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Development and reliability of test to measure perceptual-motor performance in combat sports: the Striking Reaction Time Task (SRTT)

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ORIGINAL PAPER

Abstract

The perceptual-motor performance of 15 professional mixed martial arts (MMA) athletes was evaluated using the Striking Reaction Time Task (SRTT). Six LED sensors equipped with motion sensors, controlled by a smartphone application, were attached to specific anatomical targets on a human-like figure using a body opponent bag (BOB). The SRTT consisted of two blocks: SRTT-Simple, where one LED sensor was illuminated at a time, and SRTT-Complex, where all six LED sensors were illuminated, with the target sensor highlighted in a different color. Each block included 120 stimuli. The intraclass correlation coefficient (ICC), coefficient of variation (CV), and minimal detectable change (MDC) of reaction time (RT) were analyzed. Perceptual-motor performance, measured by RT, varied according to the stimulus type, with SRTT-Complex tasks resulting in longer RTs compared to SRTT-Simple tasks for all strikes except hooks. All strikes demonstrated good to excellent reliability, with ICC values ranging from 0.76 to 0.96 (95% CI: 0.62–0.98), CV values between 11% and 17%, and MDC values ranging from 47 to 136 ms, depending on the strike and stimulus type. These findings suggest that the SRTT is a reliable tool for assessing sport-specific perceptual-motor performance in striking combat sports. Future studies should investigate its sensitivity in distinguishing between non-athletes and athletes of varying skill levels, as well as its responsiveness to training interventions.

Keywords: Martial arts; combat sports; mixed martial arts; MMA; sport performance; test; motion sensors.

Desarrollo y fiabilidad de test para medir el rendimiento perceptivo-motor en atletas de deportes de combate: el Striking Reaction Time Task (SRTT)

Resumen

El rendimiento perceptivo-motor de 15 atletas profesionales de artes marciales mixtas (MMA) fue evaluado mediante el *Striking Reaction Time Task* (SRTT). Seis sensores LED equipados con sensores de movimiento, controlados por una aplicación de smartphone, fueron colocados en objetivos de golpeo específicos de una figura antropomórfica utilizando un *body opponent bag* (BOB). El SRTT consistió en dos bloques: SRTT-Simple, donde un sensor LED se encendía cada vez, y SRTT-Complejo, donde los seis sensores LED se iluminaban a la vez, con el objetivo a golpear iluminado en un color diferente. Cada bloque incluyó 120 estímulos. Se analizaron el coeficiente de

Desenvolvimento e confiabilidade de teste para medir o desempenho perceptivo-motor em atletas de esportes de combate: o Striking Reaction Time Task (SRTT)

Resumo

O desempenho perceptivo-motor de 15 atletas profissionais de artes marciais mistas (MMA) foi avaliado por meio da *Striking Reaction Time Task* (SRTT). Seis sensores LED equipados com sensores de movimento, controlados por um aplicativo de smartphone, foram acoplados a alvos anatômicos específicos em uma figura antropomórfica utilizando um *body opponent bag* (BOB). A SRTT consistiu em dois blocos: SRTT-Simples, no qual um sensor LED era iluminado por vez e SRTT-Complexa, em que todos os seis sensores LED eram acesos, com o alvo destacado em uma cor diferente. Cada bloco incluiu 120 estímulos. O coeficiente de correlação intraclasse

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correlación intraclase (ICC), el coeficiente de variación (CV) y el cambio mínimo detectable (MDC) del tiempo de reacción (TR). El rendimiento perceptivo-motor, medido por el TR, varió según el tipo de estímulo, con el bloque SRTT-Complejo obteniendo TRs más largos que el SRTT-Simple para todos los golpes excepto los *hooks*. Todos los golpes mostraron una confiabilidad de buena a excelente, con valores de ICC entre 0,76 y 0,96 (IC 95%: 0,62–0,98), CV entre 11% y 17%, y MDC entre 47 y 136 ms, dependiendo del golpe y del tipo de estímulo. Estos hallazgos sugieren que el SRTT es una herramienta confiable para evaluar el rendimiento perceptivo-motor específico de deportes de combate con golpeos. Futuros estudios deberían investigar su sensibilidad para distinguir entre no atletas y atletas de distintos niveles de habilidad, así como su capacidad de respuesta a intervenciones de entrenamiento.

Palabras clave: Artes marciales; deportes de combate; artes marciales mixtas; MMA; rendimiento deportivo; test; sensores de movimiento.

(ICC), o coeficiente de variação (CV) e a mudança mínima detectável (MDC) do tempo de reação (TR) foram analisados. O desempenho perceptivo-motor, medido pelo TR, variou conforme o tipo de estímulo, com tarefas SRTT-Complexa resultando em TRs mais longos em comparação às SRTT-Simples para todos os golpes, exceto *hooks*. Todos os golpes demonstraram confiabilidade de boa a excelente, com valores de ICC variando entre 0,76 e 0,96 (IC 95%: 0,62–0,98), CV entre 11% e 17%, e MDC entre 47 e 136 ms, dependendo do golpe e do tipo de estímulo. Esses achados sugerem que a SRTT é uma ferramenta confiável para avaliar o desempenho perceptivo-motor específico de esportes de combate com golpes. Estudos futuros devem investigar sua sensibilidade para distinguir entre não atletas e atletas de diferentes níveis de habilidade, bem como sua responsividade a intervenções de treinamento.

Palavras-chave: Artes marciais; esportes de combate; artes marciais mistas; MMA; desempenho esportivo; teste; sensores de movimento.

1. Introduction

Perceptual-motor ability encompasses the integration of visual information and motor skills, requiring individuals to use visual input to interpret their environment and execute planned motor actions. Additionally, cognitive processes play a crucial role in evaluating and selecting the most appropriate response when multiple options are available (Ju et al., 2018; Stevens & Bernier, 2013). Despite the recognized importance of perceptual-motor abilities, their specific role and assessment in high-performance combat sports, particularly in striking disciplines, remain underexplored. Reaction time (RT) is one key marker of perceptual-motor performance (Burris et al., 2020; Hülsdünker et al., 2018; Russo & Ottoboni, 2019). Perceptual-motor RT refers to the time elapsed between the presentation of a stimulus and the completion of a motor response (Erickson, 2021). RT can be classified as simple RT, where individuals must respond to a stimulus as quickly as possible with a single response option (e.g., pressing a button when a light flashes), or complex RT, where individuals must respond as quickly as possible with multiple response options based on the characteristics of the stimulus (e.g., pressing the right button when a red light flashes or the left button when a yellow light flashes) (Janicijevic & Garcia-Ramos, 2022). Although RT is often used as a measure of perceptual-motor performance, existing assessments typically fail to reflect the complex decision-making processes involved in combat sports (Janicijevic & Garcia-Ramos, 2022; Mann et al., 2007).

