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Concurrent Measurement of Electroencephalographic and Ocular Indices of Attention during Rifle Shooting: An Exploratory Case Study

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Abstract

Combining the technologies of EEG and eye tracking has been advocated as a means of gaining a better understanding of the underlying mechanisms that regulate human visual attention. However, successful concurrent acquisition of artifact-free cortical and ocular data of this nature has not been reported. Thus, the goals of this exploratory investigation were (1) to determine whether accurate and reliable data could be simultaneously recorded from EEG and eye movement instrumentation, and (2) to create a psychophysiological profile of an elite marksman. EEG spectral activity and eye movements were investigated during a regulation indoor shooting task with the Noptel laser shooting simulation. Results indicated that EEG alpha power and the quiet eye period were significantly associated, and that this relationship was a function of performance variability. Findings are discussed in the context of both traditional and contemporary psychophysiological accounts of expertise, with specific reference made to the organization of visual-cortical structures prior to shot execution. Future possibilities for this combined methodology in both self-paced and reactive sport tasks are discussed.

Key Words: alpha power, quiet eye, EEG, visual search, marksmanship

Introduction

Considerable evidence implicates the visual system as the dominant perceptual system, and the one by which all other sensory and perceptual systems are calibrated (Abernethy, 1996; Posner, Nissen, & Klein, 1976), leading researchers to suggest that the eye is the “window to the brain”. Correspondingly, much attention has been directed toward assessment of attentional parameters while performing visually demanding tasks in basic and applied settings. A significant body of this research has been conducted through separate examination of the cortical activation and visual search patterns exhibited by relative experts and novices as they perform various motor tasks. A convergence of these visual and cortical assessments would further facilitate understanding of the nature of attentional processing during skilled motor performance.

Electroencephalographic (EEG) recordings have been routinely employed in studies of closed motor skills such as golf (Crews & Landers, 1993), archery (Salazar, Landers, Petruzzello, & Han, 1990), the martial arts (Collins, Powell, & Davies, 1990), and shooting (Hatfield, Landers, & Ray, 1984, 1987). These researchers have focused primarily on the spectral content exhibited during the preparatory (or preshot) phase of motor tasks. Additionally, research using event-related potentials has been reported (e.g., Konttinen & Lyytinen, 1992; Konttinen, Lyytinen, & Era, 1999).

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From these studies, reliable differences in EEG spectral activation [especially alpha (8-13 Hz) power], with respect to hemispheric specialization (left versus right), have been identified. In self-paced tasks (such as shooting sports), there is relative consensus that a decrease in left cortical activity (as marked by an increase in left-hemisphere EEG alpha power) is matched with little or no change in the right hemisphere prior to task execution (Hatfield *et al.*, 1984, 1987; Landers *et al.*, 1994; Rebert, Low, & Larsen, 1984). This relative quieting of the left hemisphere with stable or subsequent increases in activation of the right hemisphere (as exhibited by decreasing alpha power) is one of the most consistent findings associated with psychophysiological assessment of experts in closed tasks. Lawton, Hung, Saarela, and Hatfield (1998) have suggested that cortical activity in the left hemisphere is quieted to reduce potential interference with the spatial programming of the right hemisphere. This idea is consistent with a more general notion in the motor behavior literature that skilled performance is marked by efficient allocation of resources (i.e., reduced effort) during performance (Sparrow, 1983).

Corroborating these findings to a large extent, recent research with eye movement recording instrumentation has demonstrated the existence of what Vickers (1996) has called an extended “quiet eye” period among expert performers prior to task execution. The quiet eye period refers to the temporal duration between the final fixation to a stimulus and the motor response. The quiet eye duration has been found to be stable on a single location and is significantly longer for highly skilled performers (in comparison with lower skilled), as well as being longer for accurate compared to inaccurate performance (Vickers, 1996). Postulated is that the quiet eye is a period of “optimal organization of the neural structures underlying aiming at far targets”, during which visual spatial parameters are calibrated (Vickers, 1996, p. 25).

Given the close association between the eyes and the brain, a logical question is, “What is the degree of convergence that exists between gaze behavior and cortical activity among experts that may enable them to perform at a high level of expertise?” This issue was investigated through concurrent examination of the cortical and ocular correlates of a sharpshooter in an ecologically valid setting.

