International Journal of Strength and Conditioning

Gusciglio, B. E., & Morin, JB. (2023).Assessing The Key Physical Capabilities in Striking Combat Sports: Reliability And Reproducibility of A New Test
International Journal of Strength and Conditioning
https://doi.org/10.47206/ijsc.v3i1.207

Assessing The Key Physical Capabilities in Striking Combat Sports: Reliability And Reproducibility of A New Test

Baptiste E. Gusciglio[1] & Jean-Benoit Morin[2]

[1]Department of Sport Sciences and Physical Education, University of Saint-Etienne, France, [2]UJM-Saint-Etienne, Inter-university Laboratory of Human Movement Biology, Saint-Etienne, France

ABSTRACT

The rules and the technical aspect of combat sports make it difficult to determine key performance indicators. Therefore, the assessment of striking sports discipline-specific key components may be relevant. This study aims to present a test assessing specifically the fighters striking force-velocity (F-V) capabilities. 10 MMA fighters performed FV (two-point (TP) and multiple-point (MP) methods) and fatigue tests using the landmine punch exercise (LPE) which is considered a specific exercise for striking combat sports. A high within-subject intra-session and inter-session reliability and reproducibility were found for the FV profiles parameters and the fatigue test (most CVs<10%, ICCs>0.67, ES < 0.2 for F_0, V_0, P_{max}, S_{fv}, P_{peak}, P_{mean}, P_{min} and FI% and r > 0.9). Moreover, the TP and MP methods showed high validity and agreement (r >0.88 and ES <0.37). The novel LPE test presented in this pilot study is a highly reproducible tool for evaluating both mechanical and anaerobic components specific to the discipline. Athletes and coaches may use this test to better understand striking performance in combat sports.

Keywords: force-velocity, striking combat sports, fatigue test.

INTRODUCTION

Combat sports refer to a wide range of contact sports usually involving two fighters within a defined area. Striking sports involve combinations of blows: punches, kicks, elbows and knees (2). Because of the wide range of technical skills and rules in combat sports, it is difficult to clearly define performance indicators. Therefore, it is important to assess underlying physical qualities to optimize performance (2). It is well established that striking actions require a combination of explosive strength, power, and speed (2, 18, 29). Combat sports involve a high cardiovascular demand because of their high-intensity repeat-effort nature (2, 29). Fighting competitions alternate high and low intensities with limited recovery. For example, in a simulated striking fight, athletes reached > 90% of their maximum heart rate (HR_{peak}) and maximal oxygen consumption (VO_{2max}) (2). These striking sports also induced a significant anaerobic strain (blood lactate concentration > 12 to 14.9 mmol.L^{-1}) (2, 25). Thus, both aerobic and anaerobic components are important in combat sports performance, with the anaerobic system likely predominant (2, 14). Indeed, Girard et al. (2011) reported that high-intensity activity is primarily driven by an anaerobic component, (i.e., ATP, PCr, and glycolytic pathways) even after multiple efforts (2, 5). Hence, the assessment of anaerobic function may provide more relevant information than the aerobic component (33). The literature reports VO2max tests performed on a treadmill or a cycle ergometer (2, 28, 29), wingate tests involving the upper or lower limbs on a cycle ergometer (2, 8, 27, 33, 36), repeated countermovement jump (CMJ) (2, 9) and training circuits (2, 6, 13) to evaluate these components in striking and grappling combat sports. Alternatively, biomechanical components have been tested using force-velocity profiles (FVP) and maximum repetition efforts (1RM), performed on the bench press, squat jump, half squat, deadlift, and seated row exercises (5, 10, 18, 33). Isometric mid-thigh pull tests (18, 33) horizontal and vertical jumps tests (5, 10, 21, 33), and sled push tests (28, 29). In addition, striking assessments were performed with embedded and non-embedded accelerometers or with force, piezoelectric transducers, strain gauges, or 3D imagery systems (24, 37).

