ORIGINAL ARTICLE

Activation of upper- and lower-limb muscles during hook punch using lead- and rear-arm

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ABSTRACT

The hook punch is a fundamental technique in boxing, requiring coordinated activation of upper- and lower-limb muscles to generate maximal force and speed. While previous studies have analysed muscle activation in straight punches, research on hook punches remains limited. This study aimed to examine the peak activation (PA) and average rectified value (ARV) of seven upper- and lower-body muscles during four distinct hook punch techniques and compare activation patterns between Southpaw (SP) and Orthodox (OD) stance boxers. Twelve elite male boxers (SP: n = 8, OD: n = 4) participated in this study. Surface electromyography recorded PA and ARV of the biceps brachii (BB), triceps brachii (TB), anterior deltoid (AD), latissimus dorsi (LD), biceps femoris (BF), rectus femoris (RF), and medial gastrocnemius (MG) during four hook punch techniques: lead-arm hook to the head (LAHH), lead-arm hook to the body (LAHB), rear-arm hook to the head (RAHH), and rear-arm hook to the body (RAHB). The independent t-test and Wilcoxon test compared stance groups, while the paired t-test was used to determine intra-technique differences. No significant differences in PA or ARV were found between SP and OD, except for RF activation during LAHB (p = .038). Significant intra-technique differences were observed in LD, RF, and MG activation. In conclusion, no differences in muscle activation were observed between SP and OD stances, except for the rectus femoris during the LABH. Between punch techniques, variation in muscle activation was observed, implying differences in strategies used.
Keywords: Biomechanics, Athletic performance, Muscle strength, Combat sports, Musculoskeletal physiological phenomena, Muscle contraction.

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INTRODUCTION

Several combat sports are practised worldwide by athletes, either as a part of cultural traditions or as a competitive event (e.g., boxing, wrestling, judo, etc.). Boxing is unique among these combat sports because it allows punches, unlike other combat sports that involve techniques such as holding, kicking, grappling, elbow and knee strikes (Lenetsky et al., 2020). In the sport of boxing, precise, quick, and powerful punches enhance the likelihood of success (Beattie & Ruddock, 2022; Cheraghi et al., 2014). Different types of punches can be actually used during a competitive match. Within several types of punches in boxing, the hook is one of the most common and effective punches due to its ability to generate significant force with high speed from close range (Dinu et al., 2020; Smith et al., 2000; Thomson & Lamb, 2016). The hook technique can be used in different situations, such as in combination with other offensive punches or as a counterpunch while blocking. It can also be used to get an advantage over the opponent, to knock the opponent out, or to score a point (Lenetsky et al., 2013). Indeed, the chances of the opponent getting knocked out are higher if the hook strikes the opponent's chin (Walilko et al., 2005). However, it should also be noted that performing a hook punch may also be risky. For example, if the athlete misses the opponent during the hook punch, the opponents may then have an ample opportunity to counterpunch (Bingul et al., 2018).

Furthermore, the hook punch can be thrown from two different stance positions (i.e., southpaw and orthodox). The "*southpaw stance*" in boxing is characterized by the right foot and hand being positioned in front, while the left foot and hand are positioned behind, which is a natural setup for left-handed fighters. In contrast, the "*orthodox stance*" is the opposite configuration, with the left foot and hand leading, a position commonly adopted by right-handed individuals (Buśko et al., 2014). Moreover, the hook punch technique varies based on the arm used to deliver the punch (i.e., the lead arm hook, thrown with the front hand; the rear arm hook, thrown with the backhand) and the target area where the punch is thrown (i.e., the body hook, targeting the opponent's ribs or liver area; and the head hook, which targets the chin, jaw, temple or side of the head) (Bingul et al., 2018; Kapo et al., 2021). Research indicates that the execution of hook punches involves significant rotational movements, particularly from the trunk and lower limbs. For instance, Dunn et al. (2022) emphasize that the trajectory of the arm during hook punches is characterized by an arcing motion, which necessitates a high degree of rotational acceleration delivered to the target (Dunn et al., 2022). This rotational component is crucial for generating the force required to deliver an effective punch. Furthermore, the contribution of lower limb musculature is vital, as it provides the necessary stability and power transfer through the kinetic chain during the punch (Dunn et al., 2022; Zhou et al., 2022).