The mission of the project was twofold. First, an initial attempt was made to combine two modes of assessment for simultaneous acquisition of psychophysiological data representing known correlates of expert performance. Although this combined methodology has been recommended as a means to enhance understanding of visual attentional processing (e.g., Williams, Davids, & Williams, 1999), concerns surrounding the capability to collect simultaneous psychophysiological data of this nature while minimizing instrumental interference and artifact, presumably prevented attempts to do so. While recognizing these potential limitations, gaze behavior (assessed through the use of an eye movement recording system) and cortical activity (measured by electroencephalogram) were concurrently recorded during the preparatory period, up to and including the trigger pull sequence.

Secondly, the content of the data was of interest for the purpose of gaining a better understanding of the psychophysiological characteristics of an expert shooter. Pursuant to this objective, a within-subject comparison was made between the best and worst shots to determine whether differences existed between the preparatory states of this particular shooter, leading to disparate outcomes. The psychophysiological profile generated for the best shots was expected to more closely reflect optimal psychophysiological characteristics compared to the relatively poorer shots. More specifically, it was expected that increased alpha power in the left hemisphere and longer quiet eye periods would characterize the most accurate shots, while the converse would be true for the least accurate shots.

Methods

Participant

The participant was a 46-year old Asian-American male classified as a sharpshooter in the National Rifle Association (NRA) classification scheme. He had been shooting for approximately 9 years and was an active competitor, competing in eight matches during the year prior to being tested. He shot right-handed, was right eye dominant, and reported corrected to normal visual acuity, a self-report that was strongly supported by his high level of expertise and shooting accuracy.

Measurement Recording Devices

The following instruments were used to record gaze behavior, cortical activity and shooting performance.

Gaze behavior

An Applied Science Laboratories (ASL; Waltham, MA) 5000 SU eye movement system was used to collect eye movement information. The 5000 SU system is a video based monocular corneal reflection system that measures the point of gaze relative to video images recorded by a headband mounted scene camera and an eye camera. The system has the capability to measure pupil position and corneal reflex, which are used to compute visual gaze with respect to the optics. Data from the right pupil and cornea were processed by a Gateway 2000 IBM Pentium 233-MHz laptop computer and superimposed in the video image recorded by the headband mounted scene camera. The scene camera was arranged in a direct manner (i.e., pointing directly at the target) to maximize clarity in recorded images and to minimize interference with the natural shooting position. Although a direct scene camera position is susceptible to parallax error when dealing with targets (or individuals) moving toward or away from a point of interest, this was not an issue given the static nature of the task.

The exact point of gaze at all times could be evaluated frame by frame with respect to the visual display. System accuracy was $\pm 1^{o}$ visual angle with precision of 1^{o} in both vertical and horizontal directions. Recalibration of the eye monitoring equipment was performed consistently with manual offset commands throughout the completion of the task. Only in situations where the manual offset could not correct for errors was the entire calibration sequence redone.

EEG

A lycra cap (Electro-Cap Intl.), embedded with tin electrodes was connected to a Grass Model-12 Neurodata Acquisition amplifier. Electrocortical signals were amplified 50,000 times, and filters were set from 0.1 to 100 Hz. EEG data was sampled at a rate of 512 samples/sec. A 60-Hz notch filter was also applied. The analog EEG data were converted using a Neuroscan Analog/Digital converter, recorded online with Neuroscan Scan 4.03 software installed on a 133-MHz Gateway computer, and collected continuously.

Shooting simulator

The Noptel Shooter Training System (ST-2000, version 2.33), an optical simulation system with a light emitting and receiving optical unit, was used in favor of live ammunition for this investigation. This system enabled performance assessment without actually firing ammunition and provided other performance information besides shot accuracy, such as duration of aiming, time on target, and time on the center of the target (i.e., the bull).

A retro-reflective boarder surrounded the target, and prism techniques were utilized to transmit online trajectory information from the rifle to a Dell 486 microcomputer. To maintain distance/target size ratio, an official small-bore rifle target designed for a shooting distance of 50 m was reduced to 10 mm in diameter using photo reduction and the participant stood 5 m from the target.