A single outcome from such tests (e.g., punch force, jump height) may not clearly characterize the underlying muscle capacities that are expressed during a bout (16, 19). From that perspective, it seems relevant to assess the FVP which is considered a fundamental descriptor of muscle physiology (19, 31). Indeed, these ballistic striking movements depend on the maximal power output and the FVP of the muscles involved. The traditional multiple-point (MP) protocol, well established in sports sciences, involves at least 3 experimental points, used to build a linear regression allowing computation of the *x-y* intercepts (i.e., F_0 and V_0). Whereas the two-point (TP) method should be a more fatigue-free and faster option in a sport context (4, 16, 19) since only two data points are needed to establish the linear regression. The TP method was shown valid and reliable in several movements (e.g., bench press, vertical jumps, bench pull…) (4, 16, 19). Consequently, to better understand the performance of such ballistic striking movements, it seems relevant to assess the mechanical parameters of the FVP. As mentioned above, the FVPs used in combat sports are upper or lower body dominant (5, 10, 18, 33), while the specificity of the test should be considered (2, 30). In the training context, athletes and coaches typically use exercises allowing a better transfer of the physical qualities towards the sports discipline (35). In striking combat sports, the landmine punch exercise (LPE) is known to be an exercise with high transfer potential due to similarities to striking skills (11, 35). Furthermore, according to strength and conditioning coaches and the Ultimate Fight Championship's Performance Institute (UFCPI), both movements (i.e. the LPE and straight punches) seem dynamically similar (36). Therefore, it seems relevant to assess both neuromuscular and endurance parameters using the LPE due to its greater specificity compared to weightlifting movements (e.g., bench press, vertical jumps). Thus, the main focus of this study was to investigate the reliability and reproducibility of the LPE as a biomechanical and anaerobic assessment for striking combat sports. The second purpose of this study was to compare the FVP obtained by the MP versus the TP method. It has been hypothesized that the TP method would be as valid as the MP method, as shown for other types of ballistic exercises.

METHODS

Experimental approach to the problem

The experimentations occurred during the recovery period after the fight camp of the athletes where they followed their usual training schedule, diet, and lifestyle. The experimental protocol included familiarization and test-retest procedures. After familiarization, the fighters performed 3 test-retest sessions, each separated by 48h. The FVP parameters and the fatigue test parameters obtained from LPE were calculated throughout these experimental sessions.

Subjects

10 subjects from amateur to semi-professional MMA fighters (2 women and 8 men) participated to the study. All subjects had at least 3 years of experience in striking combat sports, no history of injuries in the last 3 months to the joints, muscles, and tendon structures, and were training between 3 and 6 times a week. Mean (±SD) age, height, and body mass (BM) were 25.7 ± 7.70 years, 181 ± 6.93 cm, 83.4 ± 8.38 kg respectively, for men, and 20.5 ± 2.12 years, 160 ± 6.36 cm, 59.0 ± 8.49 kg respectively, for women. During the experimental period, the participants were in post-fight camp and trained lightly comparing to the previous fight camp period. They maintained their usual lifestyle and diet.

Procedures

Landmine Punch Exercise

The LPE is described as a highly transferable movement to specific striking actions (i.e., straight punches) (35). The athlete grabs the top of the bar in the dominant hand while keeping an on-guard position. With a powerful extension of the lower