Of note, the upper and lower-body muscular strength is essential in boxing for generating high force and sustaining a higher level of competitiveness (Bingul et al., 2018). Therefore, understanding the muscle activation patterns during these hook punches is crucial for identifying the primary muscle groups involved, assessing the load and potential injury risks, developing new training programs to enhance the punching efficiency, and refining the hook techniques – all leading to better performance (Oliva-Lozano & Muyor, 2020; Raizada & Bagchi, 2019; Tŭrker & Sze, 2013). Assessing the muscle activation during specific movement is possible with the use of surface electromyography (sEMG), which is a non-invasive technique for recording the electrical activity of targeted muscles (Bagchi & Raizada, 2019; Massó et al., 2010; Raizada & Bagchi, 2017).

Previous studies have used sEMG to record muscle activation in boxing for different punches. For example, Valentino et al. (1990) conducted an electromyographical study in boxing, comparing muscle activation during the jab technique with the uppercut. The authors reported that deltoid muscle activation was significantly higher during the jab than the uppercut. Similarly, Kumar et al. (2022) analysed the peak activation during different jab techniques, finding significantly higher peak activation of the anterior deltoid during long-range targeting head as compared to other jab techniques. Moreover, a few studies (Izumi et al., 2009; Kumar et al., 2022; Lockwood & Tant, 1997) have analysed the upper and/or lower body muscle activation patterns during different punching techniques. Despite the significance of hook punches in boxing, no previous study has investigated muscle activation during hook punches. Although one study did measure the force of impact during different hook punches, the authors did not assess muscle activation (Bingul et al., 2018). Therefore, the current study aimed to investigate the peak activation (PA) and average rectified value (ARV) of seven upper and lower body muscles during four distinct hook techniques (i.e., lead arm hook to the head, lead arm hook to the body, rear arm hook to the head, and rear arm hook to the body). Specifically, the first objective was to compare the PA and ARV of seven upper and lower body muscles between Southpaw and Orthodox stance boxers during the execution of four distinct hook techniques. The second objective was to compare the PA and ARV values among four hook techniques for each muscle separately.

METHODOLOGY

Participants

The sample size was determined using the G*Power software version 3.1.9.7 (University of Dusseldorf, Dusseldorf, Germany). A priori analysis indicated that a minimum of 5 samples was necessary, based on the following variables: effect size = 0.80 (large), α error probability = .05, power = 0.95, number of groups = 1, and number of measurements = 4 (referring to four different hook techniques). Additionally, the correlation among repeated measures was set at .05, with a non-sphericity correction of € = 1. A purposive-convenience sampling technique was used for the recruitment of participants. The inclusion criteria were as (i) elite boxing player (i.e. participated in international competition such as world championship, Asian championship, Commonwealth Games, etc.), (ii) had a minimum of 6 years training experience, (iii) free from injury during the past 6 months. Therefore, a total of 12 male elite boxers (southpaw stance, n = 8 and orthodox stance, n = 4), slightly higher than the recommended sample size, were selected for the study considering the potential participants' attritions due to difficulties related to EMG recordings (Turker & Sözen, 2013). However, we encountered no difficulties in capturing the EMG data of any participant. The descriptive characteristics of participants are presented in Table 1. The study was conducted in accordance with the ethical guidelines outlined in the Declaration of Helsinki. Each participant received comprehensive information regarding the potential risks and benefits of their involvement, and written informed consent was obtained prior to enrolment in the study. This study was conducted as part of a doctoral program and received approval from the Departmental Research Committee (DRC) at the Department of Sports Biomechanics, Lakshmibai National Institute of Physical Education, Gwalior, India.

Table 1. Anthropometric and demographic characteristics of participants.

