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Original Research

Identifying Consistent Metrics from the Force-Time Curve of the Countermovement Jump in Combat Fighters and Physically Active Men.

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ABSTRACT

International Journal of Exercise Science 16(4): 1038-1051, 2023. We investigated the consistency of metrics obtained from the unweighting, braking, propulsive, and landing phases of the countermovement (CMJ) force-time curve in combat fighters and physically active men. Combat fighters (n=21) and physically actives (n=21) were tested for three days (2-7 days apart). Participants performed four maximal CMJ separated by 1-min for between-day comparisons. From force-time recording, the consistency of 16 CMJ metrics (peak and mean ground reaction forces (GRF), net impulse, and duration from each phase) was investigated using the intraclass correlation coefficient (ICC) and typical error (CV_{TE}). We considered as “consistent” those metrics showing no systematic differences, ICC ≥ 0.75, and $CV_{TE} \leq 10\%$. We further compared the CV_{TE} between groups and pairs of trials (days). Participants demonstrated more consistency in the braking and propulsive phases, while the unweighting phase did not show any consistent metric. There was no evidence of a learning effect (systematic changes), but analysis appointed more consistency on days 2-3 than on days 1-2 (18 metrics presented lower CV_{TE} while 11 presented higher). We identified braking and propulsive GRF (peak and mean) and propulsive impulse as consistent metrics for combat fighters, while only propulsive impulse for physically actives. The between-group analyses showed that 24 comparisons favored the combat fighters against only five favoring the physically actives. In conclusion, force-time metrics related to jumping strategy, like phase duration, are less consistent than those related to driven forces and jump output, probably because participants changed their jump strategy during testing days.

KEY WORDS: Exercise test, vertical jump testing, force platform, muscular fitness, reliability

INTRODUCTION

The countermovement jump (CMJ) is primarily used to assess lower-body neuromuscular function (20,38,56,62,63). The CMJ testing has been applied to an extensive range of individuals, from sedentary to elite athletes of all age groups (35), including individuals with musculoskeletal disorders (6) and obesity (46). The CMJ is popular because it is practical and non-fatiguing, can be quickly performed, and provides valuable information on neuromuscular adaptations induced by training regimens and exercise-induced neuromuscular fatigue

(4,7,31,54). Furthermore, researchers have pointed out that the CMJ allows for discrimination between athletes with distinct competitive levels (11,19,20,56,63) and training backgrounds (24,26,30,45,58,63).

Force platforms are considered the gold standard device for CMJ testing (9,29). A force platform allows a comprehensive assessment of the constituent phases of the CMJ, providing metrics expressing the jump output (e.g., net propulsive impulse), the driven forces of the jump (e.g., peak and mean ground reaction forces), and movement strategy (e.g., phase durations). Although there are arguments that force platforms are not accessible due to their high cost and lack of portability, the technology advance has allowed the commercialization of low-cost force platforms (27). In addition, recent publications have provided inexpensive software for CMJ force-time curve analysis (5), suggesting that the use of force platforms will likely grow.

To improve understanding and application of the CMJ data, researchers (5,39) have proposed that force-time data from CMJ testing should be segmented in phases (e.g., unweighing, braking, propulsion, and landing). Indeed, several studies have been published applying this method for CMJ phase segmentation (2,10,13,36,55). However, the segmentation of the CMJ in phases requires multiple calculations (e.g., differentiation, integration) and the identification of thresholds (e.g., integration start and take-off), which may increase the chance of computational error. In addition, errors can also arise from participants (e.g., learning, motivation, fatigue). Each potential source of error (computational and biological) may substantially affect the measurement's quality. Whether metrics deriving from CMJ phases are consistent across testing sessions is still being determined.

It is established that the jump height (estimated from flight time or takeoff velocity) and ground reaction forces produced during a CMJ vary little from day to day (52). However, this may not be the case for metrics related to jumping strategy since an individual can change the movement strategy (e.g., applying less force for longer duration) while keeping consistent the jump height (12,37).