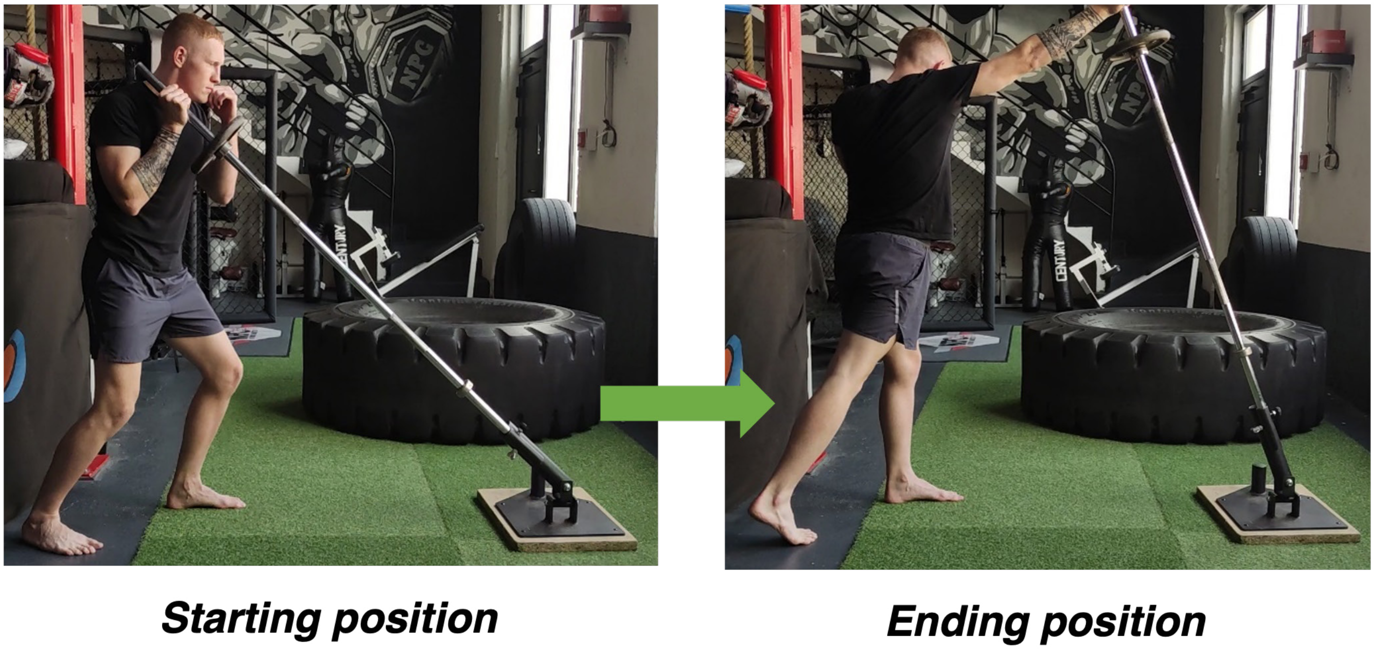

Figure 1: *Visual representation of the landmine punch exercise and its starting and ending position. A more descriptive video is accessible here (https://youtu.be/RxRTiW2pYT4).*
NB: The bar was not thrown at the end of the LPE.

limbs and dominant arm, the athlete performs a ballistic throw of the bar forwards. This movement induces a similar shift of the BM (from the rear leg to the front leg) than in straight punches (Figure 1) with the forward transition allowing a greater strike impulse (23, 35). The following set-up was designed to secure the athletes and promote their best performance. The landmine support was fixed on a 4 cm thick board with 40 kg applied onto the support to block it onto the ground. The experimenter used two threaded rods to block the bar into the landmine base. Finally, the LPE was performed outdoors facing a 45° slopping surface within an area set to receive the bar after the throw. The ensured maximal intensity, ballistic throws in all loading conditions.

Familiarization

Before taking part in any experimental session, all participants performed familiarization trials with all testing procedures. Familiarization consisted of foot position measurements, warm-up, habituation to the FVP procedures, and the fatigue test. The LPE habituation included 3 sets of 5 repetitions at a load corresponding to 20%, 30%, and 40% of their BM. The goal was to perform the movement with a good technique. If not, the visual judges (i.e., the experimenter and the coach) decided to add more repetitions until the subjects had good movement. Then, the subjects performed 30-s of an all-out effort at a load corresponding to 30% of their BM. Technical instructions were given to the athlete before and during the exercise to be reproducible.

Force-velocity and power-velocity profiles

Given the technical complexity of the movement, an accelerometer method was chosen to establish the FVP. After a specific warm-up, the athletes performed 4 repetitions for extreme loads (i.e., the lighter and the heavier) and 2 repetitions for intermediate loads. The additional 2 repetitions were used to establish the FVP with the TP method. Loads were selected based on their BM: 20% (16.1 ± 2.40 kg), 30% (24.2 ± 3.60 kg), 40% (32.4 ± 4.80 kg), and 50% (40.4 ± 6.0 kg). A 10 kg bar was used to perform the trials. If the inter-trial coefficient of variation (CV) was > 10%, another repetition was performed. All subjects took 30 seconds of passive intra-set rest, while 1 minute and 30 seconds of passive inter-set rest were provided. Body countermovement was not allowed, keeping the non-dominant arm in an on-guard position, the feet in their specific area, and immobilizing themselves. It was asked to perform the LPE as a cross punch with maximum intent at the end of a count: “3, 2, 1… Go !”. An inertial unit sensor (Microgate Gyko Repower, Bolzano, Italy) was fixed to the bar with magnetic support and covered with a protective belt to collect kinetic data. Using a custom-made spreadsheet (Microsoft, Excel 2205), the dependent variables calculated within the FVP were: F_0, V_0, P_{max}, and the slope of the relationship (Sfv).