Variables	**Overall (n = 12)**	**Southpaw (n = 8)**	**Orthodox (n = 4)**
Age (yrs)	24.4 ± 2.7	24.0 ± 3.0	25.3 ± 1.8
Height (cm)	167.9 ± 4.2	167 ± 4.5	169.8 ± 3.3
Body mass (kg)	58.7 ± 4.7	57.7 ± 5.2	60.7 ± 3.1
BMI	20.8 ± 1.3	20.7 ± 1.3	21.1 ± 1.4

Note. Data are presented as mean ± standard deviation, BMI – body mass index.

Experimental design

The EMG activity of seven muscles—biceps brachii (BB), triceps brachii (TB), anterior deltoid (AD), latissimus dorsi (LD), biceps femoris (BF), rectus femoris (RF) and medial gastrocnemius (MG)—was recorded during the execution of four hook punch types: (i) leading arm hook to the head; (ii) leading arm hook to the body;

(iii) rear arm hook to the head; and (iv) rear arm hook to the body. The experimental design involved repeated measures, with participants performing each punch type three times with a 1-minute rest interval between trials in a randomized crossover manner (www.randomizer.org).

Equipment and measurements

The EMG activity of the muscles was recorded using a portable wireless surface EMG device (BTS FREEEMG, Bioengineering, Italy), which comprises of probes, a USB receiver, and specialized EMG-Analyzer software. The device's signals from selected seven muscles were recorded at a 1000 Hz sampling rate, transmitted via a USB receiver, and processed using the accompanying software, with all values expressed in microvolts (μV) for all four-hook punch types. To ensure consistency in performance, participants used standard training gloves that adhered to size and weight specifications outlined by the International Boxing Association (AIBA, 2010). Additionally, a medium-sized punching bag (36” × 18”) was hung in the practice area, providing a standardized target for all punch techniques.

Data collection

Before the data collection, familiarization sessions were conducted for all participants, where they were briefly instructed about the study protocol and were given ample time to adapt to the test procedure. They were instructed to remove their upper-body clothing to facilitate proper placement of the EMG probes. The target muscles were located using manual palpation as described in a previous study (Kothari et al., 2014). The placement of the EMG probes followed the guidelines provided by the SENIAM project (Hermens et al., 1999). To minimize skin impedance, the designated areas were shaved and cleaned with alcohol swabs (Non-Woven Alcohol Swab, Recombigen Clear & Sure, India).

Surface EMG electrodes (H124SG, Adafruit, USA) were carefully positioned along the muscle fibre lines and securely attached to wireless EMG probes using adhesive medical tape (Mendwell Adhesive Tape USP, Prominence Healthcare Pvt. Ltd., India) to ensure they remained fixed during punching. The wireless probes transmitted data to a USB receiver connected to a laptop, and the data was processed using EMG-Analyzer software. The BTS FREEEMG system was calibrated as per the manufacturer's instructions *("Bts freeemg 300 user manual*," 2013). Normalization of the recorded EMG signal was not conducted in this study, as it aimed to compare the amplitude signals between the same muscles during different punches within the same session and under consistent experimental conditions. Additionally, there were no alterations to the EMG electrode setup throughout the process (Halaki & Ginn, 2012).

After electrode placement, participants completed a 2-minute warm-up, including shadow boxing with a focus on the hook techniques. The adhesive quality of the EMG electrodes and probes was rechecked post-warm-up. Each participant was then instructed to execute the techniques individually. Participants were encouraged to execute each punch with maximum effort; however, no external motivation was given. The punching bag was marked with temporary rectangles corresponding to the participant’s height: "*head length* × *head width*" at head level for head-targeting punches and "*torso length* × *shoulder width*" at body level for body-targeting punches. Participants were instructed to throw the hook to the head and body from a stationary position using the leading arm, while for the rear arm; they were required to take a step forward. The average of three trials was calculated for each punch type and muscle group in Microsoft Office Excel (Microsoft Office Professional Plus 2019).

