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Effectiveness of Archery Training on Attention and Cognitive Function: An Electroencephalography (EEG) Study

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This study investigates the impact of a six-week archery training intervention on cognitive function, utilising electroencephalography (EEG) signals for neural activity assessment. Twenty participants were divided into experimental (n = 10) and control (n = 10) groups. The experimental group underwent archery training, while the control group received no training. This research aims to address the need for shooting sports interventions to enhance cognitive abilities through archery training. Pre- and post-intervention assessments included cognitive tasks (Stroop effect, choice reaction time), with continuous EEG recording during cognitive task performance. Statistical analysis, utilising repeated measures ANOVA, identified significant differences between pre- and post-tests. Findings revealed increased alpha power (9–12 Hz) in the frontal and parietal regions during the Stroop effect task and choice reaction time in the experimental group compared to baseline. Moreover, notable improvements in reaction times for both cognitive tasks were observed. These results provide robust evidence for the influence of archery training on neural dynamics affecting attention and cognitive performance. The study underscores the potential of archery training to enhance cognitive abilities, addressing the imperative for effective strategies in cognitive enhancement.

Keywords: Archery; target-shooting sport; brain activity; electroencephalogram cognitive performance

I. INTRODUCTION

Electroencephalography (EEG) stands at the forefront of neuroscience research, offering a non-invasive and high-temporal-resolution approach to unravel the complexities of attention and cognitive function within the human brain (Ganasan S. *et al.*, 2021; Souza & Naves, 2021). As attention plays a pivotal role in cognitive processes, EEG's ability to capture real-time neural dynamics provides a unique opportunity to delve into the mechanisms shaping our cognitive landscape (Miller, 2011). Evidence suggests that the stage for a comprehensive exploration of EEG's role in measuring attention and cognitive function, underscoring its significance in advancing our understanding of the intricate interplay between brain activity and cognitive processes.

In the dynamic realm of sports, cognitive performance is a critical determinant of success, prompting researchers to incorporate EEG into studies exploring the cognitive impact of sports interventions. This study focuses on leveraging EEG to measure attentional enhancements resulting from targeted sports training. The integration of EEG allows for a nuanced investigation of the neural signatures associated with attention during and after sports interventions, providing invaluable insights into the cognitive benefits of athletic training. This paves the way for an in-depth examination of how EEG, as a powerful tool, contributes to our

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understanding of attentional processes in the context of sports interventions.

Engagement in shooting sports has garnered increasing attention not only for its competitive allure but also for its potential cognitive benefits, particularly in training attention. The precision and focus demanded by shooting sports, whether archery or marksmanship, create an environment that necessitates heightened mental concentration. As participants navigate the intricacies of aiming and accuracy, the training inherently hones attentional skills. The study for an exploration into the cognitive advantages of shooting sports, shedding light on how these activities serve as not only avenues for sporting excellence but also as effective training grounds for enhancing attentional capabilities.

Archery training, a prominent discipline within the realm of shooting sports, holds a multifaceted appeal as a potential catalyst for enhancing attention and cognitive function. The intricate fusion of physical precision and mental focus demanded by archery creates an optimal environment for the cultivation of heightened attentional skills. During the shooting phase, archers engage in complex visual, spatial, emotional, and mental tasks, which inherently stimulate and enhance cognitive processes through training (Lee 2009; Vrbik *et al.*, 2015). In recent times, several shooting sport were also prescribed to people with different attention problem to get a better output (Vrbik *et al.*, 2015; Wickramanayake *et al.*, 2016). However, there are a few studies available to our knowledge on the effectiveness of archery training by combining behavioural measurements and brain patterns (Ertan *et al.*, 2018; Feng, 2022). Therefore, there is a need to know the groundwork for an exploration into the cognitive advantages conferred by archery training, emphasising its potential not only as a sporting pursuit but also as a purposeful means of refining attention and cognitive capabilities using EEG. Hence, the present study is proposed to study the comparative effectiveness of archery training over received no training on attention and cognitive function using EEG through Stroop effect and choice reaction time task as an outcome measure tools.

II. MATERIALS AND METHOD

Twenty-four healthy volunteers (8 males, 16 females; mean age, 23.33 years ± 2.46; height, 1.63 m ± 0.73; weight, 62.10 kg ± 7.95) with no prior archery experience or history of attention or neurological disorders participated. All were right-handed, as per the Edinburgh handedness inventory and selected based on strict inclusion criteria, confirmed through structured interviews. One participant withdrew due to time constraints, and three were excluded for technical EEG recording issues. Randomly assigned to experimental or control groups, detailed demographics are presented in Table 1. Power analysis, conducted with G*power 3.1.9.7 software, determined a minimum sample size of N=16, considering a medium effect size (0.50), α = 0.05, and power (1-β) = 0.8, as per relevant studies (Liao *et al.*, 2022). To accommodate potential data loss, recruitment aimed for N=20. The study received ethical approval from the Medical Research and Ethics Committee of Universiti Kebangsaan Malaysia (UKM PPI/111/8/JEP-2022-428), and participants provided written informed consent before participation.