Fatigue test

The fatigue test involved 2 sets of 30-s all-out effort, performing the LPE without throwing the bar. 8 minutes of passive inter-set rest were assigned to all participants. Based on the load-velocity profile (LVP), the resistance chosen as the one associated with P_{max}. Peak heart rate (HR_{peak}) and average heart rate (HR_{mean}) were recorded (with a Polar H10 monitor) throughout the fatigue test. Athletes were asked to rate the perceived effort (RPE) with the Borg scale 30 seconds post-test (3). Instructions were to elicit maximum effort at the onset of the test, stay within the same range of motion (ROM), and avoid using the non-dominant arm. Instructions were reminded and verbal encouragements were given to allow maximum performance. The dependent variables were HR_{peak}, HR_{mean}, peak power (P^{peak}), mean power (P_{mean}), minimal power (P_{min}), and fatigue index (FI). The latter was calculated according to Čular et al. (2018) (9).

Statistical analyses

Statistical analyses were carried out using three software (JASP 0.16.1.0.Inc, Amsterdam, Excel 2302, Microsoft Office and SPSS, Inc., Chicago, IL, USA Statistics). The normality, equality of variance, and sphericity were checked with Shapiro Wilk's, Levene's, and Mauchly's tests, respectively. Analysis of variance (ANOVA) was used for statistical analyses to identify differences between dependent variables among 3 testing sessions. For the FVP (TP plus MP methods) and the fatigue test, inter-session and intra-session reliability and reproducibility were calculated with intraclass correlation coefficients (ICCs), coefficients of variation (CVs), effect size (ES), and coefficient of correlation. Finally, paired t-tests, ES, correlation coefficients, and Bland-Altman plots were used to compare the validity of the TP vs MP methods. Alpha was set at 0.05.

RESULTS

FVP and fatigue test

The mean of the FVPs indicated excellent linearity ($r^2 = 0.99$) (Figure 2).

Concerning FVP, good intra-session reliability was found (CV < 10%) for all parameters studied (Table 1). The ANOVA analyses didn't reveal any significant differences between the 3 testing sessions in all parameters, for both methods ($p > 0.05$). These results were supported by a trivial ES (< 0.2, $p < 0.001$) (17) and a strong (r > 0.85, $p < 0.001$) to very strong correlation (r > 0.9, $p < 0.001$) (32) in FVP parameters, for all testing sessions and methods. Finally, intersession CV and ICC showed small variability for all FVP parameters (CV < 10% and ICC > 0.67) (22) (Table 1).

