Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics e-ISSN: 2656-8624
Homepage: https://ijeeemi.org/; Vol. 8, No. 2, pp. 161-171, May 2026

RESEARCH PAPER

OPEN ACCES

EEG-Based Analysis of Concentration with Shooting Accuracy and Precision in Archery Athletes: A Quantitative Correlational Study

Ainun Rahmansyah Gaffar[1], Pringgo Widyo Laksono[1,2], Bambang Suhardi[1,3], Rahmaniyah Dwi Astuti[1,3], and Minoru Sasaki[4].

[1] Master Program Department of Industrial Engineering, Universitas Sebelas Maret, Surakarta, Indonesia
[2] Center for Research in Manufacturing Systems (CRiMS), Universitas Sebelas Maret, Surakarta, Indonesia
[3] Laboratory of Work System Design and Ergonomics, Universitas Sebelas Maret, Surakarta, Indonesia
[4] Department of Mechanical Engineering, Gifu University, Yanagido, Japan

ABSTRACT

Archery performance as a precision sport is determined by a complex interaction between psychological and physiological factors. Concentration, as a crucial factor, can be objectively measured through electroencephalography (EEG) by detecting beta waves. However, current coaching practices disproportionately emphasize physical aspects while systematically ignoring concentration as a crucial psychological factor. Generally, studies assess performance through aggregate scores without distinguishing between two fundamental dimensions: accuracy and precision. This study aims to analyze the relationship between concentration levels measured through beta band power activity using EEG and shooting performance in archery athletes, focusing on shooting accuracy and shooting precision. This study offers empirical contributions about the relationship between concentration and two dimensions of shooting performance, develops a methodological validation that integrates EEG monitoring with smart bow technology, and establishes a practical foundation for developing concentration-based training programs in archery. The research subjects consisted of 12 novice archery athletes. EEG data were acquired with electrodes positioned at AF7 and AF8, monitoring beta band power during shot execution. Pearson's correlation was used to analyze the relationship. The results showed a shot accuracy with an average score of 131.17, while precision showed an average SRD of 11.00 cm. Beta band power had a mean of 39.18 μV². Correlation analysis revealed a non-significant positive relationship between beta power and accuracy (r = 0.145, p = 0.652), as well as a non-significant negative relationship with precision (r = -0.327, p = 0.300). Study findings show that beta wave activity alone does not serve as a significant predictor of shooting performance in novice archers. However, the differential correlation pattern (positive for accuracy, negative for precision) confirms that these two dimensions are influenced by different psychophysiological mechanisms.

PAPER HISTORY

Received Nov. 13, 2025
Revised Feb 20, 2026
Accepted March 10, 2026
Published April 5, 2026

KEYWORDS

Archery Performance;
Beta Band Power;
Shooting Performance;
Shooting Accuracy;
Shooting Precision

AUTHOR EMAIL

ainunrgss@student.uns.ac.id
pringgo@ft.uns.ac.id
bambangsuhardi@staff.uns.ac.id
rahmaniyahdwi@staff.uns.ac.id
sasaki@gifu-u.ac.jp

I. Introduction

In modern sports, an athlete's performance is not only determined by physical and technical aspects, but psychological (mental processes) and physiological aspects also interacts as factors [1], [2], [3]. As a precision sport, the success of archery performance depends on the ability to maintain consistency in shooting (precision) and to hit close to the center of the target (accuracy), which affects the score [4]. Specifically, archery is a cyclical sport that relies on mental skills, in which an athlete's success depends on their ability to consistently hit the target in a short time with high precision and stability [5], [6]. With the intensity of archery competition, even the most minor shooting error can determine victory or failure. At the 2024 Paris Olympics, illustrating this narrow margin, the average performance difference among the top four in the male individual category was only 2.96% and 2.09% for females, so every detail that affects performance needs to be understood scientifically.

Each shot in archery represents the culmination of the integration of various systems in the body, where the level of concentration is one of the crucial determinants of a

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

successful shot [7]. Concentration allows archers to maintain maximum focus on the target by processing visual information related to the position of their gaze on the target [8], [9]. Every technique in archery requires fine motor coordination, which is greatly influenced by cognitive readiness [10]. However, in Indonesia, especially among novice athletes in Surakarta, there is a disparity between performance during training and competition. According to World Archery Federation regulations, novices are athletes who can compete up to and including age 17 [10]. At this developmental stage, empirical studies show that coaching practices still emphasize physical aspects such as posture, strength, and shooting drills, while concentration is often neglected. This aligns with the findings of Jogi et al. [11], who found that archery training practices primarily focus on physical and technical dimensions, while psychological aspects remain underexplored. This impacts performance, as athletes may experience a decline in accuracy and precision under higher competitive pressure than during training [12].

Athlete performance measurement has evolved from a traditional technique focused on simple physical ability evaluations to more modern technology, such as the use of sensors [13]. Electroencephalography (EEG) is a sensor extensively utilized in sports science to assess neurocognitive factors associated with performance [14]. Brain wave activity, particularly beta waves (12.5–30 Hz), has been identified as a marker representing concentration, alertness, and cognitive processing [15]. In the context of sports, increased beta waves are associated with focus and mental readiness to execute precise movements [16]. Previous studies have used EEG in archery studies as a tool to evaluate psychological aspects. As done by Gu et al. [17], Gu et al. [18], and Rampp et al. [19], applied EEG as the basis for analyzing studies on archery athletes. However, these studies focused on the aiming phase, which limited the representation of the complexity of archery performance in each shooting phase. Other studies by Zhu [20] focused on load intensity settings without linking them to shooting performance. Meanwhile, studies by Lee et al. [21] and Rice et al [22] evaluated the psychological aspects of athletes using questionnaire-based instruments, such as the Psychological Skills Inventory for Archery and Shooting and the Athlete Psychological Strain Questionnaire (APSQ). Although widely used, questionnaire-based approaches have limitations because they depend on participants' subjectivity and understanding, potentially leading to bias, inaccurate interpretations, and errors in data reporting [23]. EEG, a more objective alternative to psychological evaluation, directly monitors neurophysiological activity [24]. Thus, concentration is not only an abstract objective psychological construct but also a measurable neurophysiological phenomenon that can be identified through the beta wave activity of athletes. Additionally, integration with a smart bow, a digital archery device with motion and position sensors, enables accurate and precise measurement of shooting performance with controlled evaluation that can replicate competition settings [25].