The usefulness of the CMJ to assess neuromuscular function, especially to monitor exercise-induced small changes in performance (e.g., pre- vs. post-training), depends on data consistency. Consistent metrics increase the likelihood of observing true changes in performance (15). The typical error (expressed as coefficient of variation - CV_{TE}) and intraclass coefficient of correlation (ICC) are often evaluated together to determine consistency. It is generally accepted that a metric is consistent if the ICC ≥ 0.75 and the CV_{TE} ≤ 10% (1,22,57). However, these scores are estimates and should be interpreted considering the 95% confidence interval (22).

Although studies have been published reporting consistency of metrics obtained from key phases of the CMJ, mainly from the propulsive phase (aka concentric phase) (12,14,28,32,40–42,44,48,51,61), some information is still missing. For example, Warr et al. (61) and Heishman et al. (14) recently performed a reliability study on male athletes, but no information was provided about the landing phase of the CMJ. Others have not fully described data consistency since their analysis was only part of the main study (40,51) or have been focused on a few propulsive phase metrics (12,42,44,48). Furthermore, some have performed intraday analysis (28,32,41), which has limited application for those interested in monitoring exercise-induced changes in performance.

This study aimed to investigate the consistency of metrics obtained from the unweighting, braking, propulsive, and landing phases of the CMJ in combat fighters and physically active men. It is interesting to know if the training background would play a role in metrics consistency since it is recognized that athletes may present a greater movement consistency, which would reflect lower CV_{TE} (60). For this reason, we have included a group of physically active men serving as a control group. We hypothesized that (I) net propulsive impulse and ground reaction forces would be more consistent than metrics related to movement strategy (phase duration). (II) Combat fighters would be more consistent in their performance than physically actives, and (III) adding a third testing day would improve consistency.

METHODS

Participants

The sample size was estimated a priori (G*Power, version 3.1.9.6, Germany), under the assumption that combat fighters would exhibit greater propulsive impulse during the CMJ than physically active men (Cohen's d = 1.19 (58)) as well as 0.05 of alpha error, 0.90 of power. These assumptions indicated that a sample size of at least 32 individuals would reach sufficient power to avoid type II error. Combat fighters (n = 21) and physically active men (n = 21) participated in this study. The combat fighters (tier 2: trained/developmental (34)) had to be engaged in any combat sport for a minimum of three days per week for at least two years. This sample included athletes from karate (n = 5), wrestling (n = 2), taekwondo (n = 3), Brazilian jiu-jitsu (n = 8), and judo (n = 2). The sample of physically active (tier 1: recreationally active (34)) was composed of men engaged in at least 150-min moderate-intensity activities and/or 75-min of vigorous activities per week (e.g., resistance training, walking, jogging, running). Fourteen participants were classified as "very active", while seven as "active" (8). To avoid confounding, we did not included participants reporting less than the minimum criteria to be part of the group of combat fighters (e.g., engaged in combat sports for less than 2 yrs.) in the group of physically actives. We instructed the participants to avoid any vigorous activity 48 hours before testing. They reported being free from any chronic disease or injury that could compromise jump performance and were informed about the risks and benefits of their participation before signing informed consent. This study was approved by the UDF – University Center Ethical Committee (number 2.878.364). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (43).

Protocol

The participants were tested on three separate days (2 to 7 days apart) at approximately the same time of day (±1 hour), and a single investigator performed all testing procedures. A video of the CMJ protocol was viewed prior to testing. During the first testing day, body mass and stature were taken, and physical activity and health questionnaires were filled out. Before all testing sessions, participants performed a standardized warm-up protocol consisting of 2 sets of overloaded (50% of body mass) back squats and five CMJs with progressive effort (20, 40, 60, 80, and 100% of perceived effort). They performed just one jump at each perceived effort, including a jumping maximally to increase the readiness for testing.

Table 1. Participant's characteristics.

Variable	Combat Fighters	Physically Active	p-value
Age (years)	25 ± 5	22 ± 2	0.10
Body mass (kg)	80 ± 10	77 ± 17	0.53
Stature (cm)	177 ± 5	176 ± 9	0.68
BMI (kg ·m-2)	25 ± 3	25 ± 4	0.48
CMJ height (cm)	44 ± 5	39 ± 7 *	0.02

* Less than Combat Fighters. BMI, body mass index; CMJ, countermovement jump.