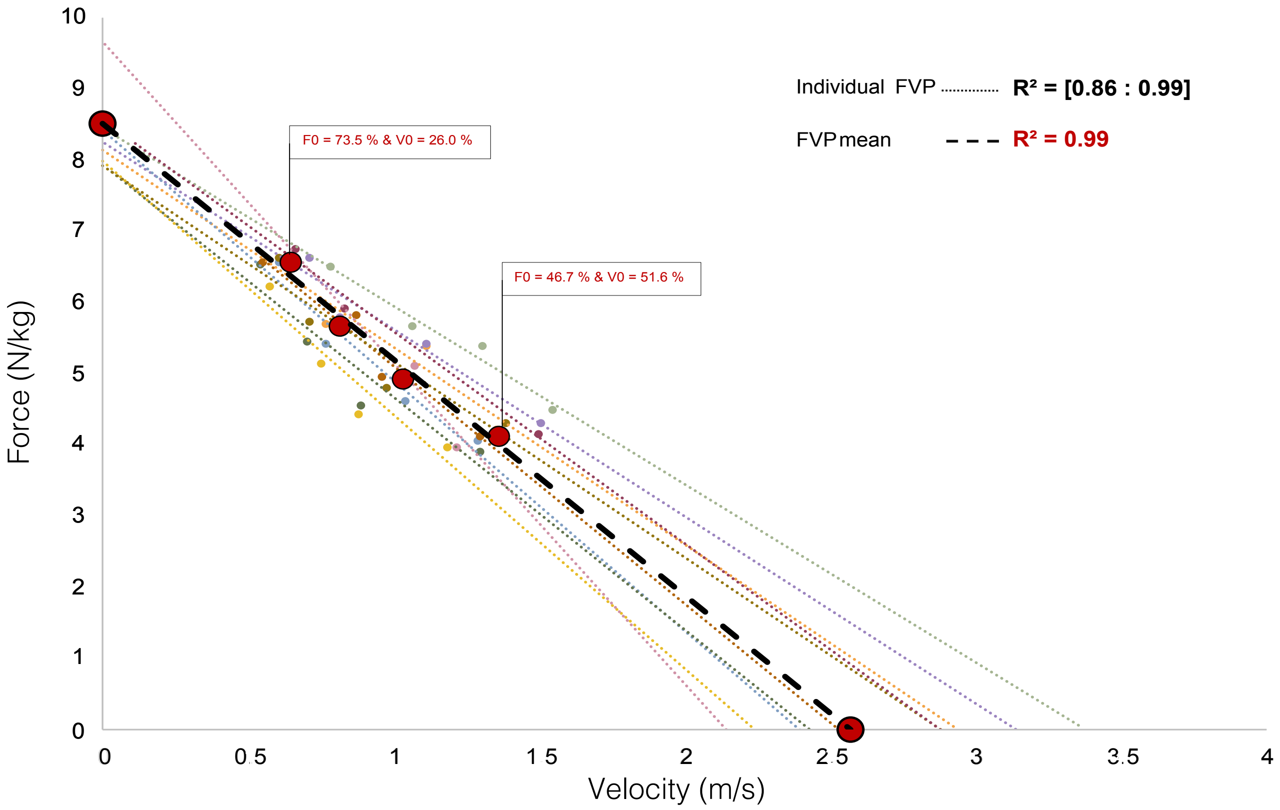

Figure 2. *Mean of the force-velocity profiles obtained through test-retest sessions.*

For the fatigue test, good intra-session and inter-session reliability was found for the following parameters of the fatigue test: P_{peak}, P_{mean}, P_{min}, and FI (CV < 10% and ICC > 0.67) (22). Moreover, trivial ES ([-0.19:0.2], $p < 0.001$) (17) and very strong ($r > 0.9$, $p < 0.001$) to strong ($r = 0.88$, $p < 0.001$) (32) correlations were also found in these 4 parameters (Table 2). No significant differences were found between all parameters of the three testing sessions ($p > 0.05$). However, the inter-session reliability (RPE: ICC < 0.67), correlation coefficient, and significance of the tests (HR_{peak}: r = 0.64 to 0.87, HR_{mean}: r = 0.04 to 0.76 with $p > 0.001$ and RPE: r = 0.15 to 0.44 with $p > 0.001$) in other parameters was lower or null (Table 2).

Comparisons and agreement between the TP and the MP methods

Strong (F_0: r = 0.88) to very strong (V_0: r = 0.95, Pmax: r = 0.96, Sfv: r = 0.93) (32) associations were found between FVP parameters of the two methods ($p < 0.001$).

Student tests revealed no significant differences in the FVP parameters between the methods ($p > 0.05$). These results were supported by Cohen's d effect size indicating trivial magnitudes of difference (32) (Table 3).

Table 1. Test-retest statistics of force-velocity methods.

F-V methods	Parameters	Coefficient of variation			*p*-value	Intersession reliability	Cohen's D effect size		
		S1	S2	S3			S1-S2	S1-S3	S2-S3
Multiple Points	F_0 (N/kg)	2.88%	4.35%	2.97%	0.155	1.14% CV; 0.986 ICC	-0.09	-0.18	-0.09
	V_0 (m/s)	3.89%	5.38%	3.36%	0.860	2.24% CV; 0.987 ICC	0.04	0.04	0.00
	P_{max} (W/kg)	3.42%	4.16%	3.38%	0.510	2.40% CV; 0.987 ICC	0.02	-0.08	-0.09
	S_{fv}	4.73%	7.45%	4.09%	0.464	2.52% CV; 0.988 ICC	-0.06	-0.10	-0.05
Two Points	F_0 (N/kg)	2.11%	2.83%	4.21%	0.374	1.27% CV; 0.957 ICC	-0.19	0.02	0.20
	V_0 (m/s)	3.86%	4.08%	4.41%	0.412	2.76% CV; 0.992 ICC	0.06	0.09	0.03
	P_{max} (W/kg)	3.28%	4.18%	3.67%	0.577	2.64% CV; 0.995 ICC	-0.02	0.03	0.06
	S_{fv}	5.59%	5.43%	6.37%	0.459	3.42% CV; 0.989 ICC	-0.10	-0.06	0.04

** = $p > 0.001$, F_0: maximal theoretical force, V_0: maximal theoretical velocity, P_{max}: maximal theoretical power, S_{fv}: slope of the relationship, S1: session 1, S2: session 2, S3: session 3.*

Table 2. Test-retest statistics of fatigue test parameters.