Table 1. General characteristics and demography of each group ($\bar{x}$, σ)

	Experimental Group (*n*=10, 4 males, 6 females) M (SD)	**Control Group (*n*=10, 4 males, 6 females) M (SD)**	**Total (*n*=20)**	***t***	***p***
Age (years)	22.9 ± 1.60	22.8 ± 2.30	22.85 ± 1.93	0.113	0.911
Weight (*kg*)	1.64 ± 0.082	1.61 ± 0.075	1.62 ± 0.079	1.373	0.187
Height (*m*)	63.9 ± 9.30	58.8 ± 7.18	61.35 ± 8.50	1.006	0.328

*p-value < 0.05, significant difference, independent t-test

A. Archery Training Intervention

The six-week archery intervention aimed to enhance brain wave patterns and cognitive performance, with three times a week, 30-minute per sessions (see Fig. 1). The training, led by expert coaches from the Malaysian Traditional Archers Organization (PERTAMA), emphasised fundamental archery skills and coordination. Following the recommendations of Ustun and Tasgin (2020), which involved four weeks of 60-minute sessions three times a week, we extended the intervention to six weeks but reduced the session duration to 30 minutes per session. This adjustment was made to allow for sustained engagement over a longer period, a strategy supported by research suggesting that longer intervention periods, even with shorter sessions, can lead to more enduring cognitive benefits (Smith *et al.*, 2018).

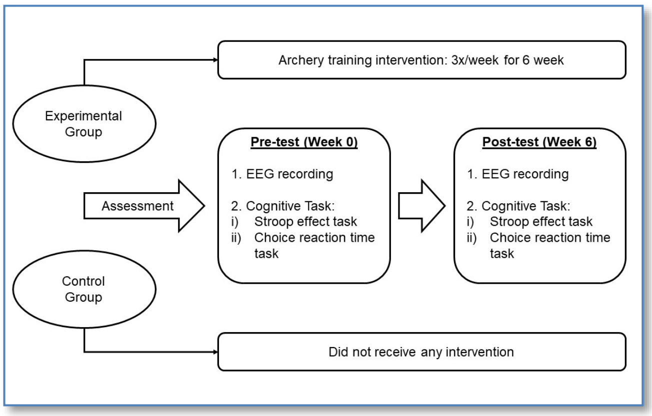

Figure 1. Timeline of the study design

Each training session provided participants with archery equipment, encouraging additional practice between sessions. Target shooting adhered to the World Archery Federation guidelines (World Archery, 2020), with the archer positioned 3 meters away, shooting 25 to 35 arrows per session. To mitigate potential learning effects between sessions, the experimental group observed a minimum two-day rest period (Tursi & Napolitano, 2014). This approach promoted skill consolidation and focused attention, contributing to improved cognitive performance. For valid comparison, a control group with no regular physical activity or specific interventions was included. By contrasting the experimental group's performance with the control group, we aimed to isolate and evaluate the specific effects of the archery training intervention on attention and cognitive function.

B. Cognitive Functions

In order to examine the effects of archery training on the performance behaviour of an active motor task, subjects were required to perform a Stroop effect (SE) and choice reaction time (CRT) task.

1. Stroop Effect (SE) task

The Stroop effects task, a well-established neuropsychological test assessing cognitive interference and focused attention (Ghosh *et al.*, 2022), was employed in this study, adopting the design formulated by John Ridley Stroop in 1935 (Stroop, 1935) and utilised in prior research studies (Atchley *et al.*, 2017; van Son *et al.*, 2018). To enhance methodological rigour, specific improvements were incorporated into the methodology.

Participants were presented with colour word stimuli on a computer screen, each displaying a colour word (e.g., "RED," "GREEN," "BLUE," or "YELLOW") in either a congruent font colour (matching the word meaning) or an incongruent font colour (non-matching the word meaning). Participants were given detailed instructions to perform the task using both hands, with their fingers placed on specific keys (as illustrated in Figure 2). Their objective was to respond swiftly and accurately by pressing the corresponding keyboard key that matched the font colour of the presented word (e.g., "R" for red, "G" for green). The task comprised 40 trials, half presenting congruent colour-word pairs and the other half incongruent pairs. Response times for each trial were recorded to assess cognitive interference.

Figure 2. Starting position of fingers on the keyboard

The attentional experimental paradigm for the Stroop effects task with both conditions is visually represented in Figure 3(A). A practice block preceded the main task, allowing participants to familiarise themselves with the task and keyboard keys. The practice block's duration and specifics were tailored to ensure participants' proficiency. The Stroop effect task, designed to induce focused attention, required participants to overcome interference between word meaning and font colour, engaging cognitive resources and measuring their ability to inhibit automatic responses.

Response time was measured using computer software recording the time from stimulus appearance to participants' key press. Collected data, including accuracy rates and error monitoring, were analysed to assess attentional control and cognitive interference ability. By employing the Stroop effect task, the study aimed to provide insights into the effects of archery training on attention and cognitive function.

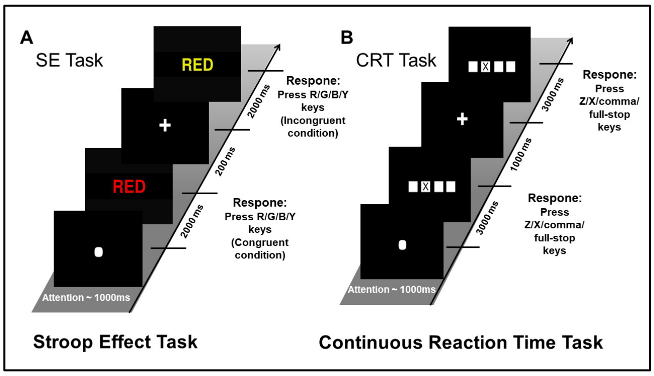

Figure 3. The attention experimental paradigm (A) is a SE task (40 trials) and (B) CRT task (150 trials)

2. Choice Reaction Time (CRT)

This study utilised the well-established choice reaction time (CRT) task, a measure of cognitive processing speed, implemented through the Deary-Liewald Reaction Time task using RT version 310 software. The CRT task, which has demonstrated reliability and validity in previous studies (Deary *et al.*, 2011; Marmeleira *et al.*, 2018), required participants to respond quickly and accurately to specific stimuli presented on a computer screen.