CMJ testing was performed on a force platform with a sampling rate set at 1000 Hz (Accupower Portable Force Plate, AMTI, Watertown, MA, USA). Participants stood still for approximately three seconds with hands akimbo and then performed their maximum effort to jump following the command "3, 2, 1, jump". We instructed the participants to jump "as fast and as high as possible" to minimize the duration of the transition between the descending and ascending part of the movement and to land with feet extended (ankle plantarflexed). The countermovement depth was self-selected, and they were instructed to take-off and land with the same body posture (i.e., hands akimbo while keeping their hip, knee, and ankle joint fully extended). On landing, participants were instructed to absorb the forces by flexing their hips, knees, and ankles achieving your preferred squat depth. They also were instructed "to land softly, without noise". Participants performed four valid CMJs with maximum effort separated by a 1-min rest interval (21,52). However, ten participants from both groups were required to perform from one to three more attempts because the jump height difference exceeded 1 cm.

Figure 1 depicts the 16 CMJ metrics (i.e., 4 metrics: peak and mean ground reaction forces, net impulse, and duration from 4 CMJ phases: unweighting, braking, propulsive, and landing). The metrics were extracted from vertical ground reaction forces (GRF) using a custom-made Python script based on previous recommendations (39). The signal was visually inspected and filtered using a fourth-order low pass Butterworth filter with a cutoff frequency of 30 Hz. This low pass threshold was determined based on previous studies successfully applying this cutoff frequency (50,53,59). The offset was adjusted by subtracting the mean residual force measured during the flight phase of the jump, guaranteeing a zeroed measure. Bodyweight and mass were measured during the one second period of the weighing phase with a lower standard deviation (SD). The start of the CMJ was identified as the instant when the force signal reached the threshold of 5 × SD of the bodyweight minus 30 ms (49). Acceleration was obtained by dividing the net force-time signal by the participant's body mass. Then velocity and displacement were calculated by numerically integrating acceleration-time and velocity-time using the trapezoidal rule. The unweighting phase was delimited from the onset of countermovement until the instant when velocity reached a minimum value. The braking phase was delimited from the end of the unweighting phase until displacement reached a minimum value. The propulsive phase was delimited from the end of the braking phase until take-off. Take-off and landing were identified when the force signal reached the threshold of 5 × SD of the flight force (platform unloaded) (47). Flight force was sampled from the middle portion of the flight interval with half of its duration. The end of the landing phase was identified when acceleration first crossed zero or at its minimum (when the signal did not reach zero).