Parameters	Coefficient of variation			*p*-value	Intersession reliability	Cohen's D effect size		
	S1	S2	S3			S1-S2	S1-S3	S2-S3
P_{peak} (W/kg)	3.72%	5.10%	4.58%	0.497	1.46% CV; 0.987 ICC	-0.06	0.07	0.01
P_{mean} (W/kg)	4.06%	5.61%	4.83%	0.584	2.73% CV; 0.991 ICC	0.07	0.05	0.02
P_{min} (W/kg)	4.19%	5.28%	4.04%	0.706	2.26% CV; 0.986 ICC	0.03	0.08	0.05
FI (%)	3.33%	4.72%	3.00%	0.602	3.16% CV; 0.954 ICC	-0.16	0.12	0.04
HR_{peak}	2.14%	1.93%	3.42%	0.267	1.74% CV; 0.880 ICC	-0.40	0.19	0.21
HR_{mean}	2.62%	12.88%	2.13%	0.748	1.90% CV; 0.673 ICC	-0.23	0.23	0.00
RPE	4.33%	3.42%	2.40%	0.356	1.86% CV; 0.372 ICC	0.00	0.52	0.52

** = $p > 0.001$, P_{peak}: peak power, P_{mean}: mean power, P_{min}: minimum power, FI: fatigue index, HR_{peak}: maximum heart rate, HR_{mean}: mean heart rate, RPE: rating of perceived exertion, S1: session 1, S2: session 2, S3: session 3.*

Table 3. Comparisons and magnitudes between both FVP methods for each session.

Sessions	FVP parameters	MP method (mean ± SD)	TP method (mean ± SD)	*p*-value	Mean difference	Cohen's d effect size
S1	F0 (N/kg)	8.45 ± 0.55	8.51 ± 0.58	0.809	0.06	-0.11
	V0 (m/s)	2.58 ± 0.41	2.57 ± 0.47	0.960	0.01	0.02
	Pmax (W/kg)	5.44 ± 0.9	5.44 ± 0.94	0.992	0.00	-0.00
	Sfv	3.35 ± 0.57	3.41 ± 0.64	0.833	-0.06	-0.10
S2	F0 (N/kg)	8.50 ± 0.56	8.62 ± 0.59	0.636	-0.12	-0.22
	V0 (m/s)	2.56 ± 0.37	2.54 ± 0.42	0.920	0.02	0.05
	Pmax (W/kg)	5.42 ± 0.74	5.46 ± 0.87	0.913	-0.04	-0.05
	Sfv	3.39 ± 0.56	3.48 ± 0.65	0.739	-0.09	-0.15
S3	F0 (N/kg)	8.54 ± 0.51	8.50 ± 0.68	0.863	0.05	0.08
	V0 (m/s)	2.56 ± 0.41	2.53 ± 0.41	0.859	0.03	0.08
	Pmax (W/kg)	5.50 ± 0.87	5.41 ± 0.85	0.814	0.09	0.11
	Sfv	3.41 ± 0.58	3.45 ± 0.69	0.896	-0.04	-0.06

**= $p > .001$; F_0, maximal theoretical force ; V_0, maximal theoretical velocity ; P_{max}, maximal power ; S_{fv}, slope of the relationship; S1, session 1; S2, session 2; S3, session 3.*

Finally, agreement for the FVP parameters between methods was assessed through Bland Altman plots. All scattered plots were included in the limits of agreement (LOA) (Figure 3).