Participants focused on the screen, promptly pressing a designated keyboard key when a cross appeared randomly within one of several squares, as illustrated in Figure 3(B). Four keys, "Z," "X," "comma," and "full-stop," corresponded to squares displayed from left to right on the screen. Participants positioned their fingers accordingly on the keyboard. Each cross remained until the corresponding key press, disappearing before another cross appeared. The inter-stimulus interval, randomised between 1 and 3 seconds, represented the time between responses and the subsequent cross appearance. The task encompassed eight practice trials and 150 test trials to ensure participants understood instructions and performed accurately.

Response time and inter-stimulus intervals were recorded for each trial, facilitating subsequent analysis. The computer program employed specific parameters and criteria for correct responses to ensure consistent measurement. Control measures, including maintaining consistent lighting conditions and standardised instructions, were implemented to minimise confounding factors and ensure task validity. Through the CRT task, this study aimed to evaluate participants' cognitive processing speed, providing insights into their ability to swiftly and accurately respond to visual stimuli and shedding light on the effects of archery training on attention and cognitive function.

C. EEG Recording

EEG signals were recorded using the Emotiv EPOC+ headset, a 14-electrode brain-computer interface (BCI) adhering to the international 10/20 system, encompassing electrodes AF3, AF4, F3, F4, FC5, FC6, F7, F8, T7, T8, P7, P8, O1, and O2 (Jurcak *et al.*, 2007), as illustrated in Figure 4. Electrodes were moistened with a saline solution to optimise contact, ensuring a reliable electrical connection between electrodes and the scalp. Two mastoid sensors, CMS/P3 as a ground reference and DRL/P4 as a feed-forward reference, minimised external electrical signals (Jalene, 2014).

Impedance levels were visually monitored using the Emotiv Control Panel software, with green indicating low impedances and good recording quality, while red indicated high impedances and poor quality. Regular checks and adjustments addressed impedance-related issues, ensuring the reliability of EEG data. The experiment commenced upon reaching acceptable impedances. To refine EEG signal quality, a hardware band-pass filter (0.15 to 269.5 Hz) was applied to eliminate high-frequency noise and low-frequency drift, enhancing the accuracy of brain activity representation. Digitised EEG data were acquired at a sampling frequency of 128 Hz per channel and transmitted via Bluetooth to a computer. This high sampling rate facilitated the capture of fine temporal dynamics, enabling a comprehensive analysis of neural activity related to attention and cognitive processes.

Participants received instructions before tasks to minimise muscle contractions and eye blinking during EEG sessions, reducing movement and ocular artefacts that could introduce noise and complicate EEG signal interpretation.

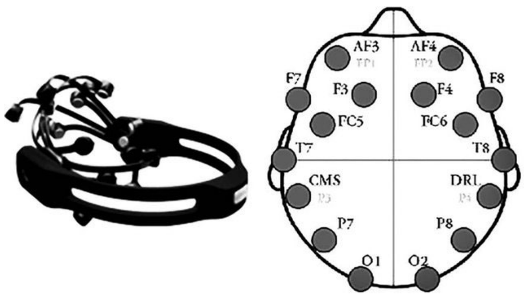

Figure 4. Location of the Emotiv EPOC+ headset

D. Experimental Design

The experimentation environment was carefully controlled, with subjects tested in a dimly lit and quiet room to minimise external distractions and maintain a consistent testing environment. Participants were seated comfortably in an armchair with flexed elbows at 90 degrees, hands in a relaxed, pronated position, and were instructed to keep their eyes open, facing a computer screen throughout the session (see Fig. 5). Before the experimental session, participants underwent a practice session to familiarise themselves with cognitive tasks, ensuring task requirements were clear and minimising potential learning effects during the actual recording session. The experimental session comprised a 20-minute recording, including resting state and two cognitive tasks, with short breaks between tasks to allow participants to rest and maintain optimal performance.

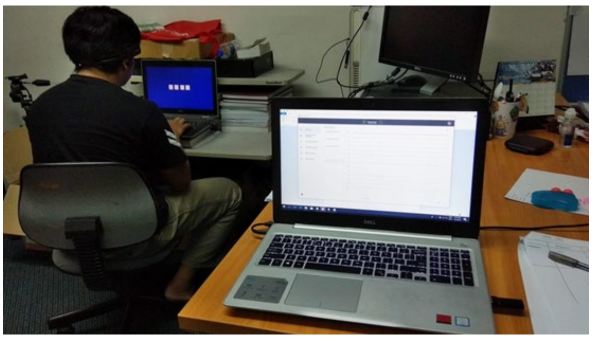

Figure 5. The setting for EEG data acquisition

During the recording session, EEG data were collected using the Emotiv EPOC+ headset, featuring 14 electrodes placed on the scalp according to the international 10/20 system for consistent and reliable signal acquisition. The session began with a baseline measurement during resting state recordings, where participants were instructed to relax, keep their eyes open, and fixate on a central cross displayed on the screen for five minutes while EEG signals were continuously recorded. Participants were explicitly instructed not to engage in specific cognitive activity, close their eyes, or fall asleep, aiming to induce a relaxed yet alert state during resting EEG recordings, minimising task-related cognitive activity's influence.