A significant gap in the literature is the lack of sport-specific assessments of perceptual-motor performance in combat sports, such as boxing, karate, taekwondo, and MMA. While studies like Bianco et al. (2008) and Brito et al. (2011) have used general or computerized tasks to evaluate reaction time (RT), these methods do not include the complex demands of combat sports, focusing instead on simple RT tasks. Incorporating decision-making elements—such as inhibition or visual search—increases task complexity, requiring greater integration of eye-body coordination, speed, and judgment (Erickson, 2021; Laby et al., 2018; Nakamoto & Mori, 2008). These integrative responses are critical in sports where quick, accurate decisions determine outcomes (Mann et al., 2007a). In open-skill activities like combat sports, athletes must rapidly perceive, process, and respond to dynamic, unpredictable scenarios (Wang et al., 2013), making perceptual-motor abilities essential. Combat-striking sports highlight the importance of these skills, as athletes must detect targets and deliver precise strikes (Ju et al., 2018). A single well-executed strike can decide match outcomes through points, knockouts, or referee decisions. However, most current assessments lack sport-specificity or complexity, raising concerns about their ecological validity for predicting real-world performance in combat athletes (Janicijevic & Garcia-Ramos, 2022).

Our study aims to address this gap in the literature by developing a novel sport-specific test, the "Striking Reaction Time Task" (SRTT), designed to assess perceptual-motor performance in combat athletes, specifically MMA athletes. The analysis of perceptual-motor performance in athletes should account for various factors, including the intrinsic characteristics of specific sports(Erickson, 2021b). Tools that integrate eye-hand and eye-foot coordination have demonstrated potential for sport-specific assessments, enabling the incorporation of sport-specific actions into the evaluation or training of athletes (Appelbaum & Erickson, 2016; Hadlow et al., 2018). However, assessing perceptual-motor skills in a sports context is challenging due to uncontrollable variables, such as environmental unpredictability, the strength and power of actions, opponent characteristics, and technological limitations. Consequently, many studies rely on computer-based assessments of perceptual-motor reaction time (e.g., responses to visual or auditory stimuli via mouse or keyboard inputs) and use these as proxies for athletes' perceptual abilities in sport-specific situations (Janicijevic & Garcia-Ramos, 2022).

Recently, light-emitting diode (LED) sensors (e.g., Fitlight, Batak) have been increasingly used to train and assess perceptual-motor capacity. These devices consist of multiple independent sensor disks that are deactivated either by touch or close-proximity movement. They are wirelessly connected to a smartphone or tablet, which controls task parameters such as light color, the number of illuminated sensors, randomization, and time limits, while also recording task performance metrics like accuracy and reaction time (RT) (Figure 1) (Appelbaum & Erickson, 2016; Hadlow et al., 2018). In comparison to traditional touch-board equipment (e.g., Dynavision D2, Sport Vision Training), LED sensors provide the advantage of flexible placement, enabling assessments that more accurately replicate on-field scenarios across various sports. This flexibility allows for the evaluation of sport-specific tasks, such as measuring change-of-direction speed and reactive agility, with greater ecological validity (Coh et al., 2018).

Although recent advances in sports science have led to the development of sport-specific assessments of perceptual-motor performance in various disciplines—such as ball-interception sports (e.g., baseball), invasion sports (e.g., basketball and handball), and racquet sports (e.g., tennis) (Habay et al., 2021; Laby & Appelbaum, 2021; Van Cutsem et al., 2019; Zwierko et al., 2014)— only a limited number of studies have specifically focused on combat sports(Faro et al., 2025; Greco et al., 2024; Liu et al., 2019). Moreover, even when combat athletes are evaluated, the tasks employed often lack the complexity of sport-specific responses required in real combat scenarios (Janicijevic & Garcia-Ramos, 2022; Liu et al., 2018). To address this gap, we aimed to design a novel test, the *Striking Reaction Time Task* (SRTT), to measure perceptual-motor performance in combat athletes and to verify its reliability specifically in mixed martial arts (MMA) athletes.

2. Methods

2.1. Study design

This study was conducted over three non-consecutive days at a commercial combat sports gym. On the first day, athletes were briefed on the study's aims and procedures, while all subsequent visits followed the same protocol. Before each session, participants completed a five-minute warm-up consisting of shadow punches and kicks to prepare for the tasks. Following the warm-up, athletes performed the SRTT-Simple and SRTT-Complex tasks in a randomized order, with a two-minute rest interval between tests. Although all athletes completed the tests during each session, the first session was designated as a familiarization period to minimize potential learning effects and ensure consistent performance in subsequent sessions. To control for external variables, all testing sessions were conducted between 08:00 a.m. and 11:00 a.m., reducing the influence of circadian rhythms on performance. Additionally, participants were instructed to maintain their regular sleep patterns (i.e. ˜8 hours/night) and morning routines (i.e. nutrition, hydration, and morning habits) throughout the study period to avoid confounding factors. The research protocol was approved by the Institutional Research Ethics Committee (CAAE: 57951616.0.0000.5537), and the study adhered to the ethical guidelines outlined in the Declaration of Helsinki. This ensured that all procedures were conducted with respect for participant safety, confidentiality, and informed consent.