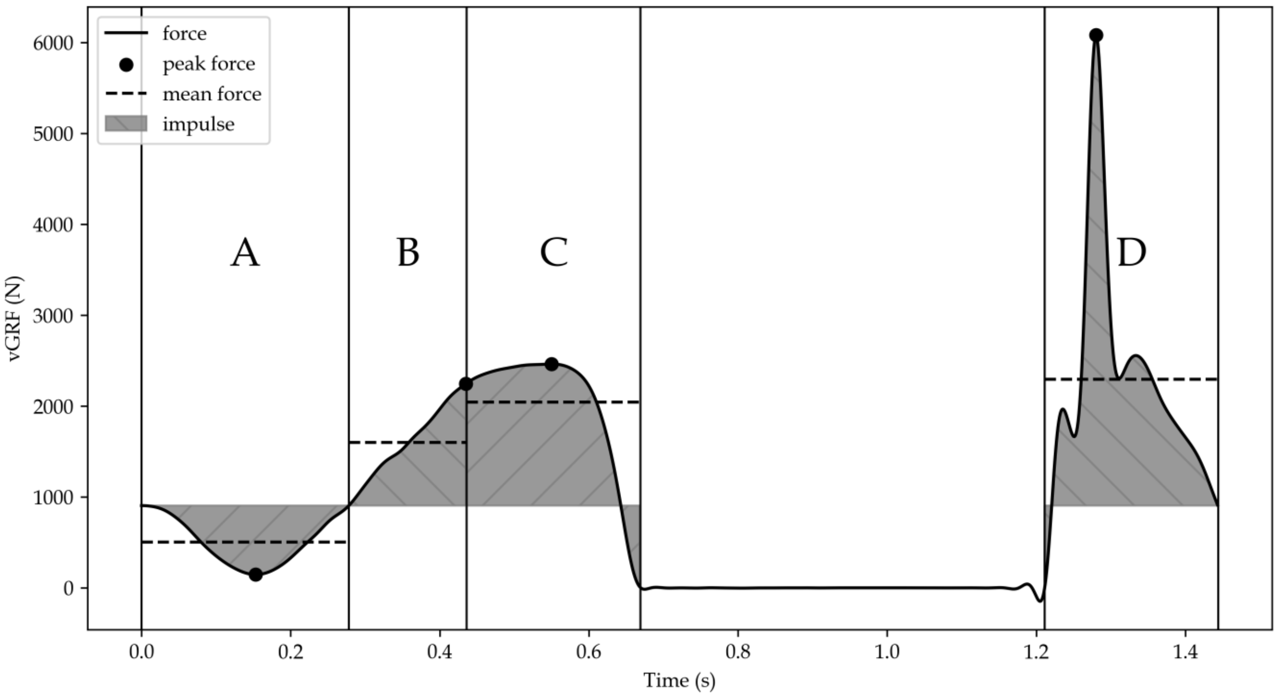

Figure 1. Typical vertical ground reaction force-time (vGRF) recording from countermovement jump (CMJ). A-D are depicting the key phases of the CMJ: A) unweighting; B) braking; C) propulsive; D) landing**.**

Statistical Analysis

Data distribution was inspected, and outliers were removed (1.2 × SD below or above the average for within- or 2 × SD for between-participants). At least two valid data from each metric (variable) were averaged and further analyzed; otherwise, the participant was excluded from that specific analysis. Table 2 describes the number of participants analyzed in each group and day. The Wilcoxon test with Bonferroni correction was used for test-retest comparisons utilizing The Statistical Package for the Social Sciences (SPSS version 23.0). Significant differences ($p \leq 0.017$) were interpreted using Hedge's g effect size (ES), with the threshold of < 0.2 for trivial; 0.2 – 0.6 for small; 0.6 – 1.2 for moderate; and 1.2 – 2.0 for large (17). The intraclass correlation coefficient (ICC) and typical error of measurement as a coefficient of variation (CV_{TE}) were calculated using a custom-made spreadsheet (16). CV_{TE} were interpreted as very large (> 15%), large (10 to 15%), moderate (5 to 10%) and low (< 5%) (57), while ICC were interpreted as poor (< 0.50), moderate (0.50 to 0.75), good (0.751 to 0.90) and excellent (> 0.90) (22). We further compared the magnitude of the CV_{TE} between groups (CV ratio = CV combat fighters ÷ CV physically active) and days (CV ratio = CV days 2 and 3 ÷ CV days 1 and 2). CV ratios exceeding

0.87 or 1.15 indicated a substantial difference (48,57). We considered as "consistent" those metrics showing ES < 0.2, ICC ≥ 0.75, and CV ≤ 10%, including their 95% confidence intervals, meaning that there was a 95% chance that the true score was ≥ 0.75 and ≤ 10%. These conditions must be met on all three testing days.

RESULTS

Tables 2 and 3 show results from force-time metrics and the ICC and CV_{TE} obtained during CMJ in combat fighters and physically active men, respectively. Combat fighters demonstrated consistent values of peak and mean GRF from braking and propulsive phases and propulsive impulse, while physically actives only demonstrated it for the landing impulse. The unweighting was the single CMJ phase not showing any consistent metric. No systematic differences were observed between testing days (i.e., learning effect), except the GRF_{PEAK} was lesser on day 2 than on day 1 in the unweighting phase of the combat fighters. Overall, the between-day comparisons using the CV ratio appointed more consistency on days 2 and 3 than on days 1 and 2 (i.e., 18 metrics presented lower CV_{TE} while 11 presented higher). The between-group comparisons showed that combat fighters demonstrated a superior number of metrics presenting lower CV_{TE} than physically actives (i.e., 24 comparisons favoring combat fighters against five for physically actives).