Procedure

Testing occurred in a sound-attenuated chamber. Upon arrival for testing, the participant was told of the general purpose of the study, was shown the data collection apparatus, and was permitted the opportunity to ask any questions regarding testing procedures. He then read an informed consent form, and was again permitted to ask any questions before signing the form.

After providing informed consent, the participant was permitted to outfit himself in regulation shooting attire (shooting pants, jacket, and shoes). He was then seated and prepared for electrocortical measurement in accordance with the Society for Psychophysiological Research guidelines (Putnam, Johnson, & Roth, 1992). The lycra cap was fitted to the participant's head and five electrode sites (T3, C3, Cz, C4, T4) were prepared using Omni-prep and ECI electrode gel based on the International 10-20 system (Jasper, 1958). All sites were referenced to the vertex (Cz) and the ground electrode was prepared using the mid-frontal (FPz) site. Bipolar electro-oculographic activity (EOG) was collected to assess vertical and horizontal eye movement artifact for subsequent off-line editing of the EEG record. Impedance values for all recording electrodes were ≤ 5 kohms and all channels were calibrated with a 12-Hz, 50-μV signal prior to the testing session.

Following EEG calibration, the participant was outfitted with the eye tracking equipment. To combine the instrumentation, the eye-tracking headband was fitted over the Electro-Cap, but was not reported to be uncomfortable, and did not interfere with the acquisition of cortical activity. In fact, the eye tracking system appeared to facilitate the degree of contact between the electrodes and the scalp. After securing the EEG and eye movement equipment, calibration of the eye tracking system commenced by having the participant focus on a nine-point reference grid, as indicated by markers affixed to the same wall on which the target was placed. In this manner, the target corresponded to the middle point of the reference calibration grid. Calibration of the eye tracking system was achieved by acquiring the coordinates of each point of the nine-point reference system as the participant shifted gaze to that location. In this manner, the point of gaze recorded on videotape corresponded to that in the actual environment. Calibration of the eye tracking system was completed with the participant in the actual shooting position to maximize the accuracy of the calibration. The shooting position of interest for this investigation was the standing small-bore position.

The Noptel system was then calibrated while the participant took 10 “sighting” shots in the standing position, with the instruction that he was to aim for the center of the target (i.e., the bull). Based on these 10 shots the center of shot grouping was established. The participant was then asked to take three more shots and to state where he thought each shot hit the target with respect to the bull. When the final three shots corresponded to where the participant stated the shots hit, testing began.

The participant was then asked to shoot 40 shots as if in competition. Although the task was self-paced, the participant was required to shoot the 40 shots during the course of an 80-min period. This is in accordance with the typical rules of competition rifle shooting at the national and international level. Over the course of the 40 shots, the participant was permitted to rest his rifle on a post, and was also permitted to sit briefly after each block of ten shots. In total, four trial blocks of 10 shots per trial block were completed.

Data Reduction

Gaze behavior

Visual search data were analyzed off-line with a Panasonic AG7350 VCR (Tokyo, Japan) in a frame-by-frame manner according to the procedures outlined by Vickers (1996). The primary eye movement measure of interest was the quiet eye period, as defined previously. To reiterate, the quiet eye period refers to the temporal duration between the last fixation to the target (i.e., the bull, in this case) until the initiation of the trigger pull. From a distance of 5 m, the cursor of the eye tracking system (representing point of gaze) completely covers the bullseye. However, the Noptel target was mounted on a white square background such that when centered on the target, the point of gaze cursor completely fit within the white border. This coordinate arrangement operationally defined fixation location on the target.

To determine quiet eye duration, a small microphone was attached to the barrel of the rifle to record the sound of trigger pull. This signal was then fed into an audio channel and recorded online with the image generated from the scene camera. When examined off-line, frames were counted from the point of trigger pull (as marked by onset of a peak in the audio channel) back to the initiation of the final fixation on the target to identify the duration of the quiet eye period.

