ORIGINAL ARTICLE

Brain activity and motor performance under different focus of attention in shooting of elite archer: An fNIRS study

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ABSTRACT

The correlation between different focuses of attention (FOAs) and performance in archery had been insufficiently explored. This study aimed to investigate brain activity under different FOAs, quantify the relationship between FOA and arrow scores in shooting. Sixteen elite archers were recruited to participate in this study. A 48-channel portable fNIRS device was used to collect hemodynamic signals in an outdoor environment. Each archer shot five arrows at a target placed 70 meters away. The results showed that motor performance at external and internal focus are not reach the statistical difference ($t = 0.527$, $p = .606$, Cohen's $d = 0.117$). compared to IF, EF have lesser ΔHbO in channel 14 ($t = -2.218$, $p = .044$, Cohen's $d = 0.640$), channel 30 ($t = -2.306$, $p = .042$, Cohen's $d = 0.598$) and channel 42 ($t = -3.506$, $p = .005$, Cohen's $d = 1.012$), but have greater ΔHbO in channel 37 ($t = 2.638$, $p = .023$, Cohen's $d = 0.762$), channel 38 ($t = 2.631$, $p = .023$, Cohen's $d = 0.759$). Additionally, compared to IF, EF have greater neural efficiency in channel 28 ($p = .026$). Compared to IF, EF enhanced activity in the visual cortex, particularly in V2 and V3, while decreasing activity in M1, S1, PMC, and SMA. Additionally, EF demonstrated greater neural efficiency in PMC and SMA. However, under IF, archers allocated additional resources to PMC and SMA to maintain performance levels comparable to those under EF.

Keywords: Performance analysis, Archery, fNIRS, External focus.

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INTRODUCTION

Archery is a sport that emphasizes accuracy (Ahmad et al., 2014). Archers need to shoot the arrow at the small bullseye from a distance of 70 meters. They must carefully control their movements and use muscle memory to control the bow (Yapıcı et al., 2018). In this situation, archers must not only complete their movements precisely, but also face many challenges from the environment, such as wind, noise, and other factors. These factors impact athletes and shift their attention away from the task of shooting. A classic example is Matthew Emmons, who missed his target in the final of the 50-meter rifle three positions event at the 2004 Athens Olympics. He may have failed to inhibit distractions from another shooter's target (Lu et al., 2021). Therefore, allocating attention resources is important for athletes who shoot.

When discussing the focus of attention (FOA), the well-known theory of external focus (EF) and internal focus (IF) highlights their differing impacts on motor performance. Wulf and colleagues have conducted extensive research in this area, they suggest that IF is harmful to performance, while EF is beneficial (Nicklas et al., 2024). The definitions of EF and IF have been described in previous studies. Briefly, EF refers to focusing on external objects, while IF refers to focusing on internal sensations. For example, when hitting a volleyball toward a mark on the wall, focusing on the mark indicates EF, while focusing on the sensation of the ball contacting your wrist indicates IF (Teasdale & Simoneau, 2001). Many studies have demonstrated that EF enhances performance in various tasks, such as dart throwing (Hitchcock et al., 2018), balance control (Sherman et al., 2021), and golf swings (Bell & Hardy, 2009). Regarding the mechanism, Wulf claims that IF shifts attention away from external tasks, increases anxiety, and heightens self-consciousness, which disrupts the automatic processes of motor control. In contrast, EF focuses attention away from the body's movements, facilitating the central nervous system's use of pre-planned motor programs to control movements (Wulf & Lewthwaite, 2019).

However, in archery, there is a lack of high-quality research comparing the effects of EF and IF on performance. Some studies suggest that archers should use EF to achieve better performance (Vrbik et al., 2021; Wang et al., 2022). Haywood claims that elite archers shift their focus to external targets before shooting (Haywood, 2006). However, these studies have limitations. They did not analyse the relationship between focus and performance or use neuroimaging to examine the brain activity of archers during different focus tasks. Archery may differ from other sports in terms of attention focus. According to the quiet eye theory, the duration of the quiet eye plays an important role in shooting performance (Behan & Wilson, 2008; Kim et al., 2019). However, if athletes focus externally, such as on the relative position between the sight and target, they may be distracted by sight motion and moment-to-moment adjustments (online error corrections), resulting in shorter QEDs and larger errors (Gonzalez et al., 2017). Meanwhile, this type of distraction is difficult to avoid because, in archery, athletes must shoot at a target 70 meters away. The target is so small that even tiny movements can cause significant shifts in their vision. To explore whether archers benefit from external focus, the best approach is to use neuroimaging tools and analyse the relationship between brain activity and performance. Although some researchers have used fMRI and EEG in this field, they typically focus on differences in brain activity between elite and amateur archers (Gu et al., 2022; Kim et al., 2008; Kim et al., 2014) or the effects of different training methods on archers (Chuang et al., 2015; Gao & Zhang, 2023). There is still a lack of understanding regarding the relationship between different attention focuses and shooting performance.