Statistical analysis

Descriptive statistics were employed to summarize the dataset, utilizing mean and standard deviation values for normally distributed variables, whereas median and interquartile range (IQR) values for variables not conforming to normal distribution. The normality assumption of the collected data was assessed using the Shapiro-Wilk test. To analyse muscle activations in different techniques between SP and OD Stances, an independent sample T-test was employed for variables exhibiting a normal distribution, while the Mann-Whitney U test was utilized for variables following non-normal distributions. The muscle activation during the four techniques was compared using a series of paired sample T-tests for variables exhibiting a normal distribution and Wilcoxon tests for those variables demonstrating a non-normal distribution. Additionally, the effect size (ES) for the Wilcoxon test was computed using the formula 'r' = Z/√n (Tomczak & Tomczak, 2014), where the magnitude of 'r' was interpreted as small (≤0.1), moderate (>0.3–0.5), and large (>0.5) (Cohen, 1988). Hedge's *g ES was calculated* for the paired sample T-test, which was categorized as trivial (<0.2), small (0.2–0.6), moderate (>0.6–1.2), or large (>1.2–2.0) (Hopkins et al., 2009). Figures were generated using GraphPad Prism version 8.0. Statistical analyses were conducted using IBM SPSS version 24.0, with a predefined significance level set at $p \leq .05$.

RESULTS

The comparative statistics of EMG activity (PA and ARV) for the selected muscles during the four hook punch techniques (LAHH, LAHB, RAHH, RAHB) between Southpaw and Orthodox stances are summarised in Table 2. No significant differences ($p > .05$) were observed in PA and ARV of all selected muscles between SP and OD stance boxers during the four-punch technique. The only exception was the PA in the RF muscle during the LAHB punch technique, which showed a significant difference ($p = .038$; r = 0.627). Additionally, a non-significant but large effect size (r = 0.513; r = 1.886) was noted in the PA of the BF muscle between the two stance groups during the LAHH and LAHB punch techniques, respectively.

The graphical representation in Figure 1 highlights the variations in muscle activation for PA and ARV across the four hook punch techniques. For overall PA (Figure 1a), significant differences were noted in the LD between LAHH and RAHH ($p = .02$, Large ES = 0.804), in the RF between LAHH and LAHB ($p = .019$, Large ES = 0.812) and in the MG between LAHH and RAHH ($p = .033$, Large ES = 0.64) as well as between LAHB and RAHB ($p = .016$, Large ES = 0.72). In the Southpaw PA (Figure 1b), a significant difference was detected in the Biceps Brachii muscle between LAHB and RAHB ($p = .047$, Large ES = 0.880). Similarly, in the Orthodox PA (Figure 1c), a significant difference was found in the Biceps Brachii muscle between LAHH and LAHB ($p = .045$, Large ES = 1.443). For overall ARV (Figure 1d), significant differences were observed in the Biceps Brachii between RAHH and RAHB ($p = .015$, Large ES = 0.802) and in the Biceps Femoris between LAHH and LAHB ($p = .030$, Medium ES = 0.734) and between RAHH and RAHB ($p = .028$, Large ES = 0.63). In the Southpaw ARV (Figure 1e), the BB muscle displayed significant differences in ARV between RAHH and RAHB ($p = .017$, ES = 0.84). However, no significant differences in ARV were observed in the Orthodox stance (Figure 1f).

DISCUSSION

The first objective of the current study was to compare the PA and ARV of seven upper- and lower-body muscles during four hook punch techniques between SP and OD stances. The primary findings revealed non-significant differences in PA and ARV of selected muscles between stance groups, except for the PA in RF during the LAHB technique. The lack of significant differences in muscle activation between SP and OD stances aligns with the hypothesis that elite athletes, regardless of stance, may exhibit similar neuromuscular activation to optimize force generation during hook punches. For instance, Bingul et al. (2018) observed no significant differences in impact force or joint kinetics during hook punch throws between SP and OD stance elite boxers.