Following resting state recording, participants performed the Stroop effect task (SE), responding to colour-word stimuli. EEG signals were recorded for three minutes during this task to capture brain activity associated with cognitive interference. Subsequently, participants completed the choice reaction time test (CRT), a task involving responding to visual stimuli by pressing corresponding keyboard keys, with EEG signals recorded for five minutes to capture neural correlates of processing speed and response execution. Break durations between cognitive tasks were carefully determined to balance participant fatigue and engagement, based on results from a pilot study and participant feedback, with a one-minute break between each cognitive task block. After six weeks of archery training intervention, post-test procedures were repeated to obtain data reflecting participants' performance after training, maintaining consistent experimental design and task order between pre- and post-test sessions. Figure 6 depicts the experimental design, task sequence, and timing of data collection.

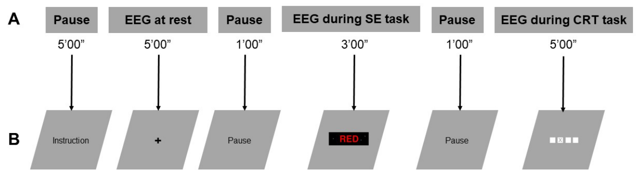

Figure 6. Experimental design

E. EEG Data Analysis

Commercial software, BrainVision Analyzer 2.0 from Munich, Germany, was utilised for EEG data analysis. Event-related power (ERPow) analysis was conducted to assess the impact of archery training on regional oscillatory activity during active states, specifically attention and motor reaction time tasks. ERPow analysis was selected due to its sensitivity in detecting changes in neural oscillations related to cognitive processes, particularly in tasks involving attention and reaction time (Klimesch, 2012; Noh *et al.*, 2016;

SantibuanaAbdRahman *et al*., 2021). Frequency bands of interest—θ (4-7Hz), α (8-12Hz), and β (13-30Hz)—associated with cognitive tasks requiring attention and motor processing were selected. EEG data from specific channels (AF3, AF4, F3, F4, FC5, FC6, F7, F8, P7, P8, O1, and O2) were chosen, processed using filters (1 Hz to 40 Hz bandpass with a 24 dB slope, and a 50 Hz notch filter) to eliminate unwanted noise. To reduce the influence of muscle or ocular activity, a semi-automatic segment inspection-rejection approach was implemented, excluding segments with amplitude values beyond the range of ±70 µV (Noh *et al*., 2016; Santibuana AbdRahman *et al*., 2021).

The filtered signals were then analysed using Fast Fourier Transform (FFT) to examine frequency components, and ERPow Modulation to assess neural power changes related to cognitive tasks. Fast Fourier Transform (FFT) analysis computed power spectra, transforming data from the time to frequency domain, enabling signal decomposition. Power spectra were computed for frequency bins ranging from 1 to 40 Hz using non-overlapping Hamming windows to minimise spectral leakage, a technique commonly applied in EEG analysis (Mitra & Bokil, 2008; Oppenheim & Schafer, 1999). For event-related relative changes in EEG power at a specific electrode, an event-related desynchronisation/synchronisation (ERD/ERS) procedure was employed (Noh *et al*., 2015). This procedure considered inter-subject and inter-electrode variations, assessing relative changes in power density compared to a pre-event baseline.

$$ERPow_x = \frac{Pow_{x_{event}} - Pow_{x_{reference}}}{Pow_{x_{reference}}} \times 100 \quad (1)$$

where,

$ERPow_x$: Percentage of instant power density

$Pow_{x_{event}}$: Power density of event

$Pow_{x_{reference}}$: Power density of baseline for 'pre-event'

ERPow modulation was interpreted as a percentage change in instant power density relative to the pre-event baseline, employing the established ERD/ERS protocol (Noh *et al*., 2016). ERD signifies a decrease in power within a frequency band compared to baseline, while ERS indicates an increase. This approach, commonly used in Transcranial Magnetic Stimulation and electroencephalography (TMS-EEG) studies for assessing interregional functional connectivity, was employed to analyse changes in neural oscillatory activity linked to specific task events. Analysing ERD/ERS patterns aimed to reveal temporal dynamics in cognitive processes and their corresponding neural mechanisms.

F. Statistical Analysis

IBM SPSS Statistics software, version 21.0, was employed for data analysis. Descriptive statistics, including means and standard deviations, were computed for demographic data. The Shapiro-Wilk test confirmed normal data distribution, and Levene's test assessed homogeneity of variances. Independent t-tests compared baseline EEG and cognitive performance between groups, with Cohen's d as an effect size measure.

To evaluate intervention effects, repeated-measure ANOVAs assessed changes over time (pre-test, post-test) for each condition of experimental group and control group (EG, CG). This analysis explored main effects of time and group, along with interaction effects. Spectral analysis of mean ERPow involved repeated-measure ANOVA for θ (4-7Hz), α (8-12Hz), and β (13-30Hz) frequency ranges during active motor tasks. Effect size was estimated using partial eta squared (η2p). Sphericity assumption was verified with Mauchly's test, applying Greenhouse-Geisser epsilon adjustments when necessary. Sphericity, a key assumption of repeated measures ANOVA, was tested using Mauchly's test to ensure the variances of differences between conditions were equal. In cases where the sphericity assumption was violated, Greenhouse-Geisser epsilon adjustments were applied to correct the degrees of freedom and reduce the risk of Type I errors. Post-hoc paired t-tests, adjusted with the Bonferroni method for multiple comparisons, were conducted for significant main effects and interactions. Post-hoc paired t-tests, adjusted using the Bonferroni method, were conducted to account for multiple comparisons, minimising the likelihood of false positives and providing a more conservative approach to identifying significant main effects and interactions (Abdi, 2007; Field, 2013). A significance level of $p < 0.05$ indicated statistical significance.