In summary, we use fNIRS to study archers' shooting performance under EF and IF in outdoor settings. By analysing motor performance and neural brain activity, we aim to assess the impact of different attention focus tasks. We believe this approach enhances the ecological validity of research in real training environments. We hypothesize that: 1) EF leads to better performance compared to IF; 2) EF results in higher activity in brain areas associated with movement and vision compared to IF; 3) EF promotes the automatic of brain areas related to motor control. We believe that exploring the relationship between attention focus and performance will deepen our understanding of archery and human attention control.

METHODS

Participants

We recruited 16 professional archers (age: 16.4 ± 1.2 years; height: 172.3 ± 3.5cm; weight: 72.2 ± 5.6 kg;) for this study. These participants were selected from the National Outdoor Archery Championship held in Lai Xi City from June 16 to June 20, 2024. These athletes are the top 16 in the elimination phase in this competition, so they represent the elite level of adolescent archers in China. The inclusion criteria were: 1) at least four years of training experience; 2) regular training maintained over the past six months; 3) male; and 4) right-handed, defined as using the left arm to hold the bow and the right hand to pull the string. The exclusion criteria were: 1) shoulder injuries, lower back pain, or other injuries within the past three months; and 2) consumption of caffeine or alcohol within 24 hours prior to testing. All participants and their coaches were informed of the risks involved in this study, and all participants volunteered to take part. They provided written informed consent after receiving a detailed explanation of the study, This study was approved by the Ethics Committee of Qufu Normal University (grant number: LL-20240005). All procedures were conducted in accordance with the latest guidelines and regulations of the Declaration of Helsinki.

Experimental procedure

The study was conducted in an outdoor field, with a target set 70 meters away from the participants. This distance was consistent with Olympic archery standards. A standard 120 cm target paper was fixed to the target. Specifically, according to the World Archery Federation standards, the target paper had five different colours, each representing a specific score range. The bullseye was yellow and scored 10 or 9 points; the red area scored 8 or 7 points; the blue area scored 6 or 5 points; the black area scored 4 or 3 points; and the white area scored 2 or 1 point.

All participants used their own bows and equipment and were allowed to shoot three or four arrows to adjust their sights before the formal tests. Then, participants wore portable fNIRS devices during the formal tests. This study used a block design. Participants rested for 30 seconds, then had 30 seconds to prepare to shoot, followed by another 30 seconds of rest, and so on. Participants shot 6 arrows in each task (see Figure 1). Participants completed tests under two different tasks, namely EF and IF. The sequence of these tasks was randomized. During EF and IF tasks, the author of this paper gave verbal instructions to the participants (Vrbik et al., 2021):

1) EF instruction: Please focus on sight's pin stable within the bullseye, try to fix it in a way to concentrate on your sight's pin and letting it melt with the centre and on the follow-through and arrow flight.
2) IF instruction: Please focus on the sensations in your bow arm and string arm and other body parts, try to use the muscle memory in the training, to locate the bow position and complete the stable shot.

To ensure that athletes understand the concept of different focuses of attention, they were asked to repeat the instructions for each task. If their repetition was correct, it was considered that they had understood the instructions. Additionally, to minimize potential confounding effects, participants were instructed to avoid unnecessary movements, such as clenching their teeth or making facial expressions, during the testing process.

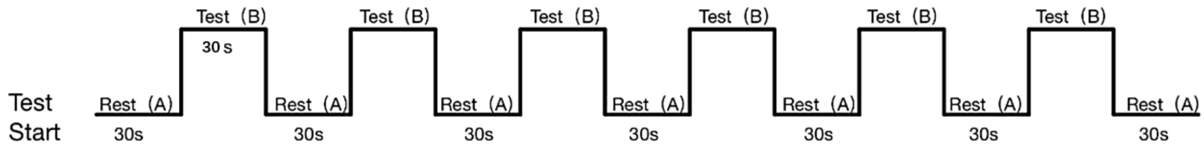

Figure 1 The block design of this study.