Table 2. Comparative statistical analysis of muscle activations in different techniques for southpaw and orthodox stances.

	Southpaw (n = 7)	Orthodox (n = 4)	*p*-value [g/r]	Southpaw (n = 8)	Orthodox (n = 4)	*p*-value [g/r]
	Mean ± SD	Mean ± SD	Magnitude	Mean ± SD	Mean ± SD	Magnitude
	Lead arm hook (head)			Rear arm hook (head)		
Biceps Brachii (Peak activation)	1908.3 ± 223.7	1759.9 ± 164	.28 [0.659][s]	1947 ± 296.2	1840.9 ± 295.1	.571 [0.331][s]
Triceps Brachii (Peak activation)	954.5 ± 363.1	923.6 ± 172	.878 [0.09][t]	1049.8 ± 259.6	869.5 ± 174.2	.243 [0.701][m]
Anterior Deltoid (Peak activation)	1348.8 ± 459.2	1336.4 ± 156.7	.96 [0.029][t]	1239.3 ± 339.8	1047.5 ± 246.2	.343 [0.562][s]
Latissimus Dorsi (Peak activation)	607.4 ± 202.2	758.8 ± 154.6	.23 [0.737][m]	490.3 ± 185.7	508.9 (96)[a]	.865[b] [0.051][s]
Biceps femoris (Peak activation)	502.1 (44.6)[a]	621.7 ± 87.2	.089[b] [0.513][l]	514.2 (459)[a]	547.4 ± 131.7	.734[b] [0.102][s]
Rectus femoris (Peak activation)	617.6 ± 143.4	733.8 ± 291.9	.39 [0.517][s]	635.2 ± 268	524 ± 113.6	.453 [0.441][s]
Medial gastrocnemius (Peak activation)	610.3 (371)[a]	588.4 (460.3)[a]	.45[b] [0.228][s]	1018.7 ± 400.9	918.3 (643)[a]	.497[b] [0.205][s]
Biceps Brachii (average rectified value)	96 ± 20.9	99.1 ± 17	.81 [0.142][t]	103 (37.2)[a]	116.5 ± 30.3	.734[b] [0.102][s]
Triceps Brachii (average rectified value)	36 ± 15.5	43.5 ± 8.2	.401 [0.505][s]	28.5 ± 10.2	31.6 ± 8.8	.622 [0.288][s]
Anterior Deltoid (average rectified value)	52.1 ± 15	42.8 (31.4)[a]	.257[b] [0.342][m]	56.2 (12.7)[a]	59.7 ± 7.3	.234[b] [0.358][m]
Latissimus Dorsi (average rectified value)	28.5 (14.4)[a]	37.5 ± 6.2	.131[b] [0.456][m]	24.1 (11)[a]	30.8 ± 1.7	.174[b] [0.410][m]
Biceps femoris (average rectified value)	35.9 ± 10.6	40.8 ± 4	.406 [0.5][s]	40.5 (35.2)[a]	66.9 (23)[a]	.126[b] [0.461][m]
Rectus femoris (average rectified value)	46.7 ± 12.3	65 ± 37.2	.403 [0.706][m]	41.6 ± 13.4	43 ± 4	.849 [0.11][t]