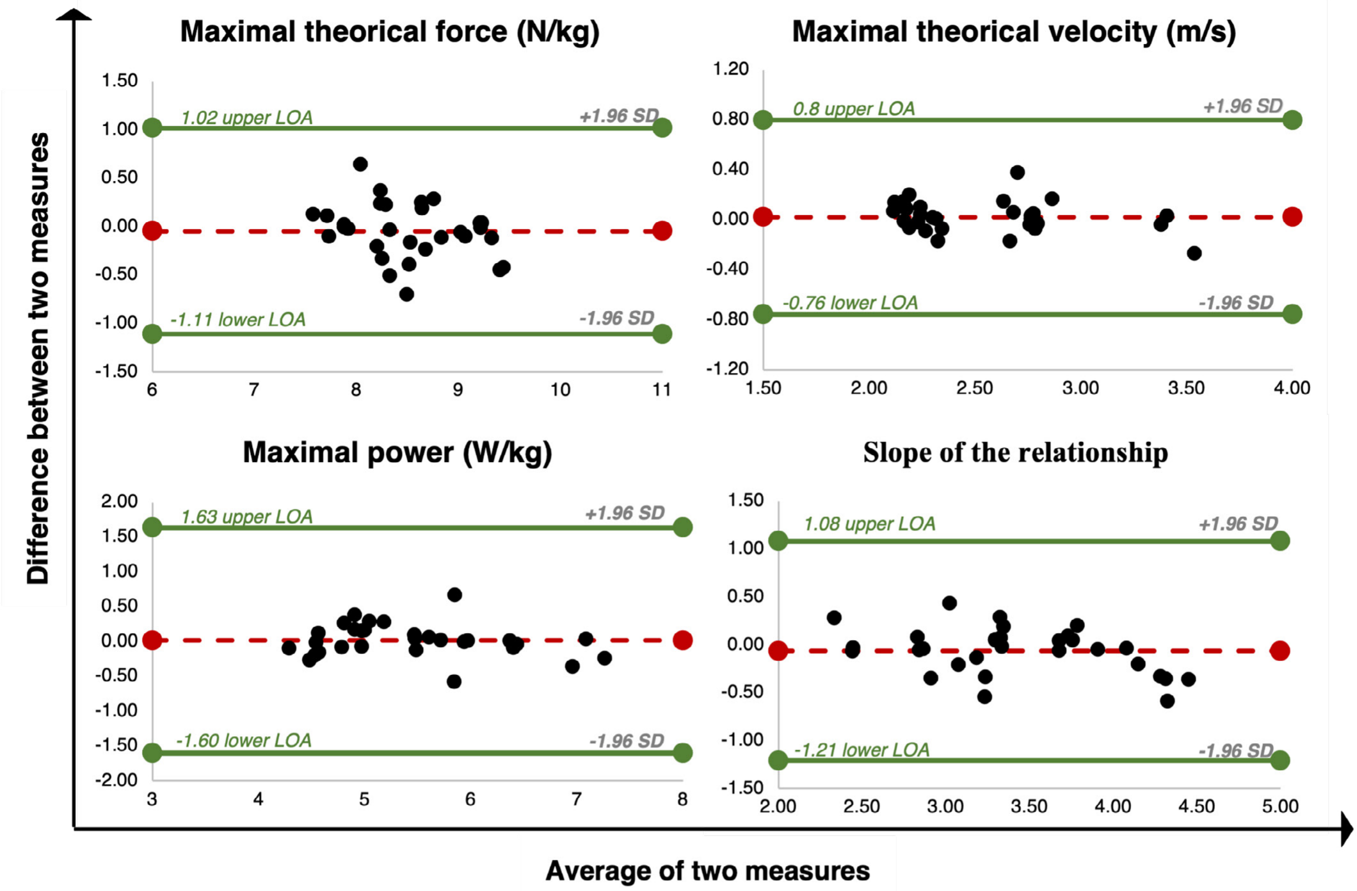

Figure 3. *Bland Altman plots showing agreement of the FVP parameters between TP and MP methods.*