Data collection

Hemodynamics

The portable fNIRS devices (Model: NirSmart-3000A, Danyang Hui Chuang Inc., China) were used to collect hemodynamic signals. These devices had 24 emitters, 16 detectors, and 48 channels. The distance between emitters and detectors was 3 cm, the sampling rate was 11 Hz, and the wavelengths were 730 nm and 850 nm. The locations of the probes were localized using a 3D digitizer. The spatial arrangement of the 48 channels on standard brain templates from the Montreal Neurological Institute (MNI) was imported into the NIRS-SPM toolbox (Ye et al., 2009) to obtain spatial distributions and probabilities for each channel. The region of interest in this study includes frontopolar cortex, orbitofrontal cortex, primary motor cortex, pre-motor cortex, supplementary motor cortex, primary somatosensory cortex and visual cortex. When placing the devices on the participant's head, the hair was carefully adjusted to ensure the detectors and emitters were as close to the scalp as possible. During the formal tests, a black blanket was used to cover the head to minimize the impact of sunlight on the signals.

Motor performance

After each shot, an expert observer used a telescope (Model: Ultima-80, Celestron Inc., USA) to observe the arrow's location on the target paper and record the corresponding ring. If the arrow was a line cutter, it was awarded the higher score. For example, if the arrow touched the 9-ring line, the score was recorded as 9.

Data analysis

Raw data were exported from the fNIRS devices and converted from NIRS format to SNIRF format using Homer3 (Version: 1.87, Boston University, USA). The raw data were visually inspected, and poor-quality channels were marked and excluded during data processing. The data processing pipeline included several steps. First, the light intensity was converted to optical density. Next, motion artifacts were corrected channel-by-channel to address spikes in the data. Wavelet functions were applied to correct noise caused by head movements. A 0.01-0.1 Hz bandpass filter was used to remove device and physiological noise, including Mayer waves (≈0.01 Hz), breathing (0.2-0.3 Hz), and heart rate (1.6-1.8 Hz). The modified Beer–Lambert Law was applied to convert optical density data into concentrations of oxyhaemoglobin (HbO). The mean value of HbO within the last 5 s of each rest period was selected as a baseline for correction, The mean values represented the change in HbO and HbR concentrations from 0 seconds before the task to 30 seconds after the task began.

The scores were organized and saved in Excel. Meanwhile, methods from previous studies were used to quantify neural efficiency between different FOAs (Curtin & Ayaz, 2019; Curtin et al., 2019). Specifically, neural efficiency was defined as the relationship between outcomes (scores) and effort (hemodynamics). The scores and ΔHbO concentrations were normalized using the Z-Score method and then projected into a two-dimensional coordinate system. The "*zero-efficiency*" line, representing outcome = effort, was calculated.

The distance between this line and each data point (score) was then determined. According to previous studies, neural efficiency can serve as an indicator of automaticity of brain areas (Callan & Naito, 2014).

Statistical analysis

SPSS (Version 26.0, IBM Inc., USA) was used for statistical analysis. First, the normality of the data (hemodynamics and scores) was checked for the two different tasks. If the data were normally distributed, a paired-samples t-test was used to assess differences between EF and IF tasks. If the data did not conform to normality, the Wilcoxon signed-rank test was applied. To avoid the problem associated with multiple comparisons, a false discovery rate (FDR)-corrected was considered. Cohen's *d* was reported as the effect size, with the following interpretation standards: 0.8 (large), 0.5 (medium), and 0.2 (small) (Sawilowsky, 2009). Pearson correlation analysis (for normally distributed data) or Spearman correlation analysis (for non-normally distributed data) was conducted to examine the relationship between hemodynamics and scores. Data in the results were expressed as means and standard errors.

To ensure the statistical power was valid, the post hoc power estimation function in G*Power (Version 3.1.9, Heinrich Heine University Düsseldorf, Germany) was used to calculate the actual power. The effect size of ΔHbO from channel 37, 0.762 (see the "*Hemodynamics Data*" section), was used. The number of groups was set to 2, the sample size to 16, and the α error probability to .05. The resulting actual power was 0.896.