III. RESULT AND DISCUSSION

The results of this study revealed significant findings regarding the effects of archery training on attention and cognitive function, as assessed through both behavioural measures and EEG recordings. Independent t-tests compared baseline EEG and cognitive performance between groups, with Cohen's d as an effect size measure. No significant differences in categorical variables (age, weight, height) were found at baseline. Analysis of the cognitive task performance demonstrated improvements in both the Stroop effect and choice reaction time tasks for the experimental group following the six-week archery training intervention.

A. Preliminary Analysis

Initial cognitive performance was compared between groups using independent t-tests. For the Stroop effect task, no significant differences were found in congruent [$t(18) = 0.824$, $p = 0.421$, $d = 0.37$] or incongruent conditions [$t(18) = 0.422$, $p = 0.678$, $d = 0.19$]. In the choice reaction time task, no significant group differences were observed [$t(18) = 1.295$, $p = 0.212$, $d = 0.57$].

B. Behavioural Data

Table 2 presents pre- and post-test average response times in the Stroop effect (SE) and choice reaction time (CRT) tasks for both the experimental and control groups. In the SE congruent condition, the experimental group exhibited a shorter post-test mean response time (Mean = 726 ms, SD = 125.85) compared to the control group (Mean = 811.4 ms, SD = 153.58). Similarly, in the SE incongruent condition, the experimental group showed a shorter mean reaction time in the post-test (Mean = 826.9 ms, SD = 111.50) compared to the control group (Mean = 866.1 ms, SD = 171.66). During the CRT task, the experimental group also displayed a shorter post-test mean response time (Mean = 519.75 ms, SD = 60.9) compared to the control group (Mean = 532.87 ms, SD =62.58). Repeated measures ANOVA indicated a main time effect for all behavioural measures, with no significant time x group interactions ($F < 1.997$, $p > 0.175$), suggesting that observed performance differences were not solely due to the intervention. Figure 7 illustrates comparable pre- and post-test performances between groups.

Table 2. The descriptive statistics and the results from a rmANOVA during the SE and the CRT task

Variable	Experimental Group		Control Group		rm ANOVA	
	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Main effect (Time)	Interaction effect (Time x Group)
SE (ms)						
Congruent	839.85 ± 191.31	726 ± 125.85	910 ± 189.23	811.4 ± 153.58	$F(1,18) = 5.74$, $p = 0.028$	$F(1,18) = 0.03$, $p = 0.865$
Incongruent	950.38 ± 181.06	826.9 ± 111.50	983.7 ± 172.39	866.1 ± 171.66	$F(1,18) = 7.704$, $p = 0.012$	$F(1,18) = 0.005$, $p = 0.947$
CRT (ms)	526.47 ± 85.1	519.75 ± 60.9	578.61 ± 94.75	532.87 ± 62.58	$F(1,18) = 3.607$, $p = 0.074$	$F(1,18) = 1.997$, $p = 0.175$

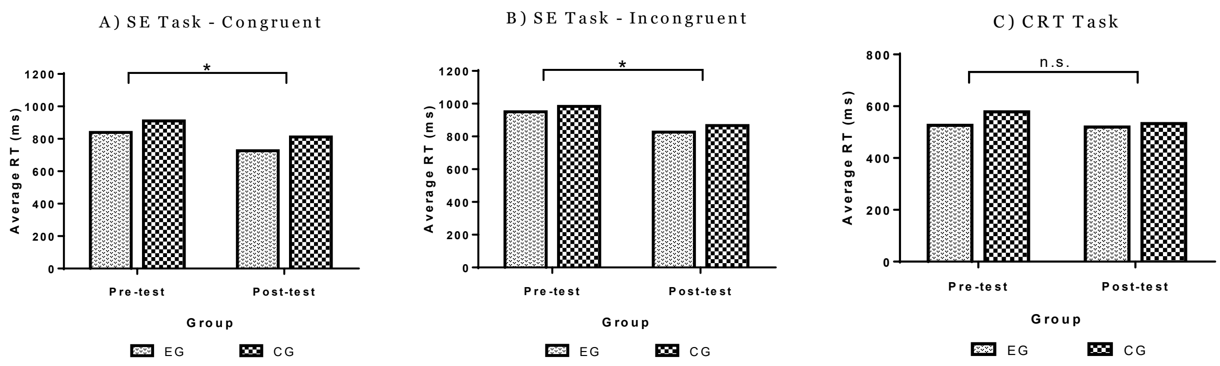

Figure 7. Average response times for pre- and post- test separated by condition and task

This study aimed to investigate the impact of archery training on cognitive function, focusing on attention, a pivotal aspect of cognitive performance. To assess attention, two well-established cognitive tasks, the Stroop effect (SE) and choice reaction time (CRT) task, were employed. These tasks, renowned for their efficacy in measuring attentional abilities and processing speed, require individuals to concentrate while disregarding distractions (Algom & Chajut, 2019; Harvey, 1984; Sargent *et al.*, 2021).

Attention, viewed as a finite mental resource, can be selectively directed towards stimuli, enhancing information processing. Whether voluntary or involuntary, attentional allocation enables the selective focus of cognitive resources, facilitating deeper information processing. The observed significant effects of archery training on cognitive function are noteworthy.

The experimental group, subjected to archery training, displayed superior performance in the SE task across all Stroop conditions (congruent and incongruent) at the post-test stage compared to the control group. This indicates that concurrent archery training led to improvements in various aspects of cognitive performance within the experimental group, encompassing fundamental knowledge and inhibitory control (Wu *et al.*, 2021). Consistent with prior research by Kim *et al.* (2014) and Hatfield *et al.* (2004), which highlighted a positive correlation between archery and cognitive abilities, our findings underscore the cognitive benefits associated with systematic archery training. Elite archers, with continuous and rigorous training, exhibited enhanced psychomotor and cognitive skills, necessitating less cognitive effort than novice archers.