DISCUSSION

The parameters calculated from the fatigue test and FVP presented mostly low variability in both intra-session and inter-session. Indeed, the ICCs and CVs% values were > 0.67 and < 10%, respectively across all assessed variables (22). Moreover, the ANOVA analyses revealed no significant differences. This was associated with small to trivial ES alongside strong to very strong correlation coefficients (r = [0.85 to 0.99]). To our knowledge, this is the only study attempting to assess specifically a striking discipline, the key physical components, with a single test. Punch force is known to be a key component of successful athletes (12), and kinematic analyses have shown that the punching technique is a key component of the punch force product (12). Because of the similarities between the punch and the LPE (36), the LPE technique can be considered equally discriminating. The technical nature of the LPE conditioned the load selection. Indeed, preliminary experiments to the current study revealed that loads close to or greater than 60% of the BM altered the technique of the movement. However, selecting 50% of the BM as the heaviest load may bias the extrapolation of x-y intercepts (16) since this load may be considered quite far from F0 value as well as the 20% of the BM load that is far from V0 value. The nature of the exercise precluded performing the LPE with a lighter bar (i.e., 10 kg). If possible, the points used to form the FV relationship must be close to the *x-y* intercepts. In the current study, the 50% of the BM load corresponded to 26.0 ± 3.52% and 73.5 ± 4.78% of V_0 and F_0, respectively. Whereas the lightest load (i.e., 20% of the BM), corresponded to 51.6 ± 4.50% and 46.7 ± 5.75% of V0 and F0, respectively. It can be assumed that the obtained FVP data were force-biased because of the proximity with the y-intercept (16). This may allow for better accuracy of F0 extrapolation, while V0 could be less accurate (16). The fatigue test was conducted with the theoretical load eliciting P_{max}. The purpose of this test was to quantify the anaerobic performance of the athletes. An average P_{peak} of 5.48 W/kg, P_{mean} of 3.23 W/kg, and P_{min} of 2.70 W/kg were found along with an average FI of 50.6%. Ouergui et al. (2013) (27) reported similar values in kickboxing population (P_{peak} = 5.89 W/kg, P_{mean} = 4.51 W/kg, and FI = 51%) during a 30-s upper body wingate test. In another study by Ouergui et al. (2014) (26), close values were found after a five-week training program (P_{peak} = 5.9 W/kg, P_{mean} = 3.4 W/kg and FI = 54.5%) from an upper body wingate test. It appears that the current fatigue test is closer to an upper body wingate test than a lower body wingate test, which may be explained by the greater ROM of the upper limbs than the lower limbs. This is supported by Barley et al. (2019) (2) who reported greater upper limbs demand than lower limbs demand in striking fighters. In addition, kinematic analyses of the cross punch from Dinu et al. (2020) (11) showed approximately 20% to 40% of contributions from the shoulder and elbow while linear and rotational contributions from the pelvis were < 20%. However, differences in resistance selection, training history, injuries, age, sex, weight, and foot position are expected to influence the results between the present study and those of Ouergui et al. (26, 27), and further research is warranted. Responses to the fatigue test elicited a HR_{peak} of approximately 156 bpm (i.e., which may correspond to ~ 82% of the maximal theoretical heart rate for this group of subjects (HR_{max} = 208-0.7*age) (1). In the literature, similar tests implied higher heart rate: Tayech et al. (2020) (34), reported that after a lower body wingate test and a taekwondo-specific wingate test, the HR_{peak} were 186 ± 9.55 bpm and 188 ± 9.05 bpm. That said, the mass involved in the aforementioned study was that of the lower limbs which can increase energy expenditure, and thus cardiovascular demand. In another study, Franchini et al. (2016) (15) indicated that after performing an upper body wingate, judo athletes elicited ~172 bpm which is closer to our findings, yet still substantially different.

The comparison between the TP method and the MP method revealed strong to very strong correlations for all FVP parameters. No significant differences were found and their magnitudes were trivial to small. Finally, Bland-Altman plots showed excellent agreement between both methods. Overall, these results indicated that the TP method is at least as valid and reliable as the MP method. Consequently, the TP method could be used to assess the FVP of striking fighters to reduce the fatigue and time required to perform the testing procedure. The extreme loads (i.e., the lightest and the heaviest) were chosen, according to Garcia Ramos et al. (2017) (16) to increase accuracy extrapolating both F_0 and V_0. Indeed, they reported a decrease in both the validity and reliability of the FVP parameters in bench press exercise with the proximity of data points: for 40–50% 1RM points the CV was 18.0% and the r = 0.64. Contrastingly, for the 20-70% 1RM points, the CV was 5.5% and the r = 0.98. In lower body exercises (i.e., deadlift and squat), was reported good reliability for the TP (i.e., 40-80% 1RM, 40-90% 1RM, and 60-90% 1RM) and the MP methods, whereas other loads (40-60% 1RM and 60-80% 1RM) showed poor reliability (5). In addition, loads close to the 1RM were superior at estimating 1RM. These results suggest that the selection of loads for lower body exercises concurs with the results of Garcia-Ramos et al. (16). Nonetheless, V0 was not assessed in the above studies (5, 16). In the current study, the TP represented 47.8 ± 5.76% and 74.1 ± 5.35% of F0 for the lightest and highest loads, respectively, while 53.5 ± 5.54% (i.e., the lightest load) and 27.0 ± 3.11% (i.e., the highest load) of V0 were found. The high reproducibility found for the LPE could be explained by the dominance of the upper limbs while the lower limbs exercises showed inconsistent results due to their complexity (5). The LPE is also a complex movement, but the subjects' experience and daily practice of punching techniques could stabilize the punch pattern, thus reducing the variability.

PRACTICAL APPLICATIONS

The results of this study show that strike-specific anaerobic and FVP variables can be obtained with a field method in less than 10 minutes. That said, this method needs to be carefully implemented regarding the execution of the exercise. The practicality of these tests allows coaches to quickly check specifically the discipline, the physical capabilities of the athletes to 1) detect the weaknesses and orient the training program (8) 2) detect the appropriate loads necessary to individually train a specific area of the FVP 3) check the efficiency of a training program 4) check the progression of an athlete and 5) compare athletes.

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