RESULTS

Hemodynamics data

Five channels showed the statistical significance between EF and IF tasks, specifically, compared to IF, EF have lesser ΔHbO in channel 14 (t = -2.218, *p* = .044, Cohen's *d* = 0.640), channel 30 (t = -2.306, *p* = .042, Cohen's *d* = 0.598) and channel 42 (t = -3.506, *p* = .005, Cohen's *d* = 1.012), but have greater ΔHbO in channel 37 (t = 2.638, *p* = .023, Cohen's *d* = 0.762), channel 38 (t = 2.631, *p* = .023, Cohen's *d* = 0.759), as shown in Table 1. Please see appendix to check the results of other channels.

Table 1. The ΔHbO (× 10−5 mmol/L) channels with statistical significance in EF and IF tasks.

Brain area	Channel	EF	IF	t	*p*
Left hemisphere PMC and SMA	14	3.05 ± 0.81	4.66 ± 1.25	-2.218	.044
Left hemisphere S1	30	2.01 ± 0.81	3.32 ± 1.06	-2.306	.042
Right hemisphere M1	42	1.43 ± 0.59	3.18 ± 1.09	-3.506	.005
V2	37	4.36 ± 1.36	1.28 ± 1.11	2.638	.023
V3	38	4.81 ± 0.66	2.32 ± 0.73	2.631	.023

Note. SMA: Supplementary Motor cortex. PMC: Pre-Motor cortex. S1: Primary Somatosensory cortex. M1: Primary Motor cortex. IF: internal focus. EF: external focus.

Motor performance

The scores between EF and IF tasks did not reach the statistical significance (t = 0.527, *p* = .606, Cohen's *d* = 0.117), as shown Figure 2.

Correlation between hemodynamics and motor performance

Correlation analysis was conducted to examine the relationship between hemodynamic features and scores. The results showed that there was a negative correlation between channel 28 (r = -0.769, *p* = .003) hemodynamic and performance in the EF task, positive correlation between channel 14 (r = 0.626, *p* = .029) in the IF task, as shown in Table 2.

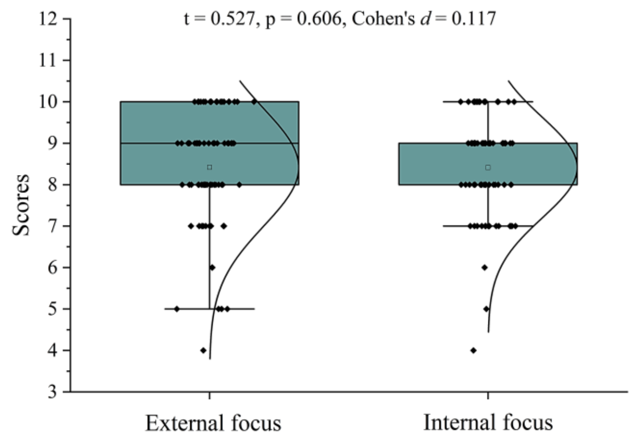

Figure 2 Motor performance in EF and IF tasks with statistical results. Each scatter point represents an individual shot.

Table 2 The correlation between ΔHbO of channels and motor performance with statistical significance in EF and IF tasks.

Brain area	Channel	Task	r	*p*
Left hemisphere PMC and SMA	14	IF	0.626	.029
Left hemisphere PMC and SMA	28	EF	-0.769	.003

Note. SMA: Supplementary Motor cortex. PMC: Pre-Motor cortex. IF: internal focus. EF: external focus.

Neural efficiency difference between two tasks

One channel showed the statistical significance between EF and IF tasks, specifically, compared to IF, EF have greater neural efficiency in channel 28 (*p* = .026), as shown in Figure 3.