Medial gastrocnemius (average rectified value)	57.8 ± 19.1	38.8 ± 17	.136 [0.938][m]	65.7 ± 17	61.4 (24.8)[a]	.61[b] [0.154][s]
	Lead arm hook (body)			Rear arm hook (body)		
Biceps Brachii (Peak activation)	1939.4 ± 224	1900.5 ± 184.4	.776 [0.168][t]	1714 ± 429.8	1978.4 ± 199.5	.277 [0.649][m]
Triceps Brachii (Peak activation)	987.6 ± 394.2	1179.5 ± 149.8	.382 [0.526][s]	995.6 ± 288.2	1003.7 (64.2)[a]	.174[b] [0.410][m]
Anterior Deltoid (Peak activation)	1315.7 ± 360.2	1138.8 ± 234.8	.406 [0.499][s]	1189.1 ± 320.7	1259.1 ± 63.6	.681 [0.239][s]
Latissimus Dorsi (Peak activation)	611 ± 174.1	711 ± 78.5	.313 [0.612][m]	467.3 (387.5)[a]	685.7 ± 81.7	.174[b] [0.410][m]
Biceps femoris (Peak activation)	493.8 ± 110.7	1012.2 ± 406	.081 [1.886][l]	582.6 (333.4)[a]	586.7 ± 188.3	.734[b] [0.102][s]
Rectus femoris (Peak activation)	531.1 (153.4)[a]	575 (332.3)[a]	.038[*b] [0.627][l]	604.4 ± 186.3	462.9 ± 109.7	.197 [0.781][m]
Medial gastrocnemius (Peak activation)	642.3 ± 189.7	420.2 ± 270.9	.142 [0.922][m]	664.1 (661.5)[a]	543.2 ± 357.5	.308[b] [0.307][m]
Biceps Brachii (average rectified value)	95.8 ± 21.9	115.6 ± 33	.258 [0.691][m]	100.1 ± 30.7	112.6 ± 32.4	.529 [0.369][s]
Triceps Brachii (average rectified value)	34.1 ± 14.4	45.8 ± 14.1	.226 [0.745][m]	28.2 (21)[a]	37.1 ± 5.9	.396[b] [0.256][s]
Anterior Deltoid (average rectified value)	51 ± 8.3	51.7 ± 13.8	.913 [0.064][t]	53.6 ± 11.3	59.8 ± 7.8	.354 [0.55][s]
Latissimus Dorsi (average rectified value)	29.6 ± 9.5	37.1 ± 5.4	.188 [0.817][m]	25.4 (17.3)[a]	31.3 ± 1.4	.174[b] [0.410][m]
Biceps femoris (average rectified value)	40.3 ± 10.1	53.2 ± 15.9	.129 [0.956][m]	53.9 (58.6)[a]	72.2 ± 11.9	.308[b] [0.307][m]
Rectus femoris (average rectified value)	46 ± 9.7	69.1 ± 40.8	.343 [0.847][m]	46.1 ± 20.1	43.4 ± 2.3	.802 [0.146][t]
Medial gastrocnemius (average rectified value)	58.2 ± 13.3	48.3 ± 23.7	.388 [0.519][s]	69.8 ± 26.8	52.9 ± 14.2	.272 [0.657][m]