Table 2. Force-time metrics obtained during countermovement jump in combat fighters (CF) and physically active men (PA). Data are presented as mean (95% confidence intervals), and [n] describes the number of participants analyzed.

Metric	Group	Day 1	Day 2	Day 3
Unweighting phase				
Duration (ms)	PA	298 (221, 375)[21]	289 (241, 323)[18]	287 (207, 365)[21]
	CF	305 (262, 340)[21]	290 (255, 326)[20]	290 (252, 316)[20]
GRF_{PEAK} (N)	PA	199 (28, 395)[20]	155 (7, 315)[19]	185 (41, 394)[21]
	CF	114 (58, 204)[17]	83 (23, 138)[18] a	66 (30, 129)[18]
GRF_{MEAN} (N)	PA	468 (302, 660)[19]	450 (236, 635)[21]	424 (233, 578)[20]
	CF	410 (295, 505)[21]	392 (307, 483)[19]	390 (268, 495)[21]
Impulse (Ns)	PA	93 (48, 119)[19]	85 (59, 115)[19]	89 (56, 125)[20]
	CF	112 (90, 136)[21]	112 (88, 140)[20]	116 (91, 140)[21]
Braking phase				
Duration (ms)	PA	115 (98, 204)[21]	160 (98, 213)[21]	161 (98, 222)[20]
	CF	168 (138, 192)[19]	160 (130, 193)[20]	167 (130, 205)[20]
GRF_{PEAK} (N)	PA	1754 (1204, 2243)[19]	1780 (1276, 2342)[20]	1759 (1164, 2310)[20]
	CF	1913 (1503, 2318)[21]	1951 (1470, 2417)[21]	1931 (1489, 2287)[21]
GRF_{MEAN} (N)	PA	1285 (935, 1661)[20]	1297 (929, 1632)[20]	1273 (846, 1619)[20]
	CF	1415 (1160, 1724)[21]	1461 (1150, 1837)[21]	1448 (1185, 1766)[21]
Impulse (Ns)	PA	80 (43, 116)[20]	83 (57, 120)[20]	85 (49, 121)[20]
	CF	108 (86, 141)[21]	108 (82, 131)[20]	110 (87, 134)[21]
Propulsive phase				
Duration (ms)	PA	259 (200, 330)[20]	256 (160, 330)[21]	261 (170, 340)[21]
	CF	296 (241, 372)[21]	292 (252, 345)[19]	300 (277, 319)[17]
GRF_{PEAK} (N)	PA	1859 (1241, 2411)[19]	1887 (1343, 2438)[19]	1901 (1309, 2455)[20]

	CF	1937 (1479, 2360)[21]	1981 (1477, 2417)[21]	1962 (1495, 2294)[21]
GRF_{MEAN} (N)	PA	1505 (1029, 1987)[19]	1501 (1072, 2003)[19]	1524 (1095, 2044)[20]
	CF	1559 (1193, 1949)[21]	1578 (1200, 1972)[21]	1559 (1203, 1951)[21]
Impulse (Ns)	PA	195 (138, 254)[20]	197 (139, 254)[20]	203 (156, 257)[19]
	CF	222 (172, 270)[21]	225 (177, 271)[21]	228 (169, 272)[21]
Landing phase				
Duration (ms)	PA	270 (160, 370)[19]	242 (130, 350)[19]	233 (200, 270)[15]
	CF	325 (192, 444)[19]	377 (191, 687)[21]	411 (205, 743)[21]
GRF_{PEAK} (N)	PA	4072 (2032, 6308)[20]	3971 (1720, 6822)[21]	3956 (1849, 6391)[19]
	CF	3867 (1945, 5176)[19]	3805 (2027, 5557)[20]	3798 (2225, 5195)[20]
GRF_{MEAN} (N)	PA	1742 (970, 2557)[21]	1736 (924, 2444)[21]	1701 (891, 2598)[20]
	CF	1607 (1233, 1900)[19]	1621 (1175, 2059)[21]	1570 (1237, 1946)[19]
Impulse (Ns)	PA	238 (169, 325)[20]	238 (160, 324)[20]	245 (162, 324)[20]
	CF	288 (222, 344)[21]	293 (220, 369)[21]	294 (217, 353)[20]

[a] less than day 1 (p = .006; ES = 0.88).