Despite advances in technology and sports science, studies on archery generally only assess performance through accuracy measured by scores. In the study by Yachsie et al. [26], psychological interventions were assessed based on shooting accuracy, similar to the study by Wattimena et al. [27], which showed an improvement in the performance of archery athletes through shooting accuracy. Scores alone cannot distinguish between two essential dimensions of archery performance, namely accuracy and precision of shots. These dimensions are two different but interrelated constructs [28], [29]. In competition, archery athletes can achieve high scores but low accuracy, or vice versa, which has different implications for the outcome of the competition. Accuracy reflects concentration on goals and visuospatial processing [30], while precision reflects attentional stability and motor consistency [31]. Furthermore, archery performance success is influenced by various interacting factors [32], so combining simultaneous measurements of these two performance constructs with aspects of concentration is crucial for providing a more comprehensive and realistic condition.

Therefore, given the gap in studies on EEG-based concentration measurement in relation to the accuracy and precision of simultaneous shots in novice archers, this study will address this gap as a quantitative correlational study to analyze the relationship between beta wave concentration and the shooting performance of archery athletes. The contributions of this study include 1) an empirical theoretical framework regarding the correlation between neural concentration and two dimensions of shooting performance, 2) the development of a validated methodological protocol that integrates EEG-based concentration monitoring with smart bow technology in a controlled laboratory setting, 3) providing an empirical basis for concentration-based archery training, thereby complementing existing physical and technical training, and 4) applied contributions through foundational knowledge for developing psychophysiological assessment protocols in the identification and selection of archery talent at the early stages of training.

This study is structured as follows: Section II shows the dataset used, study subjects, data processing, and statistical analysis. Section III shows the results of the correlation between beta-band power and shooting performance. Section IV discusses the interpretation and comparison of the results with other studies, as well as limitations. Section V, conclusions, which rewrite the objectives, main findings, and future works.

II. Method

A. Dataset

This study used purposive sampling to obtain research subjects from schools in Surakarta. The subjects consisted of 12 novice archery athletes (6 males, 6

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

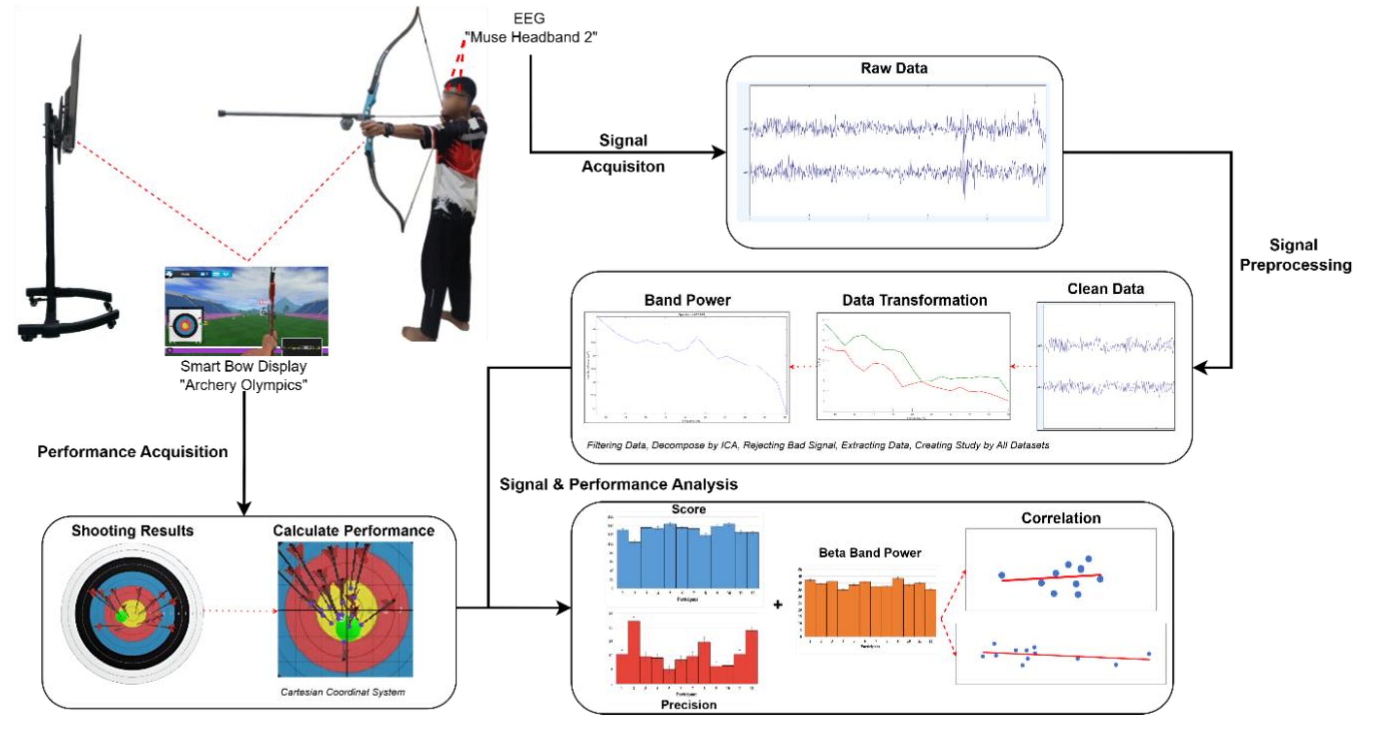

Fig. 1. Overview of the study process and data collection using EEG and Smart Bow.

females) aged 12-15 years (Mean age = 13.92, Standard Deviation = 0.90) with training experience of 2-10 years (Mean = 5, Standard Deviation = 2.13). Selected subjects had to meet specific criteria: 1) have a minimum of one prior competition experience at the regional level, 2) be right-handed, and 3) have normal eyesight. All subjects provided written consent before participating in this study. Before data acquisition, ethical approval was obtained in March 2025 from the Health Research Ethics Committee (HREC) of RSUD dr. Moewardi with ethical number 612/III/HREC/2025. Data from each research subject were combined to form a dataset and serve as the basis for the results of this study.

B. Data Collection

The study and data collection process are shown in Fig. 1. The study used a Muse Headband 2 EEG with a sampling frequency of 256 Hz. Electrodes were placed on the left anterior frontal (AF7) and right anterior frontal (AF8), as shown in Fig. 2. These electrode placements correspond to the frontal lobe, an area closely associated with attention control, executive processing, and active concentration [17], [33]. This selection is consistent with the nature of archery, which requires sustained concentration throughout the sequential phases of the shooting process [9]. EEG electrode placement is based on the International 10-20 system by Pivik et al. [34]. Before signal recording, participants were instructed to avoid unnecessary movements, including jaw tension or teeth grinding, to minimize muscle- and movement-related artifacts in the EEG signal.