2.2. Participants

Fifteen professional right-side dominant MMA athletes participated in this study (11 males; 4 females). The athletes participated in regional/national (n = 4 males and 3 females) and international (n = 7 males and 1 female) MMA events. The athletes are classified as tier 3 (highly trained/National level) and tier 4 (Elite/International level) (McKay et al., 2022). Their training routine included 8-10 sessions of training/week, including combat-specific discipline sessions (i.e., boxing, Muay Thai, kickboxing, wrestling, no-gi), MMA sessions, simulated fights (i.e., sparring), and physical training (i.e., strength training, aerobics, mobility/flexibility). Their basic combat sports discipline was: Muay Thai (n=7); Karate (n=2); Boxing (n=1); and Brazilian Jiu-Jitsu (n=5). The female athletes competed in the Strawweight (-52.2 kg; n=3) and Bantamweight (-61.2 kg; n=1), and male athletes competed in the Flyweight (-56.7 kg; n=2), Featherweight (-65.8 kg; n = 5), Lightweight (-70.3 kg; n=1), Welterweight (-77.1 kg; n=1), and Light Heavyweight (-92.9 kg; n=2) MMA bodyweight divisions (values in parentheses represent the weight limit of each division). Athletes self-reported upper limbs dominance based on the hand they used for writing and lower extremity dominance based on their preferred leg for kicking. The athletes' characteristics are presented in Table 1. To be included in this study, participants should: i) train MMA (≥5 sessions/week); ii) not present any injury that affected performance in the tests; iii) not report visual problems that compromise the color distinctions (i.e., daltonism); iv) fought in a professional MMA competition at least twice. Participants were excluded if: i) started rapid weight loss/dehydration protocol during the task period; ii) did not complete any phase of the experiment; iii) suffered an injury that impaired performance on the tasks.

Table 1. Sample characteristics.

Variables	Female (n=4)	Male (n=11)
Age (years)	23.66 ± 2.88	25.88 ± 3.33
Body mass (kg)	61.66 ± 7.23	81.77 ± 18.7
Height (cm)	161.66 ± 6.11	173.88 ± 9.37
Experience on sport combats (years)	10 ± 6.08	11.55 ± 4.21
Experience on MMA (years)	3.66 ± 1.15	7.11 ± 3.21
Total fights (n)	2 (2 – 3.5)	8 (4 – 10)
Wins (n)	2 (1.5 – 3)	7 (2 – 8)
Losses (n)	1 (0.5 – 1)	1 (1 – 2)

Note: age, body mass, height, and experience data are described as mean ± standard derivation; total fights, wins, and losses are described as median (interquartile range).

2.3. Warm-up

At the beginning of each testing session, individuals warmed-up for five minutes by performing "shadow" exercises involving MMA-specific movements at light to moderate intensity. During the shadow exercise, participants moved around the space, throwing different punches and kicks at the air in a way that mimics fighting.

2.4. Striking Reaction Time Task (SRTT)

Sport-specific RT was measured using the Striking Reaction Time Task (SRTT), which used a series of commercially available LED sensors with motion sensors (ReactionX, United Kingdom) connected to a smartphone via network Bluetooth controlled by an application (ReactionX, QuelingSport) that measures RT with high response accuracy (0.01 seconds). The LED sensors (weight: ~105 g; size: 95x85x25 mm) are hexagonal-shaped disks covered by silicone-gel for impact absorption designed to be deactivated by contact or close distance proximity movements (~3cm). To measure perceptual-motor performance, six sensors were fixated using Velcro tape onto a human-like figure at specific anatomical targets for strikes using a body opponent bag (BOB, BoomBoxe, Brazil) with adjustable height (Figure 1), each one linked to a specific punch or kick as described in Table 2. The height and distance between the athlete and the BOB were carefully adjusted to ensure optimal positioning for each participant. The height of the BOB was set to align with the athlete's shoulder level, considering their individual height. Similarly, the distance between the athlete and the BOB was determined based on the athlete's front wingspan (the distance from fingertip to fingertip with arms extended horizontally), ensuring that the athlete could reach the target comfortably and effectively during the task. This personalized adjustment was crucial to standardize the testing conditions while accommodating individual anthropometric differences. The position of the LED sensors was located in common targets for striking combat sports. Considering that the number of LED sensors activated must match the expected strikes, all tests were filmed from a fixed distance of two meters using a high-definition camera positioned at a 90-degree angle to the athlete. This setup ensured optimal visibility of both the athlete's movements and the LED sensors. The videos were subsequently analyzed by an expert in combat sports, who meticulously reviewed each trial to verify the accuracy of the strikes and ensure that only correct movements were included in the analysis. Any trials with incorrect movements, such as strikes that did not align with the activated sensors, were excluded from the final dataset to maintain the integrity of the results.

Table 2. Distribution of sensors in the dummy stand bag and each strike expected.

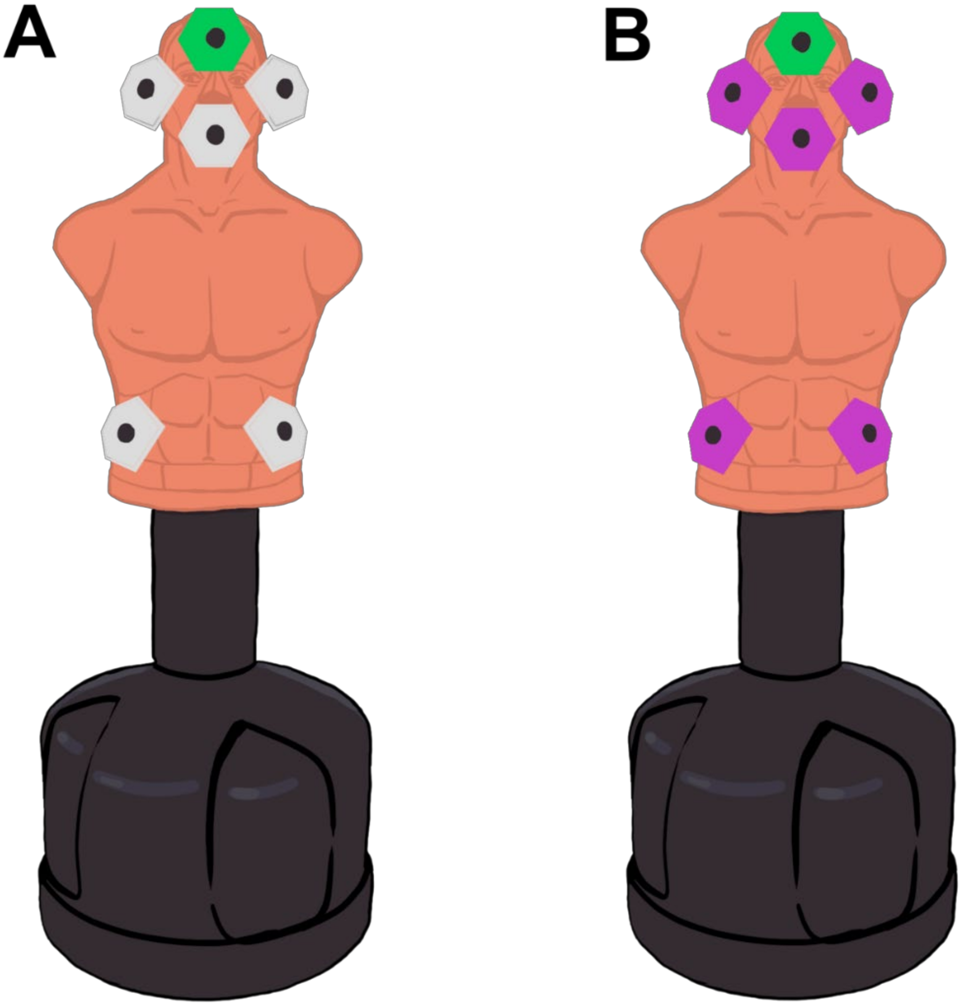
Sensor number	Position	Expected Strike
1	Forehead	Jab with the non-dominant hand
2	Chin	Cross with the dominant hand
3	Left ear	Hook with the non-dominant hand
4	Right ear	Hook with the dominant hand
5	Left side trunk	Roundhouse kick with non-dominant leg
6	Right side trunk	Roundhouse kick with the dominant leg

