 50,000 times using Grass model 12A5 Neurodata Acquisition amplifiers with a bandpass filter setting of 0.1–100 Hz. Furthermore, a 60-Hz notch filter was applied during the testing session. Analog data were collected continuously at the rate of 256 samples/s using a Neuroscan Analog/Digital converter, and recorded on-line with Neuroscan Scan 4.03 software installed on a Gateway 2000 Pentium computer. An event marker on the EEG trace indicated the execution of the shot or the initiation of putting the rifle down (i.e. shot rejection) for off-line sorting and epoching. Specifically, executed shots were marked via an acoustic trigger to the hammer of the rifle. Due to the inability to predict when rejected shots would occur, rejected trials were marked manually at the earliest sign of movement indicative of such a trial. That is, all marksmen rejected shots in a similar manner such that they raised the rifle straight upward prior to placing it on the rifle stand. Second, during data reduction, continuous data were inspected for movement artifact at the time of the manually prompted event markers. This inspection ensured that the manual marking coincided with the expected movement artifact associated with rejected trials.

Data reduction occurred off-line using NEUROSCAN EDIT 4.03 software. Each participant's continuous data were subjected to an eye-movement artifact correction algorithm (Semlitsch et al., 1986), sorted, and epoched into four 1-s periods prior to each trigger. Artifact detection for trials containing amplitude excursions of  $\pm 75 \mu$ V resulted in exclusion of the epoch. The remaining epochs were baseline corrected by subtracting the average amplitude for the 1-s epoch from each of the data points in that epoch. A bandpass filter from 1 to 35 Hz, a Hanning window with 10% taper, and a Fast Fourier Transform (FFT) were then applied to each epoch. Artifact-free, transformed epochs were then averaged for each participant

such that amplitude estimates were derived for each of the four successive epochs. Data were transformed to power spectral density values ( $\mu\text{V}^2$ ) and natural log-transformed (Davidson, 1988). Mean 8–13 Hz and 14–20 Hz log data constituted the alpha and beta power, respectively.

### 3. Results

Alpha and beta spectral power were subjected to separate within-subject  $2 \times 4 \times 2 \times 4$  (Trial Type  $\times$  Location  $\times$  Hemisphere  $\times$  Epoch) univariate repeated measures analyses of variance (ANOVA). The "Trial Type" factor referred to whether the trial was executed or rejected; "Location" indicated the region of electrode placement on the scalp (i.e. frontal, central, temporal, or parietal); "Hemisphere" compared the electrodes placed on the left and right hemispheres of the scalp; and "Epoch" referred to the four 1-s epochs during the preparatory period prior to shot execution or rejection. All analyses employed Greenhouse–Geisser correction to control for possible inflation of the Type I error value due to violation of the sphericity assumption. Follow-up analyses were conducted where appropriate using paired sample *t*-tests and Bonferroni correction to again control for inflation of the Type I error value. The alpha level was set at  $P \leq 0.05$  for all analyses prior to Bonferroni correction.

#### 3.1. Alpha spectral power

Alpha spectral power ( $\ln \mu\text{V}^2$ ) analyses revealed that Trial Type interacted with both the Epoch and Location factors, as increased alpha power was observed during rejected compared with executed shots for all epochs and locations. Specifically, The Trial Type  $\times$  Epoch interaction,  $F(1.9, 11.7) = 4.19$ ,  $P < 0.05$  ( $\phi = 0.61$ ), revealed increasing alpha power for rejected shots, while alpha power remained relatively stable for executed shots across epochs (see Fig. 1). Follow-up examination revealed increased alpha power for rejected compared with executed shots at the second and third epochs,  $t(1, 6) \geq 3.65$ ,  $P < 0.0125$ . The first and fourth epochs just missed significance ( $P = 0.017$ ) after Bonferroni correction ( $P = 0.0125$ ). Secondly, the Trial Type  $\times$  Location interaction,  $F(1.5, 9.0) = 8.05$ ,  $P < .02$  ( $\phi = 0.81$ ), revealed increased alpha power for rejected compared with executed shots at all locations (see Fig. 2). Follow-up analysis showed that significant differences were only observed at frontal and temporal locations,  $t(1, 6) \geq 3.74$ ,  $P < 0.01$ . Contrasts for the central and parietal regions yielded *t* values that approached significance ( $P < 0.03$ ). Contrary to our a priori hypothesis, the interaction of Trial Type  $\times$  Hemisphere was not significant,  $F(1.0, 6.0) = 2.01$ ,  $P > 0.21$ .