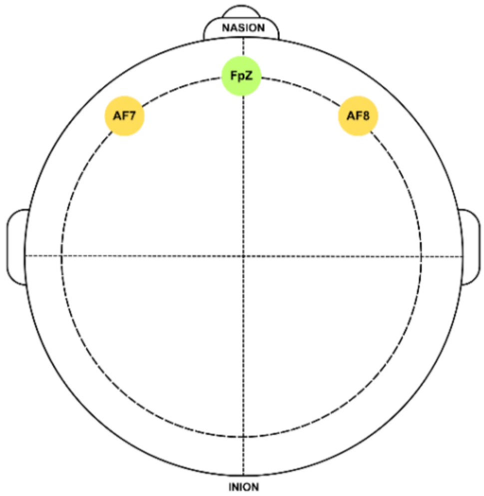

Fig. 2. Placement of AF7 and AF8 Electrodes Using Muse Headband 2.

The study was conducted in a controlled laboratory room measuring 2.5 m x 1.6 m x 4 m. The shooting data was obtained using the Houyi 2 smart bow from Wonderfitter. This device was connected to the Wonderfitter application, which offers Olympic archery training modes. Each participant used a smart bow to perform 15 shots at a 43-inch television screen from 1.5 meters, with a maximum of 30 seconds per shot. The study produced two types of output data: performance data obtained from the smart bow and EEG signals obtained from monitoring brain wave activity during archery.

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

C. Data Processing

Each subject's shooting performance was obtained from a total of 15 shots, so the maximum score that could be obtained was 150. Accuracy was determined by the total shot score, which was also used to calculate shooting precision. The method for measuring shooting precision was adapted from various previous studies.

The smart bow technology generates Cartesian coordinates for each shot based on the target face's diameter of 122 cm, as illustrated in Fig. 3. The center of the target face is located at the 10-point mark, making it the origin (0,0). The x-axis represents the width of the target (horizontal), and the y-axis represents the height of the target (vertical). The axis values are calculated based on the results of each shot, using Eq. (1) and Eq. (2) as referenced in the studies by Živković et al. [28], Ertan et al. [35], and Moon & Lee [36], as follows:

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n}, i = 1,2, \dots n \quad (1)$$

$$\bar{y} = \frac{y_1 + y_2 + y_3 + \cdots + y_n}{n} = \frac{\sum_{i=1}^{n} y_i}{n}, i = 1,2, \dots n \quad (2)$$

Shooting precision is calculated based on the Euclidean distance between each shot and the average coordinates of all shots, using the single radial derivation (r_i) Eq. (3) as referenced in the studies by Živković et al. [28], Ertan et al. [35], and Moon & Lee [36], as follows:

$$r_i = \sqrt{(\bar{x} - x_i)^2 + (\bar{y} - y_i)^2}, i = 1,2 \dots n \quad (3)$$

A larger single radial derivation (r_i) value represents lower shooting precision. Thus, the smaller the value of (r_i), the higher the shooting precision. Value (r_i) has a unit of cm.

EEG data measurement was performed while the athlete was shooting, and the acquired EEG signal was processed using EEGLAB from MATLAB software. The results of the EEG signal are displayed in the time domain. To obtain band power, the EEG signal needs to be converted into the frequency domain, one of which is by using the short-time Fourier transform (STFT) [37]. EEG classifies specific frequency components that provide discriminatory information. In the beta band power (P_β) study, it was obtained from the Power Spectral Density (PSD) value filtered in the range (12.5–30 Hz) [15]. To calculate STFT and PSD mathematically, use Eq. (4) and Eq. (5) as referenced in the study by Zhang et al. [38], as follows:

$$STFT\ (\omega, \tau) = \int_{-\infty}^{\infty} f(t)\psi^*(t-\tau)e^{-i\omega t}dt \quad (4)$$

$$PSD = \sum_{n=0}^{N-1} x(n)e^{-i2\pi nk/N} \quad (5)$$

Here, $f(t)$ is the original signal, τ signifies the translation parameter, $\psi^*(t-\tau)$ refers to the window function, e refers to the exponential operation, i represents the imaginary part, t refers to time, and ω refers to frequency. For N is the length of the signal, $x(n)$ represents the input signal of time domain, and k represents the sampling frequency. The PSD value in the beta frequency range can be calculated using Eq. (6) as referenced in the study by Zhang et al. [38] as follows:

$$P_\beta = \int_{12.5}^{30} PSD\ (f)df \quad (6)$$

The EEG data processing involves applying a bandpass filter (1-30 Hz) to obtain more accurate beta band power. ICA decomposition was performed to separate signal components containing noise and artifacts. Next, manual rejection was accomplished by deleting data segments within a specific range that contained artifacts that could not be corrected by ICA or filtering. The final step was to combine each dataset into a study that provided beta band power information on the AF7 and AF8 channels.

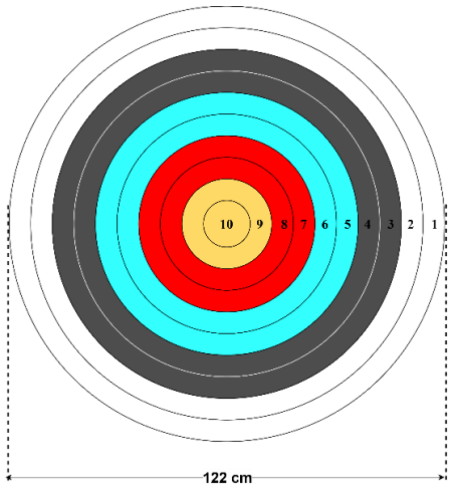

Fig. 3. A 122 diameter archery target displayed via a smart bow and television.

D. Statistical Analysis

Before conducting the correlation test, a normality test using the Shapiro-Wilk test and a homogeneity test using Levene's test were performed to ensure the fulfilment of parametric statistical assumptions. Pearson's correlation test is used to test the strength and direction of the linear relationship between concentration (beta band power) and shooting accuracy, as well as concentration and shooting precision. This analysis produces a correlation coefficient with a value range of -1 to +1, which indicates the strength and direction: +1 is perfectly positive (both increase together), -1 is perfectly negative (one increases while the other decreases), and 0 indicates no linear relationship [39]. To calculate the Pearson correlation coefficient (r) using Eq. (7) as referenced in the study by Selvanathan et al. [39], as follows:

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (7)$$

Here, (x) represents the value of the independent variable (beta band power), ($\bar{x}$) represents the average value of the independent variable, (y) represents the value of the dependent variable (shooting performance), and ($\bar{y}$) represents the average value of the dependent variable.

III. Results

The shooting results based on the scores for each subject are shown in Fig. 4. The results (Mean=131.17, Standard Deviation=11.23) were obtained from a total of 15 shots for each subject. Each athlete obtained a score above 100, with 33.33% below 131, indicating a below-average score. Two athletes obtained the highest score of 144, namely athlete 5 and athlete 10. Meanwhile, the lowest score was obtained by athlete 2 with a score of 104.