The SRTT “simple” (SRTT-Simple) and “complex” (SRTT-Complex) were composed of 120 consecutively stimuli each. The athletes performed each test once per day for assessment, with each test lasting approximately four minutes and administered in a randomized order. The total number of strikes was chosen to obtain ~20 trials per strike (Miller & Ulrich, 2013). Given the sport-specific motions involved, we assumed that 20 trials would be an appropriate cost-benefit ratio to represent an athlete's typical perceptual-motor performance without significantly increasing muscular fatigue, which would decrease performance. Woods et al., (2015) showed that simple reaction time increased from the first 20 to the last 20 trials in a 120 trials experiment, indicating that there was a fatigue effect. It should be emphasized that in their study the task involved just pressing a button. Finally, Miller and Urich (2013) showed that despite the number of trials depends on the exact situation under study, as few as 15–30 trials are often enough under realistic parameter settings, and it is usually feasible to obtain at least that many trials per participant in all conditions of an RT study.

In the SRTT-Simple, only one sensor illuminated green (target), and the athlete needed to perform an adequate strike on the sensor to deactivate it (Figure 1; Supplementary video 1). In the SRTT-Complex, all sensors illuminated, but one of them is in a different color (target). For example, one sensor is in green, and the others are in purple (Figure 1; Supplementary video 2). The target lights remained illuminated until a movement was detected by the target sensor. The interval between trials was fixed at 0.5 s, which was time enough for the athlete back in the ‘ready’ position. The order in which each target was illuminated was randomized by the app, since the app did not allow a standardized of number of trials for each sensor (limitation of the equipment).

Only correct response trials (i.e., performing the correct strike at the target sensor) were used for calculation of RT. Moreover, the trial was considered correct only if the athlete deactivated the LED sensors in the first attempt (i.e., trials in which the athletes performed more than one strike to deactivate the LED sensor were discarded from the analysis). Athletes were instructed that the test aimed to test RT (e.g., movement speed) and, thus, that they were expected to strike as fast and accurately as possible during the entire test. Moreover, they were instructed to perform like facing an opponent, in terms of keeping their guards and footwork while maintaining the distance of the BOB unless while striking at it. The order of SRTT-Simple and SRTT-Complex was randomized and counterbalanced for each testing day, and athletes had 2 minutes of passive resting interval. RT for each strike of the SRTT-Simple and SRTT-Complex was used as the test performance.

Figure 1. Striking Reaction Time Task (SRTT) stimulus types. One of the six LED sensor in the SRTT-Simple (left panel) lit up green (target). All six lights in the SRTT-Complex (right panel) illuminated, but one of them was a distinct color (target). The colors of the target and non-target LED sensor changed in the SRTT-Complex. Participants in all trials had to perform the required movement at the target as quickly as possible.



2.5. Statistics

The Shapiro-Wilk test was used to test distribution of data (Supplementary Table 2). Data are expressed as mean, standard deviation, and 95% confidence interval (95%IC) or median and interquartile range (IQR) as stated. We used a Generalized Linear Model (GzLM) to compare the SRTT performance using the testing day (2º vs. 3º days) and stimulus type (SRTT-Simple vs. SRTT-Complex) as factors, identity link function, gamma distribution (to account for the data distribution), and Bonferroni's post hoc using JAMOVI 2.1 software.

The sample size was calculated based on the methods described elsewhere (Bonett, 2002; Borg et al., 2022), using an online calculator (http://wnarifin.github.io) using the following criteria: minimum acceptable reliability (ICC) = 0.6 (moderate), expected reliability (ICC) = 0.9 (Mudric et al., 2015), significance level (α) = 0.05 (two-tailed), power (1 - β) = 80%, number of repetitions per subject (k) = 2. Accordingly, 14 subjects would be sufficient for the present study.

Test–retest reliability was assessed using the intraclass correlation coefficient (ICC) between the 2nd and 3rd days of SRTT with a 95% confidence interval (95% CI), calculated using SPSS (v.25) based on a mean-rating (k =2), absolute agreement, two-way mixed-effects model (Koo & Li, 2016). Qualitative interpretation of ICC values was classified, as follows: less than .50 = poor; between .50 and .75 = moderate; between .75 and .90 = good; and greater than .90 = excellent (Koo & Li, 2016). The coefficient of variation (CV) was calculated by the ratio between the standard deviation (SD) and the average of the data from the 2nd and 3rd days, multiplied by 100 (Hopkins, 2000); values of ≤15% are considered a good %CV threshold (Shechtman, 2013), but considering the likely high intra-participant variability in each technique used, a %CV <20% was chosen by the authors as an acceptable threshold. The standard error of measurement (SEM) was calculated using the following equation: SEM $= SD\ x\ (\sqrt{1} - ICC)$. The 95% minimal detectable change (MDC) was calculated using the following equation: MDC $= SEM\ x\ 1.96\ x\ \sqrt{2}$ (Beninato & Portney, 2011). Statistical analysis was performed using SPSS v. 25 and Jamovi 2.1, and p<0.05 was considered statistically significant.

3. Results

All strikes and sub-tasks presented significantly good to excellent reliability (p < 0.005). Table 3 presents the mean and standard deviation for each strike, each day, each sub-task, and their respective ICC and 95%CI, CV and 95%CI, SEM, and MDC.