While the improvements in the CRT task for the experimental group did not reach statistical significance ($p > 0.05$), the trends observed suggest potential cognitive benefits of archery training. This is particularly noteworthy as prior research has predominantly focused on gross motor sport interventions, such as physical exercise, while our study specifically delved into the effects of fine motor sport intervention, namely archery training. The proposed idea by Wu *et al.* (2021) that various sports experiences may counteract potential negative impacts on cognitive function adds complexity to the understanding of sports modality effects. Hence, further research is imperative to comprehensively grasp the significance of diverse sports interventions and the specific cognitive tests employed.

In conclusion, our study provides compelling evidence of the positive impact of archery training on cognitive function, particularly attentional processes. The enhanced performance in the SE task within the experimental group suggests improvements in inhibitory control and attentional abilities. While the CRT task trends toward improvement, additional research is needed to explore the enduring effects of archery training, make comparisons across different sports interventions, and encompass a broader spectrum of cognitive measures. A deeper understanding of the underlying mechanisms and potential transferability of these findings could significantly contribute to the field of cognitive enhancement through motor skill acquisition.

C. Spectral Power Changes during SE Task

For ERPow theta during the Stroop task, the statistical analysis did not show a significant effect for Time [$F(1,18) = 0.05$, $p = 0.82$, $\eta 2p = 0.00$], but did show a significant effect for Electrode [$F(5.91,106.44) = 2.39$, $p = 0.03$, $\eta 2p = 0.18$]. There was also a significant interaction between Electrode and Group [$F(5.913,18) = 2.55$, $p = 0.02$, $\eta 2p = 0.12$]. This interaction indicated higher EEG synchronisation in the experimental group compared to the control group for FC5 and P8 (see Fig. 7A).

For ERPow alpha during the Stroop task, the ANOVA revealed the following statistically significant main effects and interactions: Time [$F(1,18) = 10.78$, $p < 0.001$, $\eta 2p = 0.38$], Electrode [$F(7.02,126.26) = 2.37$, $p = 0.03$, $\eta 2p = 0.12$], and Time x Group [$F(1,18) = 5.05$, $p = 0.04$, $\eta 2p = 0.22$]. The interaction between Time and Group showed higher EEG power modulation in the experimental group compared to the control group at pre-test in AF4, F3, FC6, P7, and O1 (Fig. 7D), and at post-test in F8 (Fig. 7C).

Regarding ERPow beta during the Stroop task, no significant main effects or interactions were found according to the statistical analysis.

This study aimed to assess the impact of archery training on neural oscillatory activity, specifically focusing on attention-related brain regions. Our approach involved a thorough examination of three major brain regions – frontal (AF3, AF4, F3, F4, FC5, FC6, F7, F8), occipital (O1, O2), and parietal (P7, P8) – crucial for attention, focus, and executive functions (Noraini, 2018). Archery, characterized as a static sport, demands heightened attention and focus for precise target accuracy. While existing studies have hinted at attention improvement through archery, they often rely on cross-sectional comparisons between archers and non-archers. Our study uniquely demonstrated that a six-week archery training intervention led to a general increase in neural synchrony across theta and alpha frequency bands over time. The post-test analysis specifically indicated enhanced event-related power (ERPow) in the frontal region for the experimental group compared to the control group.

Results pertaining to alpha waves during the active state revealed modulation with increased ERPow at electrodes F8 and AF4. Traditionally considered epiphenomena, recent research highlights the functional significance of alpha waves in integrative sensory and motor processes, crucial for information processing (Noh *et al.*, 2012). Activities requiring focus, such as golf swings, have been associated with increased brain activity during cognitive tasks, stimulating cognitive abilities Thomsen (2022). Our study aligned with these findings, as the experimental group exhibited elevated theta waves, notably at electrodes FC5 and P8, during cognitive tasks (SE task) and activities demanding concentration. The increase in theta waves at P8, coupled with the decrease in alpha waves at F8 and beta waves at F7, aligns with information processing, suggesting a link with control and focused attention (Hosang *et al.*, 2022).

Conversely, the control group displayed increased beta waves, particularly at the F7 electrode after intervention, notably during cognitive tasks requiring concentration. This echoes findings by Zhang *et al.* (2021), reporting augmented beta waves and frontal brain activation in the control group following an intervention. These observations suggest that brain activity changes related to focus can manifest during the SE task post-archery training, even in the control group, due to increased concentration irrespective of archery involvement.