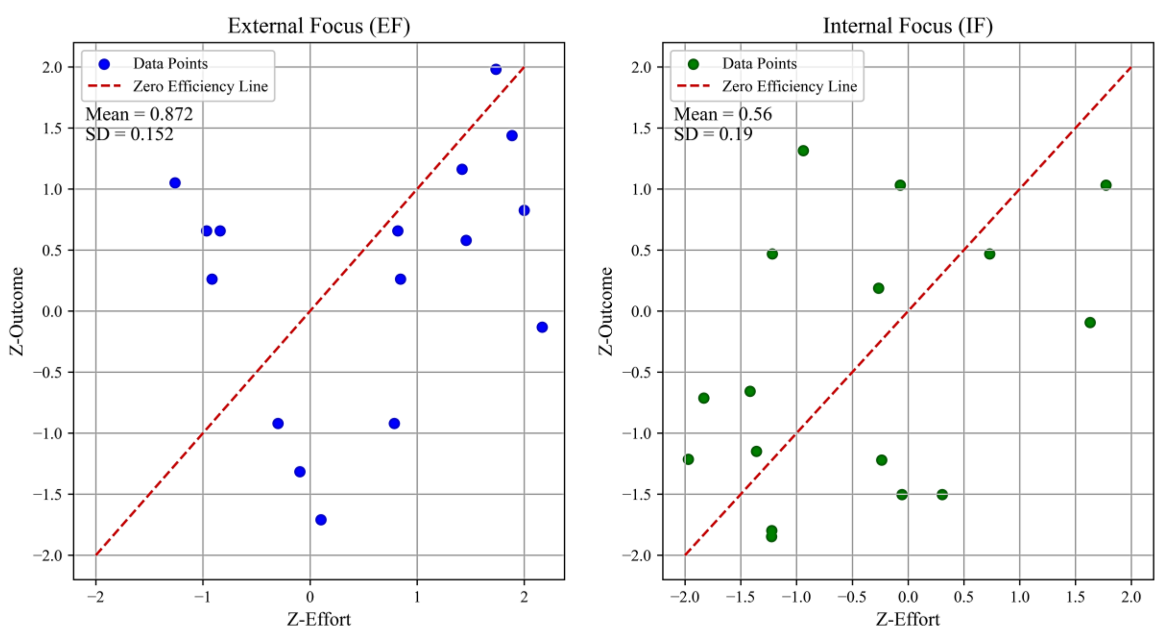

Figure 3 Neural efficiency with channel 28 in EF and IF tasks. Each dot represents the z-score of an individual shot. Higher efficiency is indicated by data points closer to the upper-right corner.

DISCUSSION

The relationship between focus of attention and performance in archery has not been thoroughly explored. In this study, we used portable fNIRS devices to investigate this relationship. The results showed that compared to IF, EF elicited greater brain activity in the V2 and V3 cortex, but has less activity in the left hemisphere PMC, SMA, S1 and right hemisphere M1. This finding is consistent with our first hypothesis. Meantime, we did not find a difference between EF and IF at shooting performance, but hemodynamic features have negative and positive correlation with scores in the EF and IF respectively, which is inconsistent with our second hypothesis. Additionally, the neural efficiency in PMC and SMA is greater in EF, which is consistent with our third hypothesis. These results are discussed in the following sections.

Results showed that EF elicited significantly higher activation in certain areas compared to IF. These results are consistent with our task design. Specifically, EF showed greater activation in V2 and V3. From V2 to V3, the numbers of direction-sensitive neurons in V2 and V3 continue to growth (Foster et al., 1985; Gegenfurtner et al., 1997). These neurons are highly sensitive to object movement (Essen & Zeki, 1978) (Furlan & Smith, 2016). So when athletes focused on the relative positions between sight and target, V2 and V3 will activate greater to processing the visual information. These can be explained that why EF have higher activation in these two areas, previous studies has been confirmed that in rifle shooting, athletes will activate these areas to finish aiming process. They also claimed that visual cortex greater activation may have harmful to shooting performance (Loze et al., 2001), because more resources input will decrease the resources input at M1, PMC and SMA areas which helpful for precisely motor control. Elite shooters usually activate their visual cortex only extremely short duration before pulled the trigger (Doppelmayr et al., 2008).