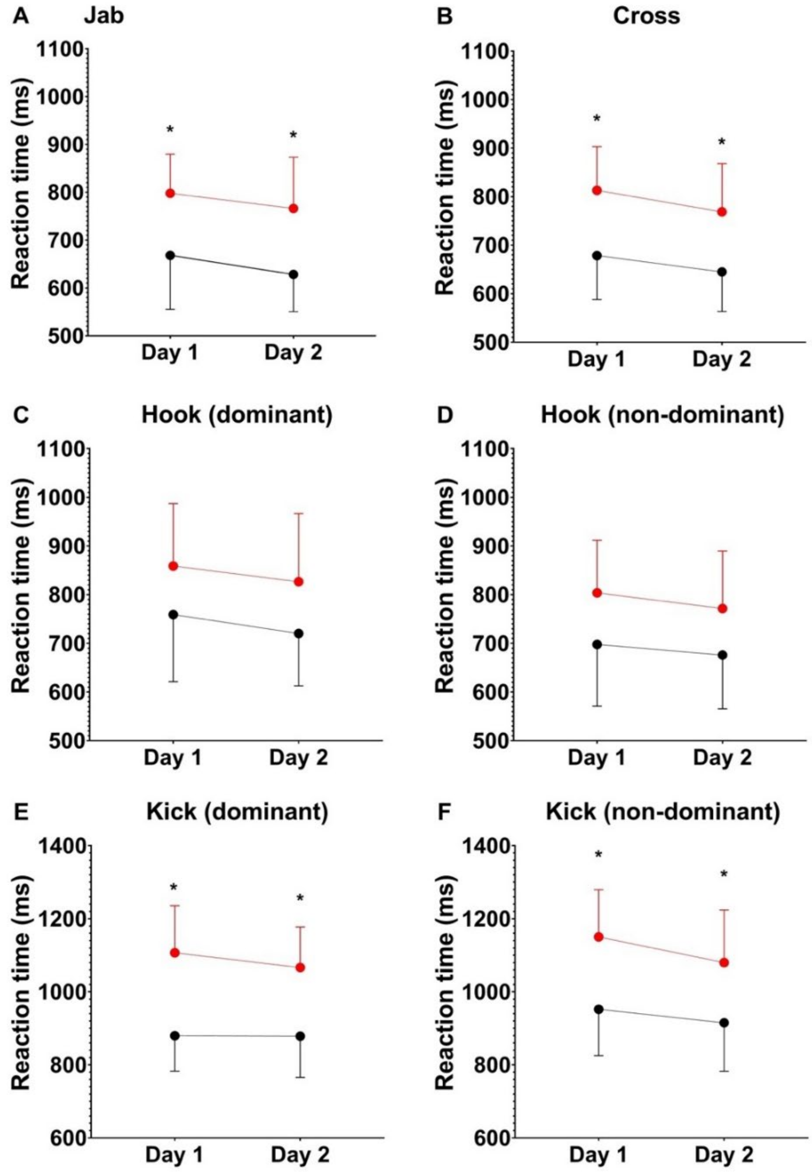
Table 3. Test-retests reliability parameters of perceptual-motor performance during the Striking Reaction Time Task "simple" (SRTT-Simple) and "complex" (SRTT-Complex) for each strike in professional mixed martial art athletes (n = 15).

Strike	Test type	Day 1 (ms)	Day 2 (ms)	ICC (95%CI)	ICC Descriptor	CV (95%IC)	SEM (ms)	MDC$_{95\%}$ (ms)
Jab	S	668 ± 113	628 ± 78	.89* (.67 – .96)	Good	15.0 (9.64–20,39)	32	89
	C	798 ± 82	766 ± 107	.90* (.72 – .96)	Excellent	12.2 (7.81–16.52)	17	47
Cross	S	679 ± 91	645 ± 81	.76** (.86 – .98)	Good	13.1 (8.38–17.73)	42	117
	C	813 ± 90	769 ± 99	.89* (.69 – .96)	Good	12.1 (7.77–16.44)	17	47
ND Hook	S	698 ± 127	676 ± 110	.87* (.64 – .95)	Good	17.1 (10.69–22.61)	41	113
	C	804 ± 108	772 ± 118	.96* (.89 – .99)	Excellent	14.3 (10.14–21.45)	22	60
D Hook	S	759 ± 138	753 ± 107	.88* (.65 – .96)	Good	16.7 (10.96–23.18)	42	116
	C	859 ± 129	827 ± 140	.93* (.81 – .97)	Excellent	15.8 (9.17–19.39)	34	93
ND Kick	S	952 ± 127	915 ± 133	.96* (.90 – .98)	Excellent	13.8 (7.55–15.97)	23	64
	C	1150 ± 129	1080 ± 144	.87* (.62 – .95)	Good	12.5 (7.08–14.97)	49	136
D Kick	S	880 ± 97	878 ± 113	.91* (.74 – .97)	Excellent	11.8 (8.86–18.74)	30	84
	C	1107 ± 129	1067 ± 111	.93* (.79 – .97)	Excellent	11.0 (8.01–16.97)	31	87

Note: ICC = intraclass correlation coefficient; CV = coefficient of variation; SEM = standard error of measurement; MDC = minimal detectable change; D = dominant limb; ND = non-dominant limb; S = SRTT-Simple; C = SRTT-Complex. * = p < 0.001; ** = p < 0.005.

Figure 2 presents the descriptive and statistical comparison of the SRTT performance. There were main effects of the stimulus type for all six strikes (all p-values ≤0.003). Post hoc analysis showed that RT performances were faster in the SRTT-Simple than in the SRTT-Complex (all p-values ≤0.008) in both the second and third testing days for the jabs, crosses, and kicks with both dominant and non-dominant legs. There was no significant difference in post hoc comparisons for the hooks with dominant and non-dominant arms. There was no effect of time or interaction for the strikes. The detailed statistical descriptions are presented in supplementary table 1.

Figure 2. Comparison of testing day and stimulus type of the Striking Reaction Time Task (SRTT).



Note: * = statistically different from SRTT-Simple stimulus type (all p-values <0.01).