Note: [*] - Significant at .05 level; [a] – Median (Inter Quartile Range); [b] – Mann Whitney U Test; g – Hedge's g Correction; r – Correlation Coefficient; [t] – Trivial Effect Size; [s] – Small Effect Size; [m] – Medium Effect Size; [l] – Large Effect Size.

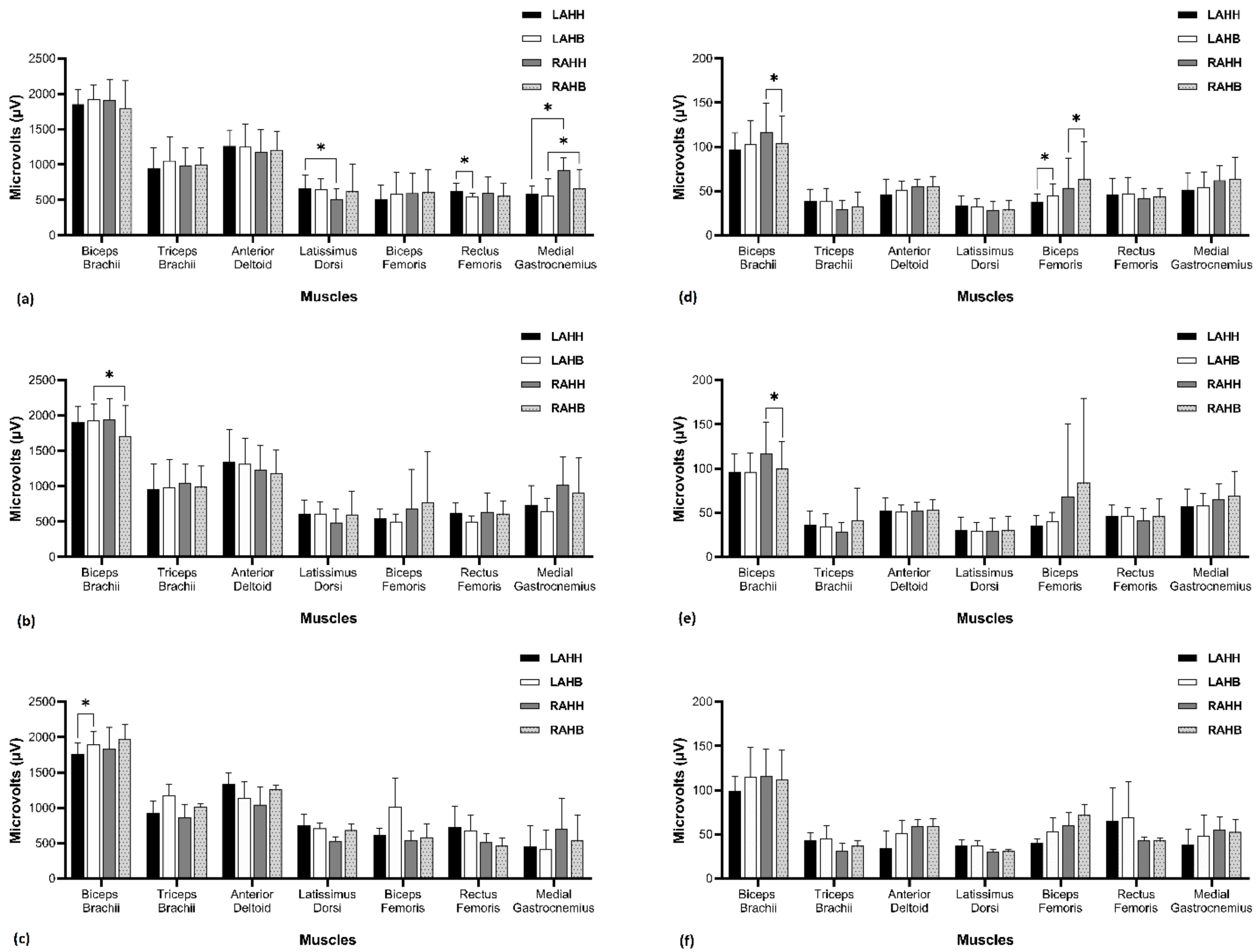

Figure 1. Comparison between lead arm hook to head (LAHH), lead arm hook to body (LAHB), rear arm hook to head (RAHH), and rear arm hook to body (RAHB) for biceps brachii, triceps brachii, anterior deltoid, latissimus dorsi, biceps femoris, rectus femoris, and medial gastrocnemius. (a) Overall peak activation, (b) Southpaw peak activation, (c) Orthodox peak activation, (d) Overall average rectified value, (e) Southpaw average rectified value and (f) Orthodox average rectified value, *p < .05.

Furthermore, the possible reason for the only difference observed in PA of RF during LAHB could be that OD boxers typically position their dominant (rear) leg farther back, potentially increasing reliance on the RF for stabilizing the lead leg during body-targeted hooks. Conversely, SP may distribute force more evenly, reducing the demand from RF muscles, as previous research found a significant difference in stride lengths during hook punch between SP (66.97 ± 15.34 cm) and OD (84.74 ± 7.88 cm) boxers (Bingul et al., 2018). Moreover, it aligns with Turner et al. (2011), who reported that stance orientation significantly influences lower limb muscle activation during rotational movements in combat sports.