EEG

Electrocortical data reduction also occurred off-line using Neuroscan Edit software. Cz referenced continuous data were corrected for vertical, followed by horizontal, eye movement artifacts using the Semlitsch, Anderer, Schuster, and Presslich (1986) correction algorithm. Each trial was then epoched. Artifact detection for trials containing amplitude excursions of ± 75 μV were excluded from further analyses. Epoched data were bandpass filtered from 1 to 35 Hz, baseline corrected, and subjected to a Fast-Fourier Transform (FFT). Data for the most accurate and least accurate shots were sorted into one-second bins for the 4 s time period preceding the trigger pull. The 8 to 13 Hz data were then natural log transformed prior to statistical analysis.

Data Analysis

The primary dependent measures of interest were the quiet eye duration, EEG alpha power, and performance measures (scores obtained by the Noptel shooting simulator). Furthermore, comparisons were made between the 13 most accurate shots and the 13 least accurate shots to determine whether these extreme discrepancies in outcome were characterized by different psychophysiological profiles. Finally, Pearson Product-Moment correlational analyses were used to examine the relationship between quiet eye duration and EEG alpha power.

Results

Quiet Eye Period

Findings for quiet eye duration indicated stable patterns across the four trial blocks (10 shots each) of interest, with values ranging from 20-25 s across trials. Specifically, mean quiet eye durations (in seconds) were 20.26 (*s*=4.02), 25.08 (*s*=5.01), 21.68 (*s*=5.78), and 24.07 (*s*=5.22) across Trial Blocks 1-4, respectively. To determine whether differences in quiet eye periods influenced performance, a *t*-test was conducted to compare the 13 least accurate shots (score of 8 or below) and the 13 most accurate shots (score of 10+), but was not significant ($t(22) = .51$, $P>.05$). However, descriptive trends indicated that quiet eye durations were shorter and more variable for poor shots (*M* =22.20, *s*=8.38) in comparison with better ones (*M* =23.44, *s*=4.31) (See Figure 1).

EEG Spectral Content

Based on previous research, alpha power differences were investigated in the left and right central and temporal regions (i.e., C3, C4, T3, and T4). Descriptive results showed that increased alpha was apparent in the left compared to the right hemisphere for both the central and temporal regions (*C3 M*=.75, *s* =.55; *C4 M*=-.17, *s* =.33; *T3 M*=2.84, *s* =.53; *T4 M*=1.53, *s* =.44). Separate 2 x 2 [Shot Quality (most accurate vs. least accurate) x Site] analyses of variance for central and temporal regions indicated no significant differences among the 13 best and 13 worst shots. Given the low statistical power, the findings of no significant differences in this analysis was not surprising. However, trends indicated that increased activation was observed in the temporal region relative to the central region. Observation of Figures 2 and 3 demonstrate disparity of alpha power among the central and temporal sites of interest for relatively good and poor shots. As was the case for the quiet eye period, tendencies in EEG alpha

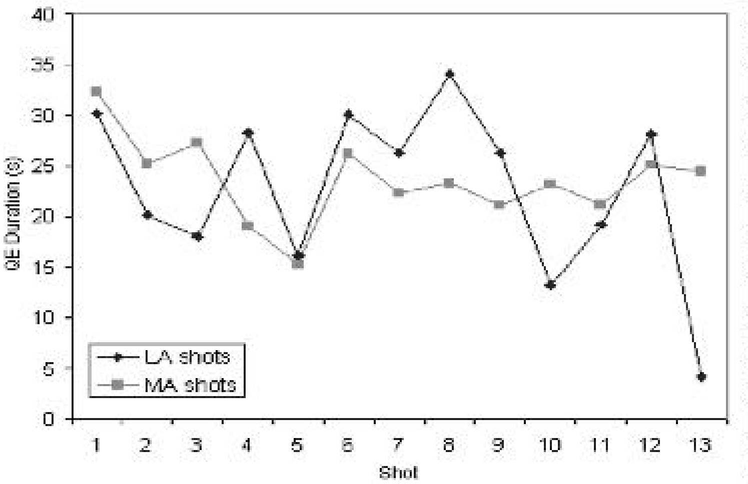

Figure 1 Quiet eye durations across the 13 most accurate (MA - score of 10+) and 13 least accurate shots (LA - score of 8 or below).

reflected a more ideal preparatory state prior to relatively good shots in comparison to relatively poor shots. The hemispheric laterality effect was expected for alpha power as these findings are robust in previous literature and suggest reduced activation of that hemisphere (Hatfield et al., 1984). The data remained stable during the preparatory phase prior to trigger pull, as minimal changes in alpha power were observed at all sites.