Table 3. Intraclass Correlation Coefficient (ICC) and Coefficient of Variation (CV_{TE}) of force-time metrics obtained during countermovement jump in combat fighters (CF) and physically active men (PA). Data are presented as mean (95% confidence intervals).

Metric	Group	Days 1 and 2		Days 2 and 3	
		CV_{TE}	ICC	CV_{TE}	ICC
Unweighting phase					
Duration (ms)	PA	10.0 (7.5, 15.4) *	0.33 (-0.18, 0.69)	12.3 (9.1, 19.0)	0.19 (-0.32, 0.59)
	CF	6.7 (5.0, 9.9) #	0.34 (-0.12, 0.68)	6.1 (4.6, 9.0) #	0.28 (-0.18, 0.64)
GRF_{PEAK} (N)	PA	91.1 (63.1, 160.6) *	0.34 (-0.14, 0.68)	115.8 (78.8, 211.9)	0.06 (-0.42, 0.49)
	CF	33.0 (23.7, 54.4) *#	0.44 (-0.04, 0.76)	56.7 (40.1, 96.1) #	-0.11 (-0.54, 0.37)
GRF_{MEAN} (N)	PA	30.6 (22.3, 48.3)	-0.23 (-0.65, 0.26)	26.4 (19.5, 40.7) *	0.13 (-0.33, 0.53)
	CF	19.4 (14.3, 29.9) *#	-0.24 (-0.66, 0.25)	22.6 (16.7, 35.2) #	-0.41 (-0.77,-0.05)
Impulse (Ns)	PA	15.2 (11.3, 23.3)	0.58 (0.18, 0.81)	11.1 (8.3, 16.9) *	0.79 (0.54, 0.91)
	CF	8.1 (6.1, 12.3) #	0.66 (0.29, 0.85)	6.8 (5.1, 10.3) *#	0.77 (0.50, 0.90)
Braking phase					
Duration (ms)	PA	7.0 (5.3, 10.2) *#	0.91 (0.79, 0.96)	16.3 (12.1, 24.7)	0.52 (0.11, 0.78)
	CF	8.4 (6.3, 12.6)	0.51 (0.08, 0.78)	6.9 (5.2, 10.3) *#	0.71 (0.40, 0.87)
GRF_{PEAK} (N)	PA	21.8 (16.0, 33.8)	-0.21 (-0.62, 0.27)	6.6 (5.0, 9.7) *	0.90 (0.77, 0.96)
	CF	**4.0 (3.0, 5.8) #**	**0.94 (0.86, 0.98)**	**2.8 (2.2, 4.1) *#**	**0.97 (0.93, 0.99)**
GRF_{MEAN} (N)	PA	6.1 (4.6, 9.1)	0.87 (0.70, 0.95)	4.3 (3.2, 6.3) *	0.95 (0.87, 0.98)
	CF	**4.5 (3.4, 6.5) #**	**0.89 (0.76, 0.96)**	**3.0 (2.3, 4.3) *#**	**0.95 (0.89, 0.98)**
Impulse (Ns)	PA	15.1 (11.3, 22.8)	0.66 (0.33, 0.85)	7.8 (5.9, 11.6) *	0.90 (0.78, 0.96)
	CF	8.6 (6.4, 12.7) #	0.63 (0.27, 0.83)	6.9 (5.3, 10.3) *	0.77 (0.51, 0.90)
Propulsive phase					
Duration (ms)	PA	18.9 (14.1, 26.8)	-0.13 (-0.55, 0.33)	5.8 (4.4, 8.5) *	0.91 (0.80, 0.96)
	CF	10.5 (7.9, 16.0) #	0.05 (-0.44, 0.49)	5.6 (4.2, 8.7) *	0.34 (-0.17, 0.69)
GRF_{PEAK} (N)	PA	5.4 (4.0, 8.0) *	0.93 (0.83, 0.97)	22.8 (16.8, 35.5)	-0.14 (-0.56, 0.33)
	CF	**3.5 (2.7, 5.1) #**	**0.95 (0.89, 0.98)**	**2.8 (2.1, 4.0) *#**	**0.97 (0.93, 0.99)**
GRF_{MEAN} (N)	PA	3.8 (2.9, 5.7) *	0.96 (0.90, 0.98)	19.2 (14.2, 29.7)	0.03 (-0.44, 0.46)
	CF	**3.3 (2.5, 4.8)**	**0.95 (0.89, 0.98)**	**2.8 (2.1, 4.0) *#**	**0.97 (0.92, 0.99)**