Additionally, three main effects occurred for the Trial Type, Location, and Hemisphere factors (see Fig. 3). For Trial Type, rejected trials were characterized by increased alpha power compared with shots executed,  $F(1, 6) = 14.32$ ,  $P < 0.01$  ( $\phi = 0.88$ ) (executed,  $M = 1.6$ , S.E. = 0.24; rejected,  $M = 2.2$ , S.E. = 0.13). The main effect for Location indicated the largest alpha power was in the temporal

region ( $M = 2.6$ , S.E. = 0.18) followed by the frontal ( $M = 2.0$ , S.E. = 0.28), and central ( $M = 1.2$ , S.E. = 0.16) region.  $F(1.7, 10.4) = 63.81$ ,  $P < 0.001$  ( $\phi = 1.0$ ). Follow-up analyses revealed that all locations differed from each other with the exception of the frontal and central regions,  $t(1, 6) \geq 3.74$ ,  $P < 0.01$ . Finally, the main effect for Hemisphere revealed increased alpha power in the left ( $M = 2.2$ , S.E. = 0.15) compared with the right hemisphere ( $M = 1.6$ , S.E. = 0.22),  $F(1, 6) = 15.63$ ,  $P < 0.01$  ( $\phi = 0.8$ ).

### 3.2. Beta spectral power

Beta power analyses showed the same interactions and main effects as observed for alpha power, but revealed less overall spectral power. Additionally, a main effect for Epoch was observed,  $F(1.5, 9.3) = 6.69$ ,  $P < 0.025$  ( $\phi = 0.74$ ), with beta power increasing across epochs. Follow-up testing showed that none of the epochs differed significantly from one another. The Trial Type  $\times$  Epoch interaction,  $F(11.3) = 6.95$ ,  $P < 0.015$  ( $\phi = 0.82$ ), was in the same direction as that observed for the alpha power analysis, and follow-up testing revealed increased beta power for rejected shots compared with executed shots across all epochs,  $t(1,6) \geq 6.86$ , (see Fig. 1). Furthermore, the Trial Type  $\times$  Location interaction,  $F(1.4, 8.3) = 6.69$ ,  $P < 0.03$  ( $\phi = 0.67$ ), was also in the same direction as that observed for alpha power.

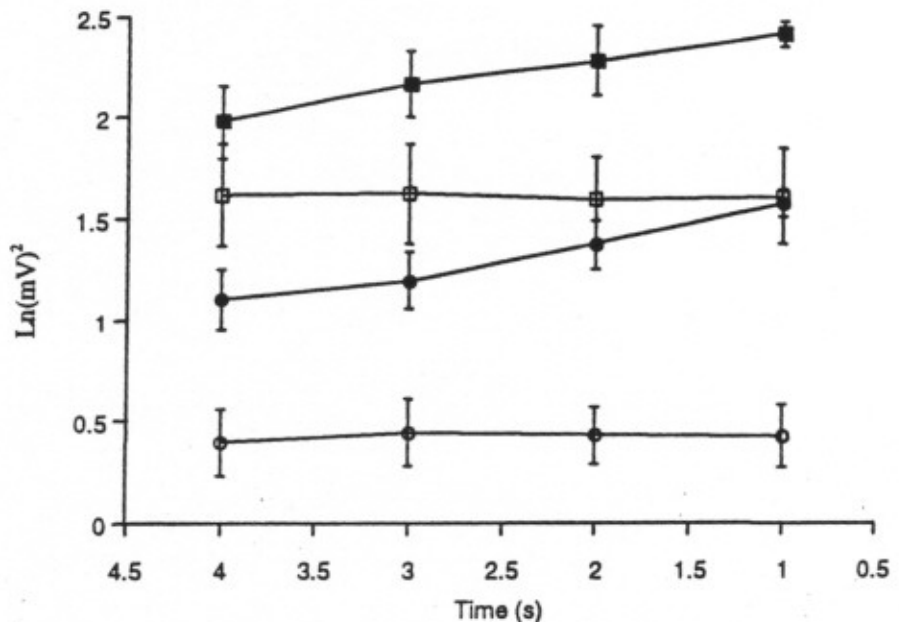


Fig. 1. Alpha and beta spectral power for the Trial Type  $\times$  Epoch interaction. The squared lines represent alpha power and the circled lines depict beta power, with open symbols referring to shots executed and the shaded symbols showing shots rejected.