However, Bingual et al. (2017) also reported that the OD stance generates higher impact force and acceleration compared to the SP stance in the straight punch technique. Nonetheless, straight punches travel directly forward by extending the elbow, whereas hook punches curve around and upwards, relying on shoulder flexion and adduction, which allows for a wider range of motion in a hook punch compared to a jab or cross. Additionally, the path of acceleration for a hook punch can be longer than that of a straight punch (Piorkowski et al., 2011). Of note, the significant differences in kinetics and kinematics between SP and OD stances during straight punches do not provide evidence of a difference in muscle activation between SP and OD stances. However, in a previous study, Dyson et al. (2007) reported higher muscle activity when the impact forces were high. Our study is the first of its kind, which directly compared the muscle activation pattern between the two stances during varied hook punch techniques in boxing, and the findings can be used as a proof-of-concept for future studies.

The secondary objective of the study was to compare each muscle's PA and ARV among four kinds of hook techniques. We found divergent results in PA and ARV in BB muscle in OD and SP stance boxers. While there was no significant difference in PA of BB, a significant difference was observed in ARV of BB between RAHH and RAHB techniques. This underscores the importance of selecting both EMG data-reduction methods, where PA captures transient, high-intensity bursts (e.g., explosive punch initiation), and ARV reflects sustained muscle activity over the movement cycle (Hibbs et al., 2011). Of note, lead arm hook punches are often performed with more velocity (closest to the target), whereas rear arm hook punches primarily rely on more force (furthest from the target) (Dyson et al., 2007). Further, the increased scapular retraction and trunk rotation in the lead-arm hook to generate a higher velocity punch might amplify the LD engagement to stabilize the torso, which explains the significant difference observed in PA of LD between LAHH and RAHH.

As previously Dyson et al. (2007) reported higher punching velocity and force when the target area was head over the body. Similarly, this study validated higher PA in RF during LAHH compared to LAHB. Furthermore, Dyson et al. (2007) mentioned that MG was the first muscle to be recruited when punches were delivered with maximal force to the head. This justifies the higher MG activation during RAHH, reflecting increased plantar flexion demands to drive rotational power from the lower body. In both lead and rear arm hooks, the BF exhibited higher ARV when it was thrown to the body compared to the head. Hooks aimed at the body require a downward trajectory and often involve trunk and knee flexion or forward lean to reach the opponent's midsection, which might increase the demand on BF muscles (Quinzi et al., 2015). The observed activation patterns highlight key training applications: Coaches should strengthen the BF for body hooks due to their prominence in LAHB and RAHB, while targeting the LD and MG can enhance force generation and stability during head hooks. Additionally, eccentric BB strength training can reduce injury risk during deceleration phases, given its dominance in hook punches. Training programs need not be stance-specific for elite athletes, though individualized adjustments, such as optimizing RF engagement in Southpaws, may further enhance performance. Besides the aforementioned practical applications, a few limitations should be acknowledged. Although a priori sample size estimation was performed the unequal group sizes (Southpaw:

n = 8 vs. Orthodox: n = 4) may limit statistical power and generalizability. Additionally, the activation pattern might differ in competition (i.e. in the ring) and in simulated combination punches (i.e. in the lab) (Pierce et al., 2007). Furthermore, we skipped normalizing EMG data to task-specific maximal voluntary contractions as proposed in dynamic normalization protocols, which could allow inter-muscle comparability (Halaki & Ginn, 2012).

CONCLUSION

This study revealed no significant differences in muscle activation between SP and OD stances, except for the rectus femoris during the lead-arm body hook. Significant variations were observed in the latissimus dorsi, rectus femoris, and medial gastrocnemius, emphasizing the necessity for muscle-specific conditioning to potentially optimize performance. These findings contribute to a deeper understanding of neuromuscular demands in boxing and provide valuable insights for training strategies tailored to enhance hook punch execution.

AUTHOR CONTRIBUTIONS

Study design: SC and RKT; data collection: SC and PP; data curation: SC and PP; data analysis: AB and RKT; writing: SC, PP, TM, PS, TSB, AB, and RKT. All authors have approved the publication of the final version of the manuscript.

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