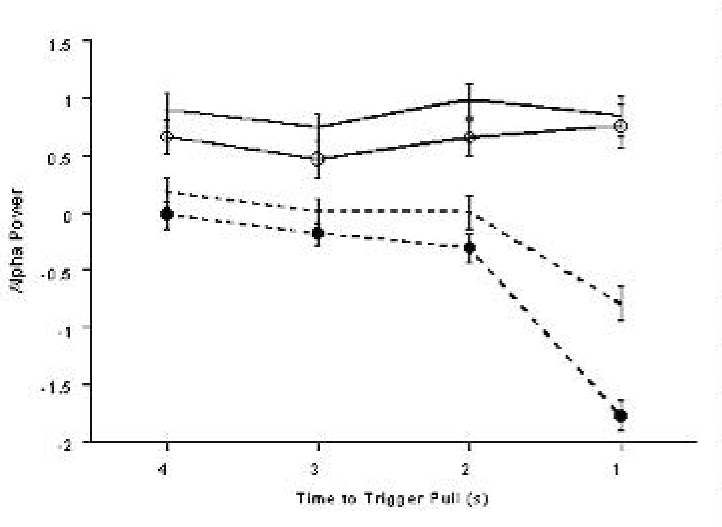

Figure 2 Left (C3) and Right (C4) alpha power at central sites for most accurate and least accurate shots. Specifically, solid lines characterize C3 and C4 is depicted with dashed lines. Closed circles represent least accurate shots and no symbols for most accurate shots.

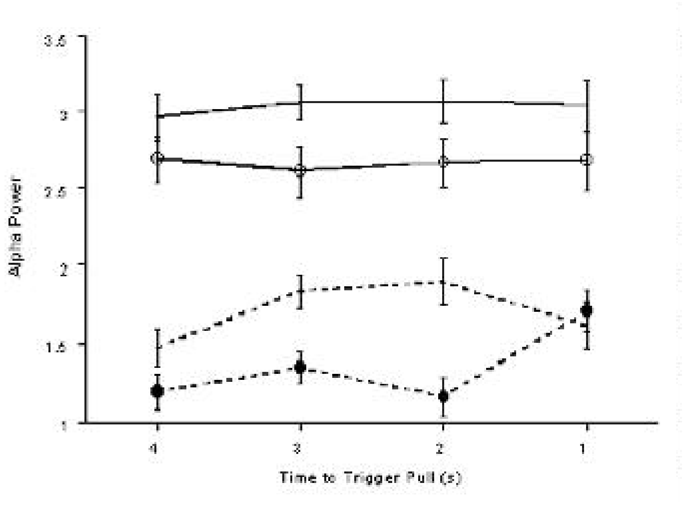

Figure 3 Left (T3) and Right (T4) alpha power at temporal sites for most accurate and least accurate shots. Specifically, solid lines characterize T3 and T4 is depicted with dashed lines. Closed circles represent least accurate shots and no symbols for most accurate shots.

Relationship between Quiet Eye and Alpha Power

To determine whether the quiet eye period was related to differences in spectral content at the specific cortical sites of interest, Pearson Product-Moment correlation coefficients were calculated among the variables. The analyses indicated a significant association between the quiet eye period and EEG alpha levels at C3 ($r = .497$, $P < .05$) and T3 ($r = .471$, $P < .05$) for the 13 best shots. Analysis of the 13 worst shots indicated no relationship between cortical activation and the quiet eye period for any of the four cortical locations.

Discussion

Typical criticisms of eye movement research tend to be related to the necessity of inferring line of attention from line of sight, as well as the inability to differentiate "looking" from "seeing" in experimental contexts (e.g., Williams, Davids, Burwitz, & Williams, 1993). This study marked an exploratory attempt to begin to address these issues through concurrent recording of gaze behavior and EEG spectral activity during the preparatory stage of elite marksmanship.