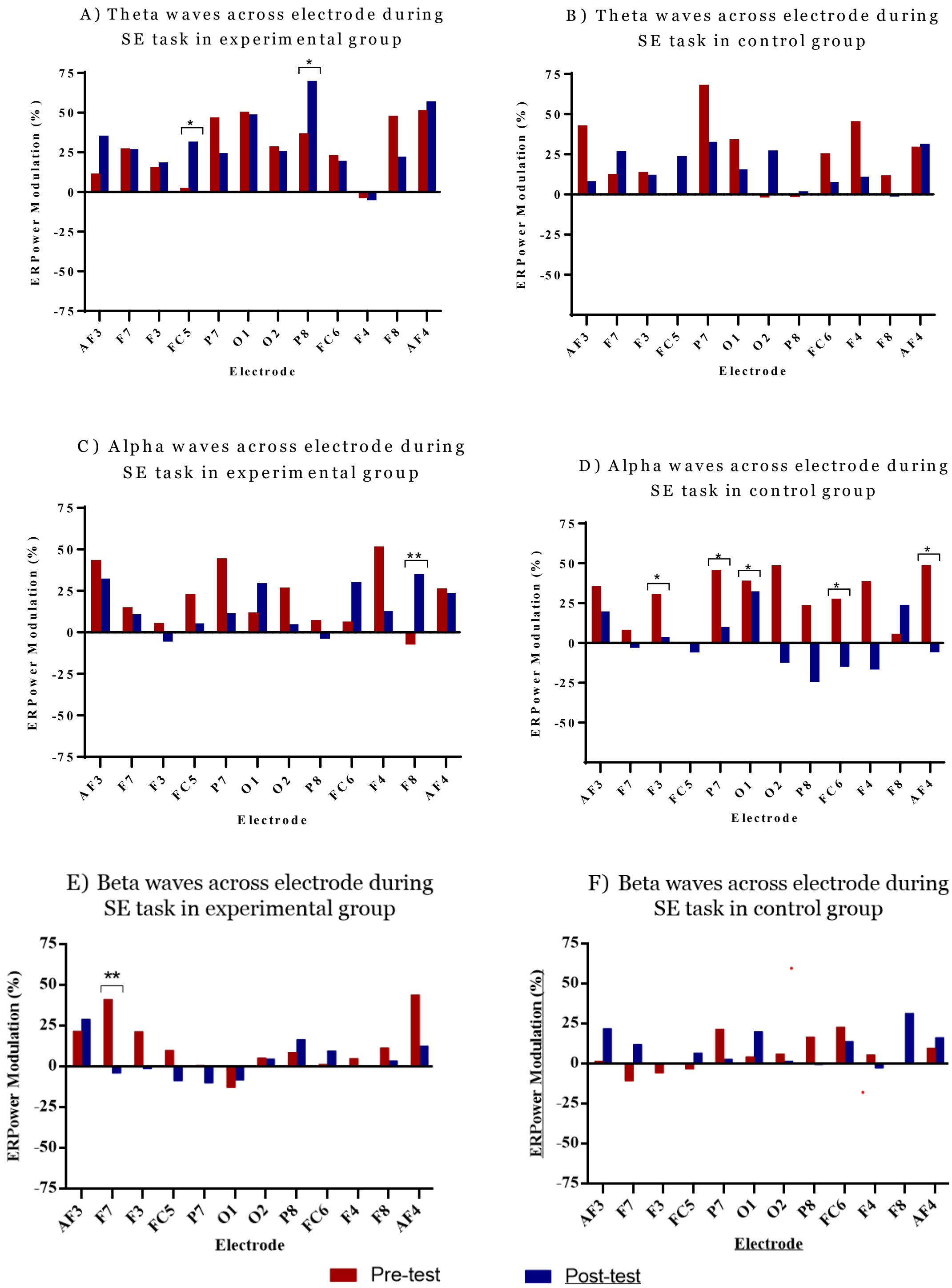

Figure 8. Average of ERPow modulation for theta (label A and B), alpha (label C and D), and beta (label E and F) waves across electrode during SE task for pre- and post-test in experimental and control group

*p-value < 0.05, significant difference

**p-value < 0.005, significant difference

D. Spectral Power Changes during CRT Task

For ERPow theta during the CRT task, the statistical analysis did not reveal a significant effect of Time [$F(1,18) = 1.50$, $p = 0.24$, $\eta 2p = 0.08$] or Electrode [$F(6.56,118.05) = 1.29$, $p = 0.23$, $\eta 2p = 0.107$]. However, several significant interaction effects were observed: Electrode x Group [$F(6.558,18) = 4.80$, $p = 0.00$, $\eta 2p = 0.21$], Electrode x Time [$F(6.56,118.02) = 2.22$, $p = 0.04$, $\eta 2p = 0.11$], and Electrode x Time x Group [$F(6.56,18) = 2.54$, $p = 0.02$, $\eta 2p = 0.12$]. The interaction effect between Electrode and Group indicated higher EEG synchronisation for the control group compared to the experimental group at F3, F4, and FC6 electrodes (Fig. 8A). The interaction effect between Electrode and Time demonstrated higher EEG power modulation during the CRT task for the experimental group compared to the control group at pre-test and post-test for F3 (29.99 vs. 58.94%) (Fig. 8A) and FC6 (7.5 vs. 48.82%) (Fig. 8B). Moreover, the interaction effect between Electrode, Time, and Group revealed a higher synchronisation in the experimental group compared to the control group across the time at F3 (pre-test: 29.99 vs. 41.62%, post-test: 58.94 vs. 17.44%), FC5 (pre-test: 67.5 vs. 0.24%), and FC6 (post-test: -11.53 vs. 48.82%) electrodes (Fig. 8A-B).

Regarding ERPow alpha during the CRT task, there was no significant effect of Time [$F(1,18) = 0.01$, $p = 0.92$, $\eta 2p = 0.00$], but a significant effect of Electrode [$F(6.10,109.82) = 2.17$, $p = 0.05$, $\eta 2p = 0.11$]. No significant interactions were found.

Similarly, for ERPow beta during the CRT task, there was no significant effect of Time [$F(1,18) = 1.28$, $p = 0.27$, $\eta 2p = 0.07$], but a significant effect of Electrode [$F(5.95,107.14) = 2.94$, $p = 0.01$, $\eta 2p = 0.14$]. No significant interactions were observed.

Our analysis of brain activation during the response time (T2) cognitive task indicated significant differences in the experimental group, particularly at the anterior frontal (AF4) and temporal (T8) electrodes for alpha and beta waves, respectively. While previous research on shooting performance emphasised lateralised functional coupling during aiming, involving the right prefrontal, frontal, and temporal lobes (Gong *et al.*, 2018), our study extends this understanding to cognitive performance. The activation of these brain regions through physical activity has been associated with heightened focus and concentration (Miyake *et al.*, 2000).