The shooting results, based on the precision of each subject, are shown in Fig. 5. The results (Mean=11.00, Standard Deviation = 5.17) were obtained from a total of 15 shots per subject. A low single radial derivation (SRD) value indicates more precise and consistent shooting results. 25% of participants had an SRD above 11 cm, indicating below-average shooting precision. The best shooting precision was achieved by athlete 5 with an SRD value of 5.17 cm, while the lowest shooting precision was achieved by athlete 2 with an SRD value of 22.25 cm.

The results of monitoring brain wave activity with EEG are shown in Fig. 6. These results were obtained from the average beta band power of the AF7 and AF8 channels across the range (12.5-30 Hz). The results (Mean= 39.18, Standard Deviation= 2.63) were obtained while the athletes performed 15 shots. There were 41.67% of athletes who showed beta band power values below 39.18, indicating a below-average level of concentration. The best concentration level was in athlete 9 with a beta value of 43.61 μV², while the lowest concentration level was in athlete 4 with a beta value of 34.96 μV².

The statistical results in Table 1 show that the relationship between beta band power and shooting accuracy has a correlation value (r = 0.145), meaning a very weak positive relationship between beta wave activity (concentration indicator) and shooting accuracy. The significance value obtained is p = 0.652, indicating that this relationship is not statistically significant. This indicates that an increase in beta wave activity has no significant effect on improving shooting accuracy. Furthermore, the relationship between beta band power and shooting precision through SRD measurement has a correlation value (r = -0.327), meaning there is a weak to moderate negative relationship between beta wave activity and shooting precision. The significance value obtained was p = 0.300, indicating that this relationship is not statistically significant. This indicates that an increase in beta wave activity is followed by a decrease in SRD values (increased precision), but this relationship is not strong enough to be considered significant.

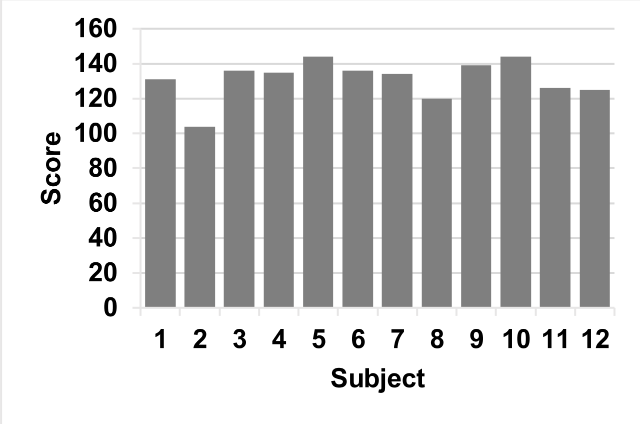

Fig. 4. Bar chart of the measurement results of each archer's shooting performance based on scores.

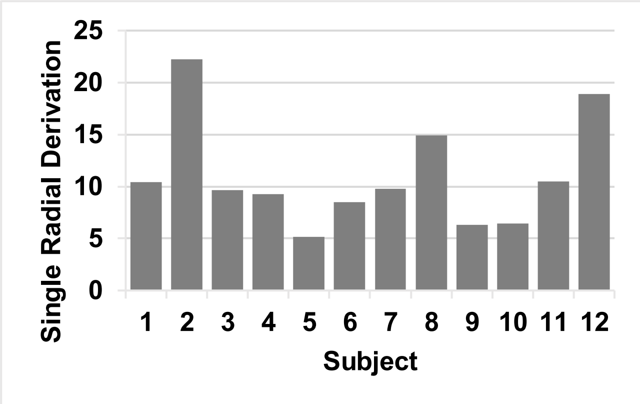

Fig. 5. Bar chart of the measurement results of each archer's shooting performance based on single radial derivation.

IV. Discussion

Shooting performance, in terms of accuracy and precision, generally shows a linear outcome: higher shooting accuracy corresponds to higher shooting precision. However, findings of this study show the opposite phenomenon. Athlete 4 obtained a score of 135 with an SRD of 9.24, while athlete 3 obtained a higher score of 136 and a higher SRD of 9.64. Although the difference is small, this supports the theory that better shooting precision cannot be directly translated into increased shooting accuracy. The study findings show that even if shooting precision improves, the results of the competition are not necessarily optimal. This confirms that archery is a complex sport in terms of athlete performance [40]. Differences in psychological factors, such as concentration, can affect the performance of archery athletes [41]. Based on the Pearson correlation test, there was no statistically significant correlation between beta wave strength and the two shooting performance metrics, and the correlation coefficient was weak. Although there was a positive correlation with accuracy and a negative correlation with SRD, the strength of both correlations was

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

weak. However, the observed correlation pattern provides valuable initial insights for further understanding of the psychophysiological dynamics in archery. Increased wave activity in beta band power is generally associated with increased focus and sensorimotor engagement [33], [42], but does not necessarily result in increased shooting accuracy and precision.

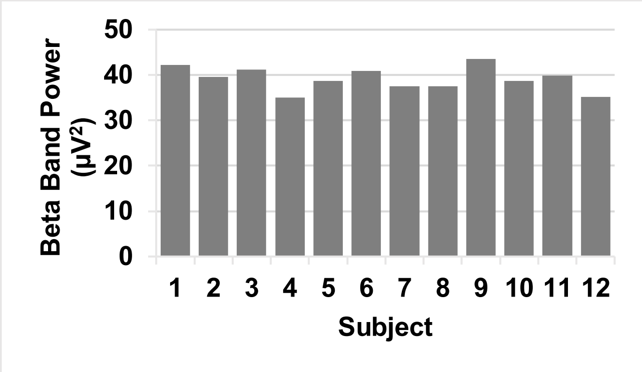

Fig. 6. Bar chart of the results of monitoring the brain wave activity of each archer based on the beta band power.

Table 1. Beta Band Power Correlation Test with Archer Shooting Accuracy and Precision.

		Accuracy	SRD
Beta Band Power	Pearson Correlation	0.145	-0.327
	p- value	0.652	0.300

The correlation between beta-band power and accuracy shows a positive correlation coefficient. This means that higher beta-band power indicates better accuracy. These findings are in line with previous studies by Zhang et al. [43], which found that in precision shooting sports, there is a linear correlation between prefrontal beta power and shooting accuracy, but that the increase in beta power in the prefrontal cortex is more pronounced under competitive conditions. The correlation between beta-band power and precision shows a negative correlation coefficient. This means that higher beta-band power indicates a smaller SRD value or better shooting precision. Considering that archery requires fine motor skills to control fine muscles, it allows for more consistent shots [10]. Through increased concentration, athletes find it easier to control fine muscles, resulting in more precise shots. This has been confirmed by studies by Chen et al. [44] and Starzak et al. [45], which state that focusing on the target is more effective in improving fine motor performance. However, given the non-significant Pearson correlation, any interpretation of these two shooting performance metrics in terms of the correlation direction must be considered highly speculative.