4. Discussion

Both SRTT-Simple and SRTT-Complex presented good to excellent reliability. SRTT-Simple and SRTT-Complex performances were different for jab, cross, and kicks but not for hooks. To the best of the authors' knowledge, this is the first study to propose a sport-specific perceptual-motor test for combat athletes. Perceptual-motor performance is paramount for many sports. For example, elite pitchers and soccer goalkeepers have around 400 ms to react to an approaching ball (Peiyong & Inomata, 2012), which may reach speeds up to 120 km/h (Rada et al., 2019). In other sports, the ball speeds are also high, reaching speeds of 60 km/h in table tennis, 70 km/h in volleyball serve, and near to 200 km/h in tennis, with relatively good accuracy (González-González et al., 2018; Le Mansec et al., 2016), which will require extremely fast RT. In combat sports, such as karate, the ability to anticipate and react quickly is equally critical. A study investigating decision-making time in karate athletes found an average reaction time of 458 ms after video occlusion (Milazzo et al., 2014). This highlights the importance of perceptual-motor skills in combat sports, where athletes must interpret and respond to opponents' movements in fractions of a second. The current study builds on this foundation by introducing a sport-specific test that can be used to evaluate and train these critical skills in combat athletes, further emphasizing the need for tailored perceptual-motor assessments in sports where split-second decisions can determine success.

Combat sport athletes must react swiftly to visual cues, such as an incoming attack or an opponent's momentary opening (i.e., a brief window of opportunity to strike). For instance, Taekwondo front kicks may reach speeds of 25 to 40 km/h, depending on factors such as gender and leg dominance. While these speeds may not appear exceptionally high, a frontal kick delivered from a distance of 1.5 meters allows the defending athlete only 136 to 214 milliseconds to react—either by evading the kick or attempting to mitigate its impact (e.g., by blocking). Punches, on the other hand, can be even faster. A recent systematic review and meta-analysis by Beránek et al. (2023) demonstrated that the speed and force of punches vary depending on the type of strike (e.g., reverse punch, straight punch, palm strike), with some studies reporting average punching speeds of approximately 53 km/h. A punch delivered at this speed from a distance of 1 meter leaves the defending athlete with roughly 68 milliseconds to react, either by defending or evading the strike. In this regard, assessing sport-specific perceptual-motor performance is inherently challenging due to the dynamic nature of combat sports, which includes environmental unpredictability, the intensity and power of actions, and technological limitations. As a result, many studies rely on computer-based assessments of perceptual-motor reaction time (RT), where responses to visual or auditory stimuli are recorded via mouse or keyboard inputs. These methods are often assumed to reflect athletes' perceptual abilities in sport-specific situations. However, such approaches may not fully capture the complexity and demands of real-world combat scenarios (Janicijevic & Garcia-Ramos, 2022).

The present study introduces a novel tool for assessing perceptual-motor performance in combat sports. In a recent systematic review aiming to evaluate the feasibility of RT tests to assess processing speed in athletes, including 38 studies, Janicijevic and Garcia-Ramos (2022) identified the lack of sport-specificity as a major limitation in the existing literature. Specifically, the stimuli and responses used in these tests often fail to replicate sport-specific actions. This study addresses this gap by proposing an RT test that incorporate a sport-specific setup as the stimulus and a range of combat-specific movements as responses, demonstrating good to excellent reliability. Although MMA does not involve reacting to illuminated lights, the setup—featuring LED sensors positioned on a human-like figure (e.g., a body opponent bag, or BOB)—mimics the presence of an opponent. The illuminated sensors simulate visual cues that athletes might identify in an opponent’s movements, signaling potential openings (i.e., windows of opportunity) in their defense. Additionally, the ability to strike accurately with a fast RT likely reflects a combination of muscle power and strength, which are critical for scoring points (e.g., in Taekwondo) or achieving knockouts (e.g., in MMA), depending on the specific combat sport. This tool thus bridges the gap between laboratory-based assessments and the dynamic demands of real-world combat scenarios.

SRTT performance remained consistent across the two testing days for both stimulus types, as indicated by the Generalized Linear Model (GzLM) results (Figure 2). This stability is crucial, as it demonstrates that a learning effect did not significantly influence the athletes' performance. However, it is important to note that this consistency was achieved after providing a familiarization session. During this session, athletes completed the full SRTT protocol to optimize their performance and minimize variability in subsequent sessions. As a result, performance on the second and third testing days was significantly improved compared to the familiarization session (results not shown). Furthermore, the lack of significant differences between the second and third testing days indicates that SRTT performance stabilizes within two sessions, highlighting the reliability of the test after an initial familiarization period.

These findings were confirmed by the reliability of the SRTT performance analysis performed in this study. SRTT performance demonstrated good to excellent reliability across all strikes, with 2 out of 6 strikes showing excellent reliability in the SRTT-Simple condition and 4 out of 6 in the SRTT-Complex condition. Additionally, the CV was relatively low and consistent across strikes and stimulus types, ranging from 11 to 17%. This shows that the sample presents homogeneous RT performance for both upper and lower limbs, as well as for different types of strikes. Beyond assessing reliability, we also calculated SEM and MDC, as this is a newly proposed test. The SEM estimates the random variation expected in a score when no real change has occurred, while the MDC (derived from SEM) represents the minimum amount of change required at either the group or individual level to be considered a true change rather than a random measurement error (Furlan & Sterr, 2018). The values presented in Table 3 provide a foundational reference for researchers and clinicians utilizing the SRTT, offering benchmarks for interpreting performance changes in future applications.

Another interesting feature of SRTT is that its two forms—SRTT-Simple and SRTT-Complex—yielded different performance outcomes for most strikes, with the exception of hooks performed with both the dominant and non-dominant arms. In the SRTT-Simple, only one green LED sensor illuminated at a time (the target), requiring athletes to execute the corresponding strike as quickly as possible to deactivate it. This task primarily involves a visual search to identify the illuminated sensor and the use of working memory to recall which strike corresponds to that specific sensor (Diamond, 2013). In contrast, the SRTT-Complex presents a more cognitively demanding scenario: all six LED sensors illuminate simultaneously, with one sensor displaying a distinct color (the target). Additionally, the colors of the target and non-target sensors change throughout the test, reducing the likelihood of participants relying on a fixed color pattern. As a result, the SRTT-Complex not only requires visual search and working memory but also engages selective attention to filter out irrelevant information (i.e., the five non-target sensors) and focus on the relevant cue (i.e., the differently colored target). It further demands inhibitory control to prevent automatic or impulsive responses, such as striking one of the non-target sensors that may initially capture attention (Diamond, 2013). The RT for the SRTT-Complex was slower than those for the SRTT-Simple for the jabs, crosses, and kicks performed with both the dominant and non-dominant leg. This suggests that the SRTT-Complex imposes greater cognitive demand compared to the SRTT-Simple. This distinction is particularly significant in sports, especially combat and team sports, where athletes must respond quickly and accurately under pressure. The SRTT-Complex, therefore, may serve as a valuable tool for assessing and training cognitive processes such as information processing, inhibitory control, selective attention, and decision-making—all of which are critical for optimal sports performance (Diamond, 2013). It is worth noting that the potential influence of cumulative fatigue from the SRTT-Simple on SRTT-Complex performance can be ruled out, as the order of the test blocks was randomized and counterbalanced across participants.