Given the need to empirically substantiate assumptions concerning the underlying psychological processes that influence visual search patterns, as well as concerns regarding the capability to record artifact-free data with these combined technologies, the goal of this investigation was to determine whether simultaneous measurement of gaze behavior and electrocortical activity was not only possible, but also a promising advance in instrumentation that could be used in future investigations. The relatively uneventful data collection process was quite auspicious in these respects. Aside from the typical re-calibration and troubleshooting that is routinely encountered with separate collection of these measures, the investigation proceeded in a systematic, error-free manner. Furthermore, from a practical point of view, the participant reported little discomfort or task interference from the instrumentation. The lack of problems experienced in the shooting context suggests that this method of assessment could also be employed with minimal difficulty in other self-paced sport tasks.

In addition to considerations regarding instrumentation capabilities, a primary purpose was to determine the coupling between EEG and gaze behavior associated with performance during the shooting task. Psychophysiological profiles were successful in delineating the performance variability of the shooter. Longer quiet eye periods were significantly associated with the development of higher levels of EEG alpha power in the left hemisphere for the most accurate when compared to the least accurate shots, corroborating previous evidence that has linked these characteristics with more effective performance of self-paced, far-aiming tasks. Trends in the EEG findings were consistent with previous research (i.e., Hatfield *et al.*, 1984, 1987) that has identified a quieting of the left hemisphere associated with relative performance expertise (Lawton *et al.*, 1998). Despite limited statistical power in the analyses, a significant association emerged between quiet eye duration and left hemisphere alpha activity, lending support to the notion of a coupling between these perceptual indicators.

Results can be interpreted such that organization of visual system parameters may lead to, or be reflective of, increased activation of relevant cortical pathways. In accordance with the view advanced by Hatfield *et al.*, (1984) as well as Lawton and colleagues (1998), increases in alpha power accompanied by longer quiet eye periods may indicate an overall quieting of visual-cortical activation. Further, Nunez (1995), contends that increased alpha power may reflect cortico-cortico communication (i.e., neural networking). In light of Vickers' (1996) notion that the quiet eye period reflects the organization of relevant neural structures, the observed increase in alpha may be indicative of such processes. As indexed by increases in left hemisphere alpha power, as well as longer quiet eye periods, enhanced shooting proficiency may necessitate an overall quieting of visuo-cortical integration. Furthermore, an intriguing finding was the relatively low variability that characterized the quiet eye periods of good shots as opposed to poor ones. From a speculative point of view, perhaps an ideal window of opportunity exists that is reflected in the degree of ocular and cortical coupling, and relative consistency of these psychophysiological states must be achieved to reach expert performance levels.

These results are encouraging to researchers who are interested in examining associations among related psychophysiological variables. Recent sport research has been directed toward developing a more coherent understanding of the temporal EEG characteristics [i.e., event-related potentials (ERPs)], that provide markers of mental chronometry such as stimulus identification, stimulus discrimination, and response selection. For example, relative expert and novice baseball players exhibit distinct temporal patterning with respect to the amplitude and latencies of ERPs during pitch recognition (Melnikov & Singer, 1998). Despite the valuable findings that have surfaced from these studies, a possible weakness is a lack of understanding with respect to the specific environmental stimuli that elicit these cortical states. Of interest would be determining how athletes or other performers search their environment, and the meaningfulness and relevance (as inferred through ERP characteristics) of these fixated cues to their anticipation and decision-making capabilities.

Conclusions

In conclusion, the initial attempt to concurrently examine the convergence between gaze behavior and cortical activation was successful and appears promising as a measurement strategy to be applied across a number of situations to further understand attentional processes. The intraexpert approach to evaluating differences in shooting performance yielded important results that warrant replication with a larger sample of expert and novice shooters. Future investigations should assess whether the psychophysiological characteristics displayed by this expert are shared by others, as well as how expert shooters compare with those of lower skill levels. Through identification of these differences, recommendations can be provided to help aspiring shooters refine their shooting approach to be more reflective of the preparatory strategies used by elite marksmen.

From a theoretical standpoint, the preliminary findings provided valuable insight into the cognitive processes that occur during the quiet eye period preceding response initiation. In addition, the methodological and instrumentation capabilities derived from this exploratory study provide new avenues for research with other self-paced tasks (as well as externally paced sport contexts) that could significantly enhance understanding of attentional processes during psychomotor performance, and the emotional factors that may influence these processes.

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