The results of the study indicate that beta wave activity alone is insufficient to explain the variation in archery performance, especially in distinguishing between accuracy and precision. However, observing variation in results among athletes in the study can provide a more comprehensive exploration and understanding of the complexity of archery. Monitoring wave activity and measuring shooting performance in athlete 1 yielded counterintuitive results: although accuracy and precision were below average, the athlete exhibited the highest beta band of 42.24 μV². Meanwhile, athlete 5, who had the best accuracy and precision, only had a beta band of 38.65 μV². The high beta band in athlete 1 may reflect excessive cognitive load or anxiety-related hyperarousal rather than productive concentration [46]. Meanwhile, athlete 5's lower beta band might indicate a more efficient neural processing characteristic of skilled performance [47]. In addition, differences in the quality of attentional focus among athletes on each shot led to variations in shooting performance [48]. Although the difference is relatively small, other factors can also affect an athlete's performance. Based on the study by Sudo et al. [49], a decrease in concentration is thought to occur due to the influence of physical stress during high-intensity exercise. Excessive concentration can cause changes in movement sensation [8], therefore, concentration stabilization is essential. The fact that athlete 1 has high potential but performs below average underscores the need for optimal concentration to achieve maximum performance. This phenomenon can be identified through various factors, such as basic technique quality, body posture stability, and the ability to manage emotions and relaxation, which also play a crucial role in determining the total score [50], [51], [52]. These various factors then became methodological and resource constraints.

The various factors that influence an athlete's shooting performance reinforce the understanding that successful archery performance is the result of a complex interaction between mental, motor, and physical aspects. This confirms that beta waves cannot be used as the sole predictive indicator of shooting performance. Previous studies by Chen et al. [44] and Shi et al. [53] have shown that a combination of increased alpha waves in the occipital area and theta stability in the motor area is associated with optimal shooting performance. Thus, archery performance is influenced by the interaction between brain wave frequencies, not just a specific frequency band. The lack of significance may be due to the relatively small sample size or intrinsic variability in EEG measurements, such as movement artifacts during archery movements. In addition, the study's subjects being novice archers may be an additional factor; previous studies have shown that elite athletes have more regular and efficient beta activation patterns prior to precision motor actions, indicating higher neural efficiency compared to non-elite athletes. This efficiency contributes to better motor performance and more stable responses [17], [54].

The limitations of this study include the relatively small sample size, which limits the generalizability of the results and statistical power to a broader population of archery

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

athletes. The study focused only on beta-band analysis, whereas archery performance may involve cross-frequency interactions, such as alpha and theta. The absence of monitoring of physiological parameters such as heart rate variability (HRV) limits the understanding of the relationship being studied. Despite these limitations, this study provides implications for understanding the relationship between brain wave activity, particularly the beta band, and precision motor performance. Furthermore, the practical implication is that it provides a basis for coaches to emphasize not only physical and technical aspects but also psychological aspects, such as concentration and focus intensity management, to avoid excessive cognitive load that can interfere with performance. Specifically, EEG monitoring with the Muse 2 headband can help coaches identify athletes with suboptimal concentration patterns (excessive or insufficient) that are not apparent through performance scores. The Muse Headband 2 portable device enables non-invasive monitoring without interfering with archery movements, allowing it to be used in training. Athletes shoot while coaches monitor brain wave activity for each shot taken. However, several operational challenges exist, such as device cost, the device's sensitivity to movement artefacts, and the need for easy data visualisation for coaches without a technical background in EEG to interpret. Developing user-friendly EEG software to translate brain signals into practical indicators would greatly support data-driven training. By overcoming these limitations, EEG has the potential to become a helpful training tool for optimizing concentration stability, preventing cognitive fatigue, and supporting coach decision-making. Additionally, EEG monitoring can provide insights into talent assessment and development in novice archery athletes by examining brainwave activity rather than relying solely on shooting performance outcomes. However, this implementation is a complementary tool rather than a deterministic selection criterion to avoid over-reliance on neurophysiological data. Finally, the methodological implications of distinguishing between accuracy and precision measurements in archery performance analysis can provide greater methodological rigor in archery studies.

V. Conclusion

This study aims to analyze the relationship between the level of concentration based on EEG beta wave activity and the shooting performance of archery athletes. The main findings of this study indicate that in novice archery athletes, the level of concentration manifested through beta wave activity does not play a significant role as a predictor of the ability to hit the center of the target and consistency in individual shots. Beta band power had a weak positive correlation with shooting accuracy (r = 0.145; p = 0.652) and a weak negative correlation with single radial derivation values (r = -0.327; p = 0.300). This opposite correlation direction with beta power indicates methodological differences in shooting performance metrics. Higher shooting precision does not always translate to higher scores, reinforcing the need to evaluate these dimensions separately. Further studies are recommended to collect data from a larger, more diverse sample, including experienced archers. Specifically, comparative studies of archery across different skill levels to further examine and test the hypothesized relationship between EEG beta activity and shooting performance metrics (accuracy and precision) measured simultaneously. To establish a stronger evidence base, it is recommended to integrate experimental designs or longitudinal assessments to examine the causal effects of concentration levels on shooting accuracy and precision. Incorporating EEG multi-band (alpha, theta, beta, and their interactions) analysis could provide a more comprehensive understanding of the neurophysiological mechanisms underpinning concentration and shooting performance, and consider measuring other aspects using other bioelectrical devices.

Acknowledgment

The authors would like to express their sincere gratitude to the Master's Program, Department of Industrial Engineering, and the Laboratory of Work System Design and Ergonomics for providing the facilities, technical support, and research environment that made this study possible. Their assistance and resources greatly contributed to the successful completion of this study.

Funding

This study received financial support provided by the National Research and Innovation Agency (BRIN) through the Riset dan Inovasi untuk Indonesia Maju (RIIM), under grant numbers 178/IV/KS/11/2023 and 3200.1/UN27.22/PT.01.04/2023.

Data Availability

The data presented in this study are available on request from the corresponding author.

Author Contribution

Ainun Rahmansyah Gaffar contributed to the conceptualization of the study, experimental design, data curation, formal analysis, and preparation of the original manuscript draft. Pringgo Widyo Laksono assisted in data acquisition, signal processing, and contributed to data validation as well as manuscript review. Bambang Suhardi conducted the development of the methodology, supplied laboratory resources, and contributed to visualization and manuscript editing. Rahmaniyah Dwi Astuti contributed to the preprocessing of EEG signals, the implementation of analytical procedures, and supported the interpretation of the results and manuscript refinement. Minoru Sasaki provided supervision throughout the research process and approved the final version of the manuscript.