One might argue that the stimuli used in the SRTT are not sport-specific because color and motion are traditionally thought to be processed in separate, parallel, and independent regions of the brain (Gegenfurtner & Hawken, 1996; Zeki, 1993, 2015). Indeed, human vision relies on multiple specialized areas within the visual cortex, primarily located in the occipital lobe, where visual information is processed in stages (Zeki, 1993). Specifically, area V4 is primarily responsible for color and shape perception (Zeki, 1993), while area V5 processes motion and direction (Livingstone & Hubel, 1988). However, emerging evidence suggests that these regions are not entirely independent but are interconnected, with significant interdependencies between the color and motion processing pathways (Derrington, 2000; Gegenfurtner & Hawken, 1996; Grossberg, 2014; Self & Zeki, 2005; Seymour et al., 2009). Although V4 and V5 specialize in distinct aspects of vision, they do not operate in isolation (Zeki, 2015). These regions interact with each other and with other visual areas, such as the primary visual cortex (V1), which provides input to both V4 and V5 (Zeki, 2015). Furthermore, V5 has reciprocal connections with V4, and some of its neurons respond to moving isoluminant edges (Seymour et al., 2009). In certain conditions, such as visual illusions, the brain may struggle to integrate color and motion information seamlessly, highlighting the complexity and interconnectedness of visual processing (Grossberg, 2014). This integration of information allows the brain to combine color and motion into a cohesive visual experience, which is essential for perceiving and responding to complex stimuli (Bartels & Zeki, 2000; Gegenfurtner & Hawken, 1996; Zeki, 2015). Therefore, from a neurophysiological perspective, there is sufficient evidence to suggest that color and motion processing overlap to some degree, supporting the idea that the stimuli used in the SRTT could serve as a proxy for sport-specific tasks in combat sports. While flashing lights may not perfectly replicate the dynamic movements of an opponent, the SRTT provides a controlled and reliable method for assessing perceptual-motor skills, which are often difficult to measure in unpredictable, real-world environments. Thus, despite its limitations, the SRTT represents a viable and practical tool for evaluating sport-specific perceptual-motor performance in combat athletes.

One could also argue that light flashes do not represent an opponent's movement and, therefore, the SRTT should not be considered a "sport-specific" measure of perceptual-motor reaction time. While we agree that light flashes are not the same as an opponent's movement, we maintain that the SRTT is sport-specific. The test setup and the required responses were intentionally designed to reflect the demands of combat sports. As discussed earlier, a major limitation in the current scientific literature on reaction time (RT) in athletes is the reliance on computer-based tasks, where RT is measured in response to visual or auditory stimuli, and responses are typically made by pressing buttons on a keyboard (Janicijevic & Garcia-Ramos, 2022). In contrast, the SRTT requires athletes to perform sport-specific movements, such as punches and kicks, to respond. These movements are fundamental to striking combat sports. Additionally, athletes are positioned in front of a human-like figure representing an opponent, maintaining a fighting stance throughout the test, with strikes directed at specific locations on the figure, closely simulating actual combat scenarios. This setup more accurately reflects the sporting context compared to traditional RT tests involving sitting in front of a computer and pressing buttons.

Moreover, while the color of the lights in the SRTT may not directly replicate an opponent's movements, the ability to visually search for and select relevant stimuli is crucial for interpreting an opponent's actions, which can significantly influence the outcome of a match (Russo & Ottoboni, 2019). This ability is closely tied to perceptual-cognitive skills, which involve processing environmental information and integrating it with prior knowledge to generate appropriate responses. These skills encompass include attention, visual discrimination, anticipation, problem-solving, and decision-making (Mann et al., 2007; Marteniuk, 1976; Russo & Ottoboni, 2019). To succeed, athletes must focus on key cues (e.g., specific body parts) to extract relevant information and anticipate their opponent's intentions (Russo & Ottoboni, 2019; Williams et al., 1999). This selective attention is particularly vital in environments cluttered with both relevant and irrelevant information, as it allows athletes to filter out distractions and concentrate on critical signals (Mann et al., 2007). Expert athletes excel at allocating attention to critical cues and processing this information efficiently, setting them apart from less experienced individuals (Mann et al., 2007; Russo & Ottoboni, 2019). The primary objective of the SRTT is not color identification but rather visual search and pattern recognition. Athletes are required to identify which LED sensor differs from the others, simulating the need to detect subtle cues in an opponent's movements. The specific colors used are not inherently important; rather, the variation in colors between the target and non-target sensors prevents participants from relying on a fixed pattern, thereby increasing the task's complexity. This design mirrors the dynamic and unpredictable nature of combat sports, where athletes must quickly identify and respond to fleeting opportunities in their opponent's defense.

Finally, if we were to consider "sport-specificity" at its highest level, the only way to truly assess it would be during actual combat competition. The most specific sporting action is competition itself, where the entire environment—including the unpredictability of the opponent, the physical exchanges, the stakes of winning or losing, and the crowd's presence— directly influences performance. Any assessment outside of this context is inherently an estimation and carries limitations. Some studies have attempted to simulate sport-specific scenarios using video stimuli, prompting athletes to anticipate or respond to predetermined actions (Mann et al., 2007; Russo & Ottoboni, 2019). However, while video-based tasks may present sport-specific actions, the act of sitting in front of a computer and pressing buttons lacks the physical and environmental demands of real-world competition. It is important to reiterate that the SRTT is designed to serve as a sport-specific measure of perceptual-motor reaction time for combat sports. It is not intended to evaluate decision-making or predict overall combat sport performance, as previously clarified. Instead, the SRTT provides a controlled yet ecologically valid tool for assessing key perceptual-motor skills that are critical in combat sports, bridging the gap between laboratory-based assessments and the dynamic demands of real competition.