Impulse (Ns)	PA	2.6 (1.9, 3.8) *#	0.97 (0.94, 0.99)	10.9 (8.1, 16.6)	0.59 (0.20, 0.81)
	CF	**3.4 (2.6, 5.0)**	**0.93 (0.83, 0.97)**	**3.9 (2.9, 5.6) #**	**0.91 (0.81, 0.96)**
Landing phase					
Duration (ms)	PA	23.3 (17.2, 36.4) #	0.09 (-0.37, 0.52)	19.2 (13.7, 31.9) *	0.04 (-0.55, 0.52)
	CF	31.4 (22.9, 49.7)	0.14 (-0.36, 0.55)	15.1 (12.0, 23.8) *#	0.82 (0.61, 0.92)
GRF_{PEAK} (N)	PA	33.8 (24.8, 53.0)	0.33 (-0.13, 0.67)	25.5 (18.7, 39.9) *	0.59 (0.20, 0.82)
	CF	27.5 (20.1, 43.2) #	0.05 (-0.42, 0.49)	11.9 (0.9, 17.9) *#	0.83 (0.61, 0.93)
GRF_{MEAN} (N)	PA	8.1 (6.1, 11.9) *#	0.92 (0.82, 0.97)	32.6 (23.9, 51.0)	0.03 (-0.42, 0.46)
	CF	12.1 (9.0, 18.5)	0.26 (-0.23, 0.64)	12.1 (9.0, 18.4) #	0.29 (-0.19, 0.65)
Impulse (Ns)	**PA**	**4.4 (3.3, 6.6) ***	**0.95 (0.88, 0.98)**	**6.3 (4.7, 9.6) #**	**0.89 (0.75, 0.95)**
	CF	3.1 (2.4, 4.6) *#	0.94 (0.86, 0.97)	12.3 (9.2, 18.4)	0.31 (-0.15, 0.65)

GRF = ground reaction force. **Bold numbers** identify consistency. A substantial difference was defined as a CV ratio < 0.87. Symbols stand for less CV_{TE} for *trials and #groups.

DISCUSSION

We investigated the consistency of the duration, GRF, and net impulse produced during the unweighting, braking, propulsive, and landing phases of the CMJ in combat fighters and physically active men. Our study design considered three testing days allowing two pairwise comparisons (days 1 vs. 2 and days 2 vs. 3) and the comparisons between two groups with a distinct training background, where the physically actives served as a control. Our results demonstrated that from 32 metrics investigated, six metrics (5 from combat fighters) were considered consistent on days 1 - 2 and days 2 - 3. Four other metrics reached acceptable scores only on days 1 - 2, while three were only on days 2 - 3. Furthermore, adding a third testing day substantially reduced the typical error in 7 out of 8 metrics of the braking phase (Table 3).

We hypothesized that GRF (peak and mean) and net propulsive impulse (usually converted to jump height applying the impulse-momentum theorem) would be more consistent than phase durations related to movement strategy. Our hypothesis was partially confirmed with the combat fighters showing consistent GRF_{PEAK} and GRF_{MEAN} on braking and propulsive as well as the net propulsive impulse. At the same time, the physically actives were less consistent in these metrics, which follows our second hypothesis that combat fighters would be more consistent than physically actives. Previous studies support that individuals with superior training backgrounds may demonstrate more consistency (18,60). Furthermore, we hypothesized that adding a third testing day would improve performance consistency since some learning could be expected from the previous trial. However, our results showed no systematic changes in the mean of almost all metrics of both groups (Table 2), and 11 metrics showed a higher typical error on days 2 - 3 than on days 1 - 2.