Declarations

Ethical Approval

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

This study was approved for ethical clearance from the Health Research Ethics Committee (HREC) of RSUD dr. Moewardi with ethical number 612/III/HREC/2025. Informed consent was obtained from the parents or guardians of all participants, and confidentiality and anonymity of the participants were maintained throughout the research process. All procedures adhered to ethical guidelines for research involving human subjects.

Consent for Publication Participants

Consent for publication was given by all participants.

Competing Interests

The authors declare no competing interests.

REFERENCES

[1] A. Wijaya *et al.*, "Exploring the Research Trend and Development of Sports Science Technology in the Last 4 Decades: Systematic Review," *Retos*, vol. 61, pp. 655–667, 2024, doi: 10.47197/retos.v61.109306.

[2] J. M. Williams and V. Krane, *Applied Sport Psychology: Personal Growth To Peak Performance*. New York: McGraw-Hill Education, 2021.

[3] S. Navabinejad and M. Rostami, "Mind and Body in Sync: The Fascinating Field of Psychophysiology in Sports," *Health Nexus*, vol. 1, no. 3, pp. 38–40, 2023, doi: 10.61838/kman.hn.1.3.5.

[4] B. Zhang and Z. C. Lin, "Comparative Analysis of Shooting Consistency Among Archers of Different Skill Levels," *Quality in Sport*, vol. 36, 2024, doi: 10.12775/QS.2024.36.56935.

[5] E. J. Kim, H. W. Kang, and S. M. Park, "The Effects of Psychological Skills Training for Archery Players in Korea: Research Synthesis Using Meta-Analysis," *International Journal of Environmental Research and Public Health*, vol. 18, no. 5, p. 2272, 2021, doi: 10.3390/ijerph18052272.

[6] E. Vendrame *et al.*, "Performance assessment in archery: a systematic review," *Sports biomechanics*, pp. 1–23, 2022, doi: doi.org/10.1080/14763141.2022.2049357.

[7] Susanto, Siswantoyo, Y. Prasetyo, and H. Putranta, "The effect of circuit training on physical fitness and archery accuracy in novice athletes," *Physical Activity Review*, vol. 9, no. 1, pp. 100–108, 2021, doi: 10.16926/par.2021.09.12.

[8] C. Feng, "Concentration Improvement Test for Athletes in Archery Training," *Rev Bras Med Esporte*, vol. 29, pp. 1–4, 2023, doi: 10.1590/1517-8692202329012022_0382.

[9] X. Pei *et al.*, "A simultaneous electroencephalography and eye-tracking dataset in elite athletes during alertness and concentration tasks," *Scientific Data*, vol. 9, no. 1, p. 465, 2022, doi: 10.1038/s41597-022-01575-0.

[10] R. Pelana and N. D. Oktafiranda, *Basic Archery Techniques*, 1st ed., vol. 3, 3 vols. Depok: PT RajaGrafindo Persada, 2022.

[11] R. Jogi, J. Kaur, M. Saini, and M. Malik, "Effect of Physical Training on Target Accuracy of Archer Athletes - A Systematic Review," *Journal of Bodywork and Movement Therapies*, vol. 40, pp. 695–705, 2024, doi: 10.1016/j.jbmt.2024.05.023.

[12] S. M. Steven, C. Stewart, T, and B. Hazel, "An Interpretative Phenomenological Analysis of Performance Influencing Factors Within the Practice Environment," *Journal of Physical Education and Sport*, vol. 20, no. 4, pp. 1646–1657, 2020, doi: 10.7752/jpes.2020.04224.

[13] A. Ç. Seçkin, B. Ateş, and M. Seçkin, "Review on Wearable Technology in Sports: Concepts, Challenges and Opportunities," *Applied Sciences*, vol. 13, no. 18, 2023, doi: 10.3390/app131810399.

[14] M.-Y. Cheng *et al.*, "Evaluating EEG neurofeedback in sport psychology: a systematic review of RCT studies for insights into mechanisms and performance improvement," *Front. Psychol.*, vol. 15, 2024, doi: 10.3389/fpsyg.2024.1331997.

[15] R. D. Astuti, B. Suhardi, P. W. Laksono, and N. Susanto, "Investigating the Relationship between Noise Exposure and Human Cognitive Performance: Attention, Stress, and Mental Workload Based on EEG Signals Using Power Spectrum Density," *Applied Sciences*, vol. 14, no. 7, p. 2699, Mar. 2024, doi: 10.3390/app14072699.

[16] J.-H. Guo *et al.*, "Enhancing shooting performance and cognitive engagement in virtual reality environments through brief meditation training," *Scientific Reports*, vol. 15, no. 1, 2025, doi: 10.1038/s41598-025-01462-9.

[17] F. Gu *et al.*, "From Expert to Elite? — Research on Top Archer's EEG Network Topology," *Frontiers in Human Neuroscience*, vol. 16, pp. 1–17, 2022, doi: 10.3389/fnhum.2022.759330.

[18] F. Gu *et al.*, "Research on Top Archer's EEG Microstates and Source Analysis in Different States," *Brain Sciences*, vol. 12, no. 8, pp. 1–23, 2022, doi: 10.3390/brainsci12081017.

[19] S. Rampp *et al.*, "Archery under the (electroencephalography-)hood: Theta-lateralization as a marker for motor learning," *Neuroscience*, vol. 499, pp. 23–39, Sep. 2022, doi: 10.1016/j.neuroscience.2022.07.019.

[20] C. Zhu, "EEG And Central Nervous System Transmitter on Athletes Training," *Rev Bras Med Esporte*, vol. 27, no. 7, pp. 703–705, 2021, doi: 10.1590/1517-8692202127072021_0347.

[21] G. Lee, J. Ryu, and T. Kim, "Psychological Skills Training Impacts Autonomic Nervous System Responses to Stress During Sport-Specific Imagery: An Exploratory Study in Junior Elite Shooters," *Frontiers in Psychology*, vol. 14, pp. 1–9, 2023, doi: 10.3389/fpsyg.2023.1047472.

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

[22] S. Rice *et al.*, “Mental health screening: severity and cut-off point sensitivity of the Athlete Psychological Strain Questionnaire in male and female elite athletes,” *BMJ Open Sport Exerc Med*, vol. 6, no. 1, 2020, doi: 10.1136/bmjsem-2019-000712.

[23] A. Shelley and K. Horner, “Questionnaire surveys - sources of error and implications for design, reporting and appraisal,” *Br Dent J*, vol. 230, no. 4, pp. 251–258, 2021, doi: 10.1038/s41415-021-2654-3.