IF has greater activity in S1, M1, PMC, and SMA is interesting results. Greater activity in these areas means highly resources input. For prospective of archery skills, continues, smoothly sequencing to execute the technique movement is crucial for success. PMC and SMA has been shown in previous studies to play an important role in the sequential control of motor actions (Chang et al., 2011; Cona & Semenza, 2017), according to the neural efficiency hypothesis, if the neural efficiency increase, the PMC should exhibit lesser activity, automation level of locomotion increases (Callan & Naito, 2014). So, based on the results of EF have greater neural efficiency in PMC and SMA compared to IF, which means EF have greater automatic of motor control, consistent with constrain hypothesis (McNevin et al., 2003). However, our correlation analysis also supports that PMC and SMA activity increase have positive impact for performance in IF, which means greater activity in PMC and SMA may be associated with athletes are tried to conquer the automatic performance decrease in IF. Previous studies claim that brain will recruit additional areas to compensation and maintain the performance in balance or obstacles negotiation task when challenging increase (Chen et al., 2017; Kan et al., 2025). Meantime PMC and S1, M1 usually simultaneously activate (Urquhart et al., 2019), previous studies claim that the functional connectivity between PMC and M1 enhanced in motor executed and motor imagination (Kim et al., 2018), we believed that greater activity in S1 and M1 at IF have two reasons, one of them from our verbal instruction in IF, namely imagination of inner feeling of body or muscle memory of technique movements, one of them are caused by additional activity of PMC and SMA. We are already know that S1 are mainly responsible to processing the sensory information, such as touching feelings and inner feelings, Previous studies have found that S1 enlargement emerges in tactile-sensitive sports, such as handball (Meier et al., 2016). Greater S1 activity allows athletes to process tactile information from the bow and string more precisely (Davis et al., 2022). Meanwhile, the direct neuronal mapping from S1 to M1 is patterned (Ghosh et al., 1987; Pons & Kaas, 1986), specifically following somatotopic maps. Studies have found that finger sensory information can elicit motor support for the same finger from M1 (Shelchkova et al., 2023). Thus, greater activity of M1 can better utilizes sensory information from S1 to adjust bow stability and anchor positions, achieving consistent and stable shots. Based on the above, we believed that athletes may be through increased activity in PMC, SMA, S1 and M1 to maintain a similar performance of EF.

In summary, we believed that the training and competitive experiences of high-level athletes may help them better adapt to various conditions in training or competition (Song et al., 2024). More specifically, considerate the S1 M1 did not have correlation with performance in IF, athletes through increased additional activity PMC and SMA may is a key factor for maintaining stability of performance. This is a reason of why arrows scores didn't statistical difference between different FOAs. Meidenbauer and colleagues has been prove that there have positive correlation between brain activity and task requirements (Meidenbauer et al., 2021), this kind of requirements are not only task difficulty, but including all features with relation with finish task, even they are focus on the frontal lobe, but also should applicable for others areas. This kind of mechanism may be crucial for humans, as various adaptive motor solutions, supported by the inherent degeneracy of neurobiological systems, can be utilized to allow different system components to achieve the same performance outcomes (Chow et al., 2009; Davids & Glazier, 2010).

The findings of this study could provide valuable insights for coaches and elite archers. In competitive sports, an athlete's ability to quickly and flexibly adapt their strategies to changing environments is crucial for success (Doron & Martinent, 2021; Gaudreau & Blondin, 2004). Archers may struggle to use EF in adverse conditions, such as darkness or rain, as these factors can obscure the target. In such cases, they may have difficulty concentrating on the relative position between the sight pin and the target, making IF a better alternative. However, if the environment permits the use of EF, archers should consider it, as EF enhances neural efficiency and promotes the automation of motor control.

Limitations

We did not collect data from lower-skilled athletes, so we were unable to compare brain activity and performance across different skill levels. This limitation arose because we aimed to collect data in a real-world environment while ensuring that every athlete maintained their optimal condition. To achieve this, we conducted data collection during competition periods. However, due to scheduling constraints, we could not collect data from all athletes. Despite this limitation, we believe that this study remains valuable, as it is the first fNIRS investigation of the shooting process in archery and conducted in a testing environment designed to closely resemble an Olympic field.

CONCLUSION

This study was conducted in a standard Olympic field to quantify the impact of EF and IF on elite archers' performance, hemodynamics, and neural efficiency. The findings revealed that, compared to IF, EF enhanced activity in the visual cortex, particularly in V2 and V3, while decreasing activity in M1, S1, PMC, and SMA. Additionally, EF demonstrated greater neural efficiency in PMC and SMA. However, under IF, archers allocated additional resources to PMC and SMA to maintain performance levels comparable to those under EF.

AUTHOR CONTRIBUTIONS

Kun Qin, Juan Wu, and Shikun Wang made substantial contributions to the conception, design, and execution of this study. Kun Qin: conceptualization, methodology, investigation, writing—original draft preparation, and visualization. Juan Wu: validation, resources, writing—review and editing, supervision, project administration, and funding acquisition. Shikun Wang: data curation, statistical analysis. All authors have read, revised, and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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