Although several metrics can be readily obtained from CMJ phases, our results suggest that more attention should be given to data consistency. We observed inconsistent results from the unweighting phase for both groups. This result corroborates with a previous study (61) reporting CV ranging from 19 to 40% in the unweighting. Furthermore, even metrics obtained from braking and propulsive phases, which indicated more consistent results, should be seen carefully since some inconsistencies were found. We and others (14,61) have observed that metrics related to jumping strategy are less consistent, indicating between days changes in jumping strategy while keeping jumping output consistent. It is important to note that our testing procedure focused on jump height consistency (jump height within 1 cm variation) since jump height is usually the metric of primary interest. Our results suggest that more than this approach is needed for other metrics beyond jump height. A previous study demonstrated that individuals might maintain the jump height output while adopting different strategies (e.g., expending a longer time to perform the countermovement) under symptoms of high-intensity exercise-induced fatigue (12). Therefore, our findings suggest that the protocol applied in the current investigation needs to be revised for those interested in monitoring time-based metrics (e.g., phase durations). Further studies might find better consistency in performing "real-time" monitoring of the metrics of interest. For example, suppose the metric of interest is the propulsion duration, related to neuromuscular fatigue (3). In that case, its variability (e.g., change in mean or coefficient of variation) should be monitored during the testing. In this case, we also recommend monitoring countermovement depth since the athlete may perform a deeper squat (i.e., negative displacement) in the countermovement, resulting in a longer propulsion duration. We also might suggest that the verbal instruction should be more phase-specific. Previous literature (33) has indicated that maximal force and the rate of force (force over time) should not be measured in the same trial since verbal instruction may influence metrics magnitude. Furthermore, a recent study (25) demonstrated that verbal cues might affect the magnitude of phase-specific jump variables (e.g., braking time and force) in recreationally active individuals. Taking it together, we recommend that practitioners consider performing two separate jump tests with foci of attention on specific phases of the jump when interested in both jump output and time-related metrics.

To our knowledge, this is the first study investigating the consistency of metrics obtained during the CMJ landing phase. Our results partially agreed with a previous study (28), demonstrating consistent impulse and net mean force while reporting inconsistent landing duration. However, an interesting result was that the physically actives demonstrated consistent landing impulses, while combat fighters only demonstrated it on days 1 - 2. We might speculate that physically actives had to put less effort into the landing to stabilize their center of mass since they jumped on average 5 cm less (↓ 11%) and had 3 kg less (↓ 4%) body mass than combat fighters. Although we did not aim to compare the jump mechanics between phases, we noticed that the magnitude of the landing impulse is slightly greater on landing (238 - 288 Ns) than on the propulsive phase (195 - 222 Ns). This difference may be related to the way the landing impulse was measured. The landing phase integration was ended when the center of mass acceleration first crossed zero, but integration drift or any change in strain gages properties might have occurred. Although this issue may have affected the magnitude of the landing impulse, it did not affect our results since it would have affected both groups equally during the three testing days.

Although this study provides some relevant information about consistency of metrics obtained from key phases of the CMJ in combat fighters and physically active men, it is not free of limitations. Three testing days were insufficient to produce acceptable scores for several force-time metrics. Therefore, more testing days may have been required until our study participants reach consistency. However, requiring a participant to stay away from their exercise routine is challenging, so we only included three testing days in the present study, completed in one or two weeks. Although we have applied the forward dynamics on force-time recordings to identify CMJ phases, we did not investigate other relevant metrics that could be derived from velocity-time and displacement-time curves. Our decision considered that force-time is the primary data captured from a force platform and would be unappropriated to derive data from a source whose data quality was a priori unknown.

In conclusion, our results indicate that combat fighters (i.e., developmental athletes) are more consistent during the braking and propulsive phases of the CMJ than physically active men. Force-time metrics of the CMJ related to the jumping strategy (e.g., phase duration) are less consistent than driven forces and jump output metrics, probably because our participants changed their jump strategy. Adding a third testing day may improve performance consistency, especially from the braking phase.

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