In conclusion, our findings suggest that archery training induces changes in oscillatory neural activity, resulting in increased synchrony and activation in specific brain regions. The alterations observed in alpha and beta waves during cognitive tasks offer insights into the neural mechanisms underpinning attention, focus, and concentration in the context of archery training. However, acknowledging the need for further research to comprehensively grasp the specific neural processes involved, our study emphasises the potential cognitive benefits of archery training. Comparative studies across various sports interventions and exploration of a broader array of cognitive measures are essential for a nuanced understanding of the impacts of different sports on cognitive function.

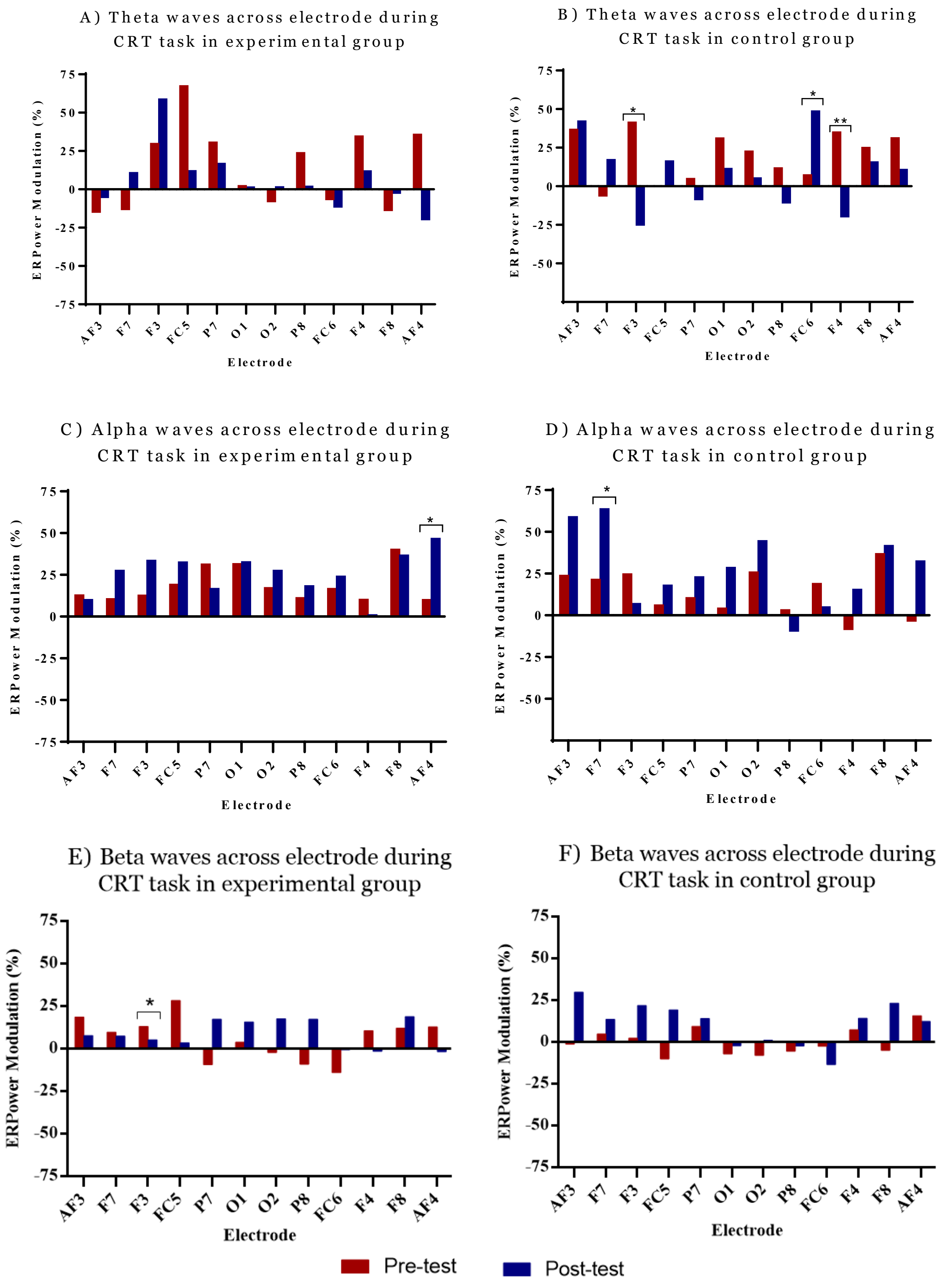

Figure 9. Average of ERPow modulation for theta (label A and B), alpha (label C and D), and beta (label E and F) waves across electrode during CRT task for pre- and post-test in experimental and control group

*p-value < 0.05, significant difference

**p-value < 0.005, significant difference

IV. CONCLUSION

In conclusion, this study highlights the positive effects of archery training on attention and cognitive function. The intervention resulted in enhanced reaction times, increased alpha power in frontal and parietal regions, and improved performance on cognitive tasks. These outcomes signify improved information processing speed, efficient response selection, and heightened attentional engagement. The observed benefits underscore the potential of archery training as an effective strategy for enhancing cognitive abilities, particularly in domains requiring focus and attentional control. These findings offer valuable implications for the integration of archery training interventions in diverse settings, including sports, academics, and occupations, to foster improved cognitive performance.

As part of the growing evidence supporting the positive impact of physical activity, further research is warranted to delve into neural mechanisms, individual differences, and the long-term effects of archery training on attention and cognitive function. In essence, this study contributes to the development of evidence-based interventions aimed at optimising cognitive performance across various contexts.

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