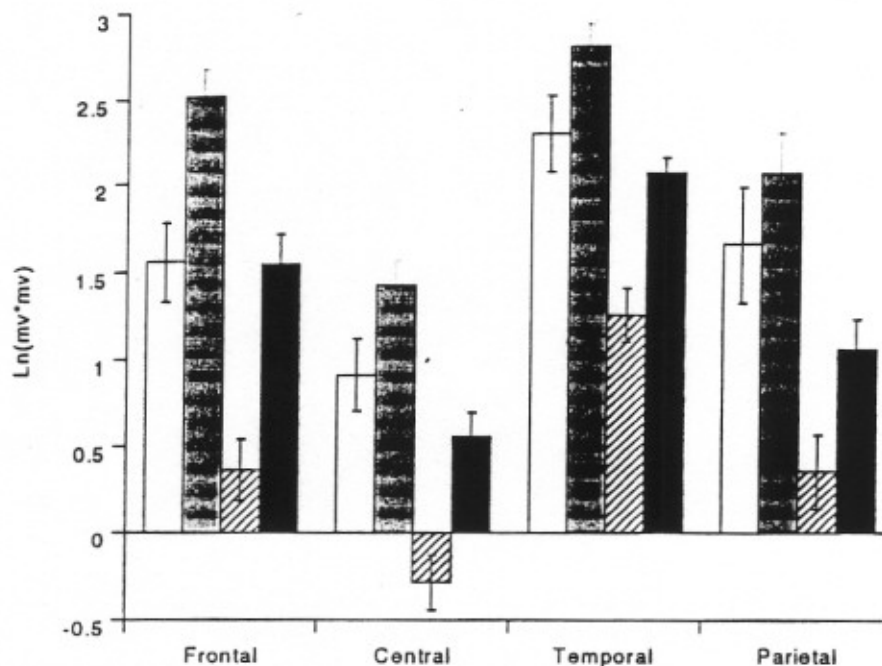


Fig. 2. Alpha and beta spectral power for the Trial Type  $\times$  Location interaction. The white bars depict alpha power for shots executed and the gray bars represent alpha power for shots rejected. The lined bars indicate beta power for shots executed and the black bars refer to beta power for shots rejected.

power analyses, and follow-up tests revealed increased beta power for rejected compared with executed shots across all locations,  $t(1,6) \geq 6.00$ ,  $P < 0.001$  (see Fig. 2). Similar to the finding for alpha power, and contrary to our a priori hypothesis, the interaction of Trial Type  $\times$  Hemisphere was not significant,  $F(1.0, 6.0) = 0.04$ ,  $P > 0.85$ .

The means for the other three significant main effects were as follows. Trial Type: executed,  $M = 0.42$ ,  $S.E. = 0.16$ ; rejected,  $M = 1.3$ ,  $S.E. = 0.10$ ;  $F(1, 6) = 68.31$ ,  $P < 0.001$  ( $\phi = 1.0$ ). Location: temporal,  $M = 1.7$ ,  $S.E. = 0.12$ ; frontal,  $M = 0.95$ ,  $S.E. = 0.15$ ; parietal,  $M = 0.72$ ,  $S.E. = 0.19$ ; central,  $M = 0.14$ ,  $S.E. = 0.14$ ;  $F(3, 4) = 54.96$ ,  $P = 0.001$  ( $\phi = 1.0$ ). Hemisphere: left,  $M = 1.1$ ,  $S.E. = 0.10$ ; right,  $M = 0.62$ ,  $S.E. = 0.15$ ;  $F(1, 6) = 23.59$ ,  $P < 0.01$  ( $\phi = .98$ ). All trends were in the same direction as that observed for the alpha power analyses (see Fig. 3). Finally, follow-up tests for the Location main effect revealed that all locations differed significantly with the exception of frontal and parietal regions,  $t(1,6) \geq 4.35$ ,  $P < 0.005$ .