From a practical perspective, the present study showed that by using a relatively inexpensive device one can reliably measure sport-specific perceptual-motor performance in strike combat athletes. The LED sensors can be attached to a torso-like punching bag. It should be noted that at least one day of familiarization is needed to obtain reliable results, to avoid changes in performance due to learning effects. Future studies should try to replicate the present findings, as well as assess the sensitivity of the SRTT to different interventions (e.g., acute and chronic effects of training, weight cycling, perceptual-motor training, etc.,), differentiate among athletes and non-athletes, sport-type (e.g., MMA, Karate, Muay Thai, Taekwondo), competitive levels (i.e., amateurs, sub-elite, and elite athletes), experience (e.g., beginners, intermediate, advanced), etc.

Despite the promising results, several limitations should be acknowledged. First, the sample size was relatively small, consisting of 15 professional MMA athletes, which may limit the generalizability of the findings to other combat sports or amateur athletes. Future studies should aim to include larger and more diverse samples to validate the SRTT across different populations and skill levels. Second, while the SRTT was designed to mimic real combat scenarios, the use of LED sensors and a static human-like figure may not fully replicate the dynamic and unpredictable nature of actual combat. This could affect the task's ecological validity, as real-world combat situations involve more complex and variable stimuli, such as an opponent's movements and environmental factors. Third, the study did not account for potential confounding variables, such as the athletes' physical and mental fatigue, which could influence RT performance. Fourth, other factors like sleep quality, stress levels, and nutritional status were not controlled. Fifth, the equipment presents many limitations of control of stimuli, such as the impossibility of controlling how many trials were applied in each LED. Finally, the SRTT's reliance on visual stimuli may not fully capture the multisensory nature of combat sports, where auditory and tactile cues also play significant roles in decision-making and reaction times. Future research should consider integrating multisensory stimuli to further enhance the task's sport-specificity.

5. Conclusion

The present study introduced the Striking Reaction Time Task (SRTT) as a novel, sport-specific tool for assessing perceptual-motor performance in combat athletes, particularly in mixed martial arts (MMA). The SRTT demonstrated good to excellent reliability across various strikes and acceptable variation values, indicating its potential as a reliable measure for evaluating RT in combat sports. The task's ability to differentiate between simple and complex stimuli further highlights its utility in capturing the cognitive demands inherent in combat sports, such as selective attention, inhibitory control, and decision-making. The SRTT's design, which incorporates sport-specific movements and a human-like figure, enhances its ecological validity compared to traditional computer-based RT tests. This study provides a foundation for future research to explore the SRTT's sensitivity to different training interventions, its ability to discriminate between athletes of varying skill levels, and its applicability across different combat sports disciplines.

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Supplementary Table 1. Statistical values description of the Generalized Linear Models of the Striking Reaction Time Task in professional mixed martial art athletes (n = 15).

Variable	Main effect of the day of test	Main effect of the stimulus type	Interaction
Jab	X^2 = 2.00; P=0.157	X^2 = 28.47; P<0.0001	X^2= 0.02; P=0.871
Cross	X^2 = 2.728; P=0.099	X^2 = 30.28; P<0.0001	X^2 = 0.04; P=0.823
Hook – dominant	X^2 = 1.132; P=0.287	X^2 = 9.56; P=0.002	X^2 = 0.009; P=0.922
Hook – non-dominant	X^2 = 0.791; P=0.374	X^2 = 11.12; P<0.001	X^2 = 0.03; P=0.862
Kick – dominant	X^2 = 0.500; P=0.48	X^2 = 50.74; P<0.0001	X^2 = 0.44; P=0.50
Kick – non-dominant	X^2 = 2.361; P=0.124	X^2 = 27.33; P<0.0001	X^2 = 0.227; P=0.634
Heart rate (bpm)	X^2 = 0.437; P=0.508	X^2 = 0.011; P=0.915	X^2 = 0.216; P=0.642
Heart rate (%HRmax)	X^2 = 0.465; P=0.495	X^2 = 0.01; P=0.912	X^2 = 0.226; P=0.634

Supplementary Table 2. Shapiro-Wilk results.

Variables	Test	Simple		Complex	
		W	P	W	p
Jab	SRTT 1	0.918	0.179	0.9	0.09
	SRTT 2	0.922	0.206	0.94	0.49
Cross	SRTT 1	0.954	0.587	0.94	0.47
	SRTT 2	0.961	0.707	0.94	0.39
D Hook	SRTT 1	0.948	0.493	0.95	0.53
	SRTT 2	0.990	1.000	0.92	0.19
ND Hook	SRTT 1	0.937	0.351	0.93	0.31
	SRTT 2	0.909	0.129	0.93	0.36
D Kick	SRTT 1	0.938	0.359	0.86	0.02
	SRTT 2	0.911	0.141	0.91	0.16
ND Kick	SRTT 1	0.962	0.725	0.86	0.03
	SRTT 2	0.880	0.048	0.89	0.07

Note: ICC =; D = dominant limb; ND = non-dominant limb

Supplementary Table 3. Descriptive (mean ± SD) and statistics (Wilcoxon test) values of number of incorrect responses.

Strike	Test	Day 1	Day 2	W	p
Jab	Simple (%)	5.5 ± 6.1	4.1 ± 4.6	37.00	0.35
	Complex (%)	2.2 ± 6	1.3 ± 3.9	8.00	0.36
Cross	Simple (%)	6.3 ± 5.7	7.7 ± 10.6	32.00	0.96
	Complex (%)	0.7 ± 2	0.3 ± 1.3	4.00	0.78
D Hook	Simple (%)	6.7 ± 7.8	3 ± 5.6	50.50	0.13
	Complex (%)	2.7 ± 6.5	3.7 ± 7	14.50	0.67
ND Hook	Simple (%)	1.8 ± 3.7	1.6 ± 3.5	9.00	0.78
	Complex (%)	3.1 ± 4.8	2.3 ± 3.8	20.00	0.35
D Kick	Simple (%)	4.1 ± 5.3	4.4 ± 5.8	25.00	0.83
	Complex (%)	8.6 ± 7.4	6.2 ± 8.1	66.50	0.39
ND Kick	Simple (%)	7.4 ± 9.3	4.4 ± 4.5	48.00	0.5
	Complex (%)	4.2 ± 5.1	6.9 ± 8.4	43.50	0.59

Note: ICC =; D = dominant limb; ND = non-dominant limb