

Reactive strength index-modified: reliability, between group comparison, and relationship between its associated variables

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ABSTRACT: To investigate and compare the reliability of reactive strength index-modified (RSImod) and its associated variables (jump height [JH] and [time to take-off]) 20 combat fighters and 18 physically active men participated in this study. They visited the laboratory three times; firstly, for jump familiarization and two sessions for test-retest (2–7 days apart). For both groups, the between-day changes in performance were trivial to small ($\leq 1.1\%$). The coefficient of variation (CV) comparisons (*i.e.* CV ratio) demonstrated that combat athletes had a lower test-retest variation for RSImod (0.87) and JH (0.80) than non-athletes. Combat athletes demonstrated a greater JH than physically active men (0.43 vs 0.37; $p = 0.03$, $g = 0.73$), but small and non-significant differences were observed for RSImod (0.60 vs 0.55; $p = 0.24$, $g = 0.38$) and TTT (0.70 vs 0.72; $p = 0.32$, $g = 0.33$). RSImod was more positively correlated with JH ($r = 0.75$ – 0.87 ; $p < 0.001$) than negatively correlated with TTT ($r = 0.45$ – 0.54 ; $p < 0.001$). This study suggests that RSImod is a reliable variable obtained during CMJ testing in combat athletes and physically active men, with scores being slightly better for combat athletes. In terms of performance, combat athletes jumped higher than physically active men, but no differences in RSImod or TTT were observed. Lastly, RSImod was more strongly related to JH than TTT, and this was more evident in athletes than nonathletes. This indicates that the combat athletes were able to better utilize their (equal) time spent jumping (higher), possibly via greater utilization of the stretch shortening cycle, faster or more optimal motor unit recruitment, or an array of other factors.

CITATION: Vieira A, Tufano JJ. Reactive strength index-modified: reliability, between group comparison, and relationship between its associated variables. *Biol Sport*. 2021;38(3):451–457.

Received: 2020-07-07; Reviewed: 2020-07-30; Re-submitted: 2020-08-07; Accepted: 2020-09-25; Published: 2020-11-04.

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Key words:

Combat fighters
Countermovement jump
Jump performance
Stretch-shortening cycle
Test-retest reliability

INTRODUCTION

The countermovement jump (CMJ) is one of the simplest and most prevalent performance tests used in practice and in research. It provides valuable information relating to general lower limb neuromuscular capabilities, which is highly useful for training assessment, prescription, and monitoring [1,2]. Specifically, jump height (JH) is one of the most measured and reported variables since it directly provides relevant information for sports in which jumping or reaching are required (*e.g.* basketball, volleyball, soccer). Although simply measuring the JH from a single CMJ is worthwhile, athletes rarely have ample time to perform a maximal-effort CMJ from a static position [3]. As such, the ability to quickly develop force to jump during competition may be limited by the short period of time in which athletes have to initiate these movements. In these cases, athletes may apply different jumping strategies (*e.g.* reduced and/or quicker countermovement). Therefore, combining JH alongside time-sensitive variables (*e.g.* movement time) would likely improve the quality of information obtained from CMJ tests.

The reactive strength index (RSI) obtained during a CMJ (RSI-modified, hereafter RSImod) is the ratio between JH and movement

time, hereafter referred to as time to take off (TTT) (*i.e.* jump initiation to take-off) [4]. Since RSImod encompasses both JH and TTT, which is a time metric related to jump strategy (TTT), it has been considered a primary variable of interest obtained from CMJ tests [5]. Furthermore, RSImod may provide valuable information for athletic and non-athletic populations since the neuromuscular ability to produce a substantial level of force in a short period of time has been advocated as important to prevent falls, for instance, in elderly individuals [6].

Some studies have reported that RSImod is a valid measure of performance that is able to distinguish athletes of different competitive levels [3, 7, 8]. Several others have reported that RSImod can be a reliable measure obtained from CMJ tests [4, 9–14]. Primarily, these studies have been conducted in collegiate athletes of team sports such as soccer, volleyball, baseball and rugby [4, 9–14]. However, only few studies have been conducted in non-athletic populations [15] or in combat fighters [3]. Furthermore, athletes from different sport modalities may exhibit large differences in RSImod and its associated variables [10, 16].

Combat fighters are often required to quickly produce a substantial amount of force while punching and kicking, without giving their opponents an opportunity to defend or counter their attack. As such, the amount of time they can afford from initiating to completing a movement is often minimal, which can require combat athletes to reduce preparatory movement (*i.e.* countermovement). For this reason, RSI_{mod} seems to be an informative metric about neuromuscular function that could be useful to more effectively monitor combat fighters. To the best of the author's knowledge, only one study has