#### 4. Discussion

Taken together, the data suggest that EEG spectral activity is sensitive to preparatory periods that are classified according to shot execution and rejection. The results reported here revealed increased alpha power for rejected compared with executed shots across both cerebral hemispheres. Furthermore, the difference in alpha power for Trial Type was found to increase during the second and third epochs compared with that observed for the first and fourth epochs. Additionally, the magnitude of the Trial Type differences in beta power increased across epochs. These findings are in opposition to the authors' a priori hypothesis that increased alpha power would be evident in the left hemisphere prior to successfully executed shots when compared with rejected shots. However, Salazar et al. (1990) reported that moderate increases in alpha power were related to better performance and that

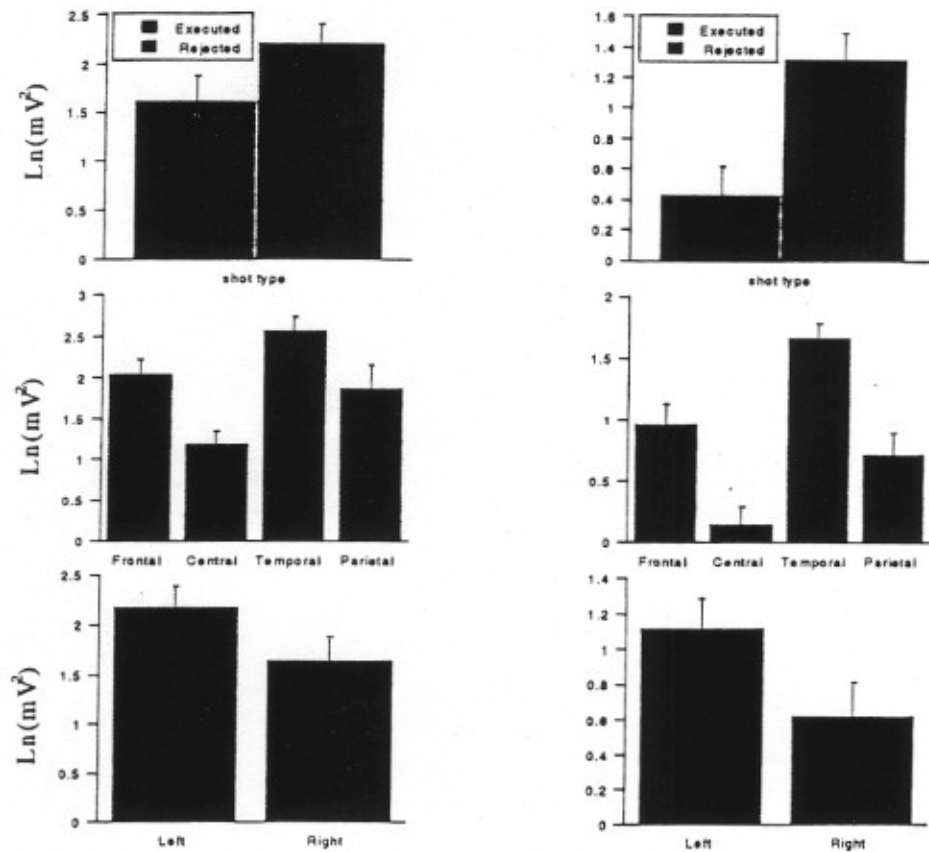


Fig. 3. Alpha and beta power for the three main effects. Alpha power is illustrated in the left column and beta power in the right column. The top row shows the main effect for Trial Type, the middle row illustrates the Location main effect, and the bottom row shows the effect for Hemisphere.

too great an increase resulted in poorer performance in elite archers. Therefore, the alpha power observed prior to the rejected shots in the present study may have been excessive.

The observed increase in alpha power for rejected compared with executed shots is consistent with previous findings (Earle, 1988; Salazar et al., 1990; Landers et al., 1994). Specifically, Salazar et al. (1990) compared left hemispheric EEG activity between better and worse shots in elite archers, and found increased alpha and beta power (i.e. 12 and 28 Hz) for the worst shots. Additionally, Landers et al. (1994) also found that poorer shots were associated with increased left hemispheric alpha power (i.e. 12 Hz), compared with better shots in novice marksmen. Similar findings have been reported outside of the psychomotor performance literature, as Earle (1988) showed that participants who exhibited increased alpha amplitude in the left and right hemispheres during high visual-spatial challenge also experienced confusion. These findings are consistent with the current study as increased spectral power was observed for rejected compared with executed trials across both hemispheres.