[24] T. S. Bel-Bahar, A. A. Khan, R. B. Shaik, and M. A. Parvaz, “A scoping review of electroencephalographic (EEG) markers for tracking neurophysiological changes and predicting outcomes in substance use disorder treatment,” *Frontiers in Human Neuroscience*, vol. 16, 2022, doi: 10.3389/fnhum.2022.995534.

[25] T. Ogasawara, H. Fukamachi, K. Aoyagi, S. Kumano, H. Togo, and K. Oka, “Archery Skill Assessment Using an Acceleration Sensor,” *IEEE Transactions on Human-Machine Systems*, vol. 51, no. 3, pp. 221–228, 2021, doi: 10.1109/THMS.2020.3046435.

[26] B. T. P. W. B. Yachsie, S. Suharjana, A. S. Graha, Y. Prasetyo, A. Nasrulloh, and S. Suhasto, “Mental Training to Improve the 40-Meter-Distance Archery Accuracy with Imagery and Meditation Methods,” *International Journal of Human Movement and Sports Sciences*, vol. 11, no. 2, pp. 450–456, 2023, doi: 10.13189/saj.2023.110223.

[27] F. Y. Wattimena, T. Tomoliyus, A. Alim, B. Basyiruddin, and Y. Ockta, “Mental Imagery and Relaxation Methods of Novice Archers: A Comparative Analysis,” *International Journal of Human Movement and Sports Sciences*, vol. 13, no. 4, pp. 865–872, 2025, doi: 10.13189/saj.2025.130422.

[28] A. B. Živković, N. P. Hristov, D. D. Jerković, B. S. Bogdanović, and J. M. Milutinović, “Automatic Measurement of Precision and Accuracy from the Hit Pattern of Small Arms Using Electronic Target System,” in *Materials Science and Engineering*, IOP Conference Series, 2019, pp. 1–6. doi: 10.1088/1757-899X/659/1/012015.

[29] S. Shirmohammadi, L. Mari, and D. Petri, “On the Commonly-Used Incorrect Visual Representation of Accuracy and Precision,” *IEEE Instrumentation & Measurement Magazine*, vol. 24, no. 1, pp. 45–49, 2021, doi: 10.1109/MIM.2021.9345597.

[30] A. Guillot, C. Collet, C. Molinaro, and A. Dittmar, “Expertise and Peripheral Autonomic Activity during the Preparation Phase in Shooting Events,” *Percept Mot Skills*, vol. 98, no. 2, pp. 371–381, 2004, doi: 10.2466/pms.98.2.371-381.

[31] A. Badarin *et al.*, “Psychophysiological Parameters Predict the Performance of Naive Subjects in Sport Shooting Training,” *Sensors*, vol. 23, no. 6, p. 3160, 2023, doi: 10.3390/s23063160.

[32] M. Paul, S. Ganesan, J. Sandhu, and J. Simon, “Effect of sensory motor rhythm neurofeedback on psycho-physiological, electro-encephalographic measures and performance of archery players,” *Ibnosina Journal of Medicine and Biomedical Sciences*, vol. 04, no. 02, pp. 32–39, 2012, doi: 10.4103/1947-489X.210753.

[33] A. Widyanti and G. B. Pratama, *Ergonomi Kognitif*, 1st ed. Bandung: PT Remaja Rosdakarya, 2022.

[34] R. T. Pivik, R. J. Broughton, R. Coppola, R. J. Davidson, N. Fox, and M. R. Nuwer, “Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts,” *Psychophysiology*, vol. 30, no. 6, pp. 547–558, Nov. 1993, doi: 10.1111/j.1469-8986.1993.tb02081.x.

[35] H. Ertan, S. Yagcioglu, A. Yılmaz, P. Ungan, and F. Korkusuz, “Accuracy in Archery Shooting is linked to the Amplitude of the ERP N1 to the Snap of Clicker,” *Montenegrin Journal of Sports Science and Medicine*, vol. 10, no. 1, pp. 37–44, 2021, doi: 10.26773/mjssm.210306.

[36] J. Y. Moon and E. Lee, “Analysis of Bullet Impact Locations in the 10 m Air Pistol Men’s Competition Based on Covariance,” *Applied Sciences*, vol. 14, pp. 1–14, 2024, doi: 10.3390/app14146006.

[37] E. J. Rechy-Ramirez and H. Hu, “Bio-signal based control in assistive robots: a survey,” *Digital Communications and Networks*, vol. 1, no. 2, pp. 85–101, 2015, doi: 10.1016/j.dcan.2015.02.004.

[38] H. Zhang *et al.*, “The applied principles of EEG analysis methods in neuroscience and clinical neurology,” *Military Medical Research*, vol. 10, no. 1, p. 67, 2023, doi: 10.1186/s40779-023-00502-7.

[39] M. Selvanathan, N. Jayabalan, G. K. Saini, M. Supramaniam, and N. Hussin, “Employee Productivity in Malaysian Private Higher Educational Institutions,” *PJAEE*, vol. 17, no. 3, pp. 66–79, 2020.

[40] S. Corrado *et al.*, “Improving Mental Skills in Precision Sports by Using Neurofeedback Training: A Narrative Review,” *Sports*, vol. 12, no. 3, pp. 1–30, 2024, doi: 10.3390/sports12030070.

[41] D. Wang *et al.*, “Effect of Cognitive Reappraisal on Archery Performance of Elite Athletes: The Mediating Effects of Sport-Confidence and Attention,” *Front. Psychol.*, vol. 13, 2022, doi: 10.3389/fpsyg.2022.860817.

[42] J. A. Mutang, C. B. Seok, and W. Wider, “Sensorimotor Rhythm (SMR) Neurofeedback Training on Anxiety: A Case Study on Archers,” *Journal for ReAttach Therapy and Developmental Diversities*, vol. 6, no. 1, pp. 282–291, 2023.

[43] J. Zhang *et al.*, “Preshooting Electroencephalographic Activity of Professional Shooters in a Competitive State,” *Computational Intelligence and Neuroscience*, vol. 2021, no. 1, 2021, doi: 10.1155/2021/6639865.

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

[44] T.-T. Chen, K.-P. Wang, W.-H. Chang, C.-W. Kao, and T.-M. Hung, "Effects of the function-specific instruction approach to neurofeedback training on frontal midline theta waves and golf putting performance," *Psychology of Sport and Exercise*, vol. 61, 2022, doi: 10.1016/j.psychsport.2022.102211.
[45] M. Starzak *et al.*, "Attentional focus strategies in racket sports: A systematic review," *PLoS ONE*, vol. 19, no. 1, 2024, doi: 10.1371/journal.pone.0285239.
[46] S. Chikhi, N. Matton, and S. Blanchet, "EEG Power Spectral Measures of Cognitive Workload: A Meta-Analysis," *Psychophysiology*, vol. 59, no. 6, p. e14009, 2022, doi: 10.1111/psyp.14009.
[47] M. E. Costanzo *et al.*, "Neural Efficiency in Expert Cognitive-Motor Performers During Affective Challenge," *Journal of Motor Behavior*, vol. 48, no. 6, pp. 573–588, 2016, doi: 10.1080/00222895.2016.1161591.
[48] H. G. Bull, A. C. Atack, J. S. North, and C. P. Murphy, "The Effect of Attentional Focus Instructions on Performance and Technique in a Complex Open Skill," *European Journal of Sport Science*, vol. 23, no. 10, pp. 2049–2058, 2023, doi: 10.1080/17461391.2022.2150895.
[49] M. Sudo, J. T. Costello, T. McMorris, and S. Ando, "The effects of acute high-intensity aerobic exercise on cognitive performance: A structured narrative review," *Frontiers in Behavioral Neuroscience*, vol. 16, 2022, doi: 10.3389/fnbeh.2022.957677.
[50] E. Zemková and L. Zapletalová, "The Role of Neuromuscular Control of Postural and Core Stability in Functional Movement and Athlete Performance," *Frontiers in Physiology*, vol. 13, 2022, doi: 10.3389/fphys.2022.796097.
[51] C.-H. Fan, C.-N. Liao, and W.-H. Hsu, "Associations of Scoring Accuracy with Postural Stability and Strength Measures in Archers on a Standard Archery Site," *Sports*, vol. 13, no. 9, p. 310, 2025, doi: 10.3390/sports13090310.
[52] K. A. Tamminen, J. Kim, C. Danyluck, C. E. McEwen, C. R. D. Wagstaff, and S. A. Wolf, "The effect of self- and interpersonal emotion regulation on athletes' anxiety and goal achievement in competition," *Psychology of Sport and Exercise*, vol. 57, 2021, doi: 10.1016/j.psychsport.2021.102034.
[53] Q. Shi, A. Gong, P. Ding, F. Wang, and Y. Fu, "Neural Mechanisms of Visual–Spatial Judgment Behavior under Visual and Auditory Constraints: Evidence from an Electroencephalograph during Handgun Shooting," *Brain Sciences*, vol. 13, no. 12, 2023, doi: 10.3390/brainsci13121702.
[54] Y. Kim and T. Chang, "A Case Study on the Effect of Imagery Training for Elite Archers of South Korea," *International Journal of Applied Sports Sciences*, vol. 32, no. 2, pp. 48–65, 2020, doi: 10.24985/ijass.2020.32.2.48.

AUTHOR BIOGRAPHY

Ainun Rahmansyah Raffar received a Bachelor of Engineering degree from the Industrial Engineering Study Program, Faculty of Engineering, Sebelas Maret University, Surakarta, Indonesia, in 2019. During his undergraduate studies, he served as a laboratory assistant in Work System Design and Ergonomics from 2021 to 2023. He was actively involved in student practicums, learning module development, and research assistance related to human factors and workplace design. He has been pursuing a Master of Industrial Engineering at Sebelas Maret University since 2024, with a research focus on technology integration in human performance optimization. His specific research interests include sports engineering, particularly the development and application of sensor technology for athlete performance analysis, cognitive ergonomics with an emphasis on psychophysiological assessment, and human-technology interaction in the context of sports.

Pringgo Widyo Laksono is a senior lecturer and researcher at the Faculty of Engineering, Universitas Sebelas Maret (UNS), Indonesia. He got Doctoral of Engineering degree from Gifu University, Japan. His research interests span smart manufacturing systems and automation, mechatronics, human–machine interaction, and intelligent systems engineering. He has led and collaborated on various research projects funded by national and international institutions. As a professional engineer member of the Indonesian Engineers Association (PII), he actively promotes engineering ethics and professional practice through education, research, and community service. His works have been published in reputable journals and presented at international conferences, advancing intelligent and sustainable engineering systems in Indonesia and beyond.

Bambang Suhardi is a Professor in the Work System Design and Ergonomics Laboratory, Department of Industrial Engineering at Universitas Sebelas Maret, Surakarta, Indonesia. He obtained his doctoral degree in Industrial Engineering and has been dedicated to advancing the field of ergonomics and human factors engineering in Indonesia. As a senior lecturer in the Doctoral Program in Industrial Engineering at Universitas Sebelas Maret, he has supervised numerous graduate students and contributed significantly to the development of research capacity in industrial engineering disciplines. His research interests include ergonomics, environmental ergonomics, accessibility of public facilities, work system design, occupational safety and health, lean healthcare,

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284

plant layout, and improving work methods in small and medium enterprises.

Rahmaniyah Dwi Astuti is an Associate Professor in the Work System Design and Ergonomics Laboratory, Department of Industrial Engineering at Universitas Sebelas Maret, Surakarta, Indonesia. She received a bachelor's degree from the Industrial Engineering Universitas Islam Indonesia, Yogyakarta (1998). Master of Engineering from Universitas Gadjah Mada (2007), Indonesia; Doctor of Philosophy in Industrial Engineering from Universitas Sebelas Maret (2024), Indonesia. Her research interests include cognitive ergonomics and neurophysiology with emphasis on EEG-based assessment of mental workload and attention, environmental ergonomics focusing on noise and thermal exposure effects, occupational health and safety, work system design and optimization, participatory ergonomics in healthcare settings, and age-friendly facility design.

Minoru Sasaki is a distinguished Japanese scholar in mechatronics, control engineering, and robotics. He earned his bachelor's degree in Mechanical Engineering from Yamagata University in 1980, followed by a Master's in 1982 and a PhD in 1985 from Tohoku University. His research contributions span actuator position/force control, flexible manipulators, bio-signal interfaces (such as EMG/EEG/EOG for human–machine interfaces), autonomous flying robots, and smart actuators. He has also built an international research network, collaborating with many institutions. He played a key role in leadership and service: he has held key positions in professional societies (e.g., the Society of Instrument and Control Engineers, the AEM Society of Japan), chaired conferences, and acted as a mentor for international students and researchers from Asia and Africa. He remains active in research and international collaboration as Emeritus Professor at Gifu University, contributing to regional development, education, and cutting-edge mechatronic systems.

Corresponding author: Pringgo Widyo Laksono, pringgo@ft.uns.ac.id, Master Program Department of Industrial Engineering & Center for research in Manufacturing System (CRiMS), Universitas Sebelas Maret, Jl. Ir. Sutami No.36 A, Jebres, Kec. Jebres, Kota Surakarta, Jawa Tengah 570126, Indonesia.
Digital Object Identifier (DOI): https://doi.org/10.35882/ijeeemi.v8i2.284