Furthermore, the findings for beta power were similar to those observed for alpha power in all respects. This finding is in direct opposition to classical interpretations of EEG spectral activation that would predict increases in alpha power to be accompanied by decreases in beta power, and vice-versa (Adrian and Matthews, 1934). However, Nunez (1995) provides an alternative explanation for the neural basis of EEG that reconciles this apparent contradiction. Nunez (1995) views both alpha and beta as lower frequencies relative to the entire EEG spectrum, whereas high-frequency activity would be characterized by gamma or 40-Hz activity, as identified by Sheer (1989). These lower frequencies are thought to index global cortico-cortico communication within the cortex. Accordingly, increases in alpha and beta power observed during the rejected shots may imply increased intracortical communication and, hence, more effortful processing. That is, more neuronal activity may be involved with rejecting a trial compared with shot execution. Alternatively, Pfurtscheller et al. (1996) have advanced the notion that increased alpha power or synchronization is indicative of 'cortical idling' or a state of disengagement of a cortical region during the negotiation of a challenge.

Additionally, due to the complex nature of the task, several processes must be utilized to successfully perform a shot. The management of these processes (i.e. attention, motor control, postural stability, etc.) may be differentially indexed by EEG spectral frequencies. For example, Ray and Cole (1985) have provided evidence that EEG alpha activation is primarily associated with specific attentional demands, while beta activity is more related to cognitive processes. Specifically, Ray and Cole (1985) found support for the notion that alpha power is related to the intake-rejection dimension of attentional processing such that 8–12 Hz power was associated with internal elaborations while rejecting or excluding environmental input. One could speculate that a failure to properly allocate task-relevant attentional resources to execute the shot could result from such internal task-irrelevant cognitive elaborations. In other words, the participant may have been subscribing to an inappropriate attentional style with regard to task demands. The finding of

increased beta power during the rejected shots may also be consistent with excessive cognitive elaboration during the preparatory period. This notion is supported by Ray and Cole (1985), who suggest that EEG beta is indicative of cognitive processing.

The finding of increased alpha power in the left relative to right hemisphere for both executed and rejected shots supports earlier research, not just with marksmen, but with other closed motor sport tasks. While this finding was initially observed in elite marksmen (Hatfield et al., 1984), it was extended to other tasks such as archery and golf putting (Salazar et al., 1990; Crews and Landers, 1993). Furthermore, increasing alpha power in the left hemisphere has been shown during "rallies" in individuals participating in a complex visuomotor performance tasks (i.e. the video game Pong) (Rebert et al., 1984). Moreover, Landers et al. (1994) showed that novice archers increased alpha power in the left hemisphere during a 14-week performance training course such that increased cerebral asymmetry was observed at the post-test compared with the pre-test. As stated earlier, the skilled participants in the present study were able to maintain a relative dominance of right hemisphere activity (i.e. increased left hemispheric alpha power) prior to both executed and rejected shots. The similarity in hemispheric dominance in both conditions may be due to the fact that both executed and rejected trials involve visual-spatial processing.

Collectively, these studies indicate that cognitive changes associated with skilled performance were accompanied by increases in hemispheric alpha asymmetry. This suggests that some degree of specialization ensues in the brain, as well as a state of increased processing efficiency (as interpreted by reduced activation, i.e. increased alpha power, in the left hemisphere). Since alpha power increases in the left hemisphere during the preparatory period of skilled performance, and the left hemisphere has been associated with verbal activation, this indicates the reduction of verbal processing and, possibly, the relative augmentation of visual-spatial processes that are relatively localized to the right hemisphere (Lawton et al., 1998). These findings can be interpreted as increased efficiency of cerebral activation as they imply appropriate allocation of resources underlying the achievement of a focused state.

Finally, regional differences in cerebral activation were found as Trial Type interacted with Location, suggesting varying levels of cortical specificity with the task. Previous research has shown that the left hemisphere is less active compared with the right hemisphere during the preparatory period in elite marksmen at central, temporal, and parietal sites. (Hatfield et al., 1984; Haufler et al., 1999). Furthermore, Pulvermüller et al. (1995) found decreased alpha power in the central, compared with other regions, during a fine motor task (i.e. finger tapping). Interestingly, the present data also revealed the same regional pattern, such that the lowest alpha power was observed in the central region that overlies the motor cortex; thus supporting Pulvermüller et al. (1995).

In conclusion, the data provided in this report support previous EEG performance research using closed motor tasks and extend the literature concerning the marksman's psychological state during the preparatory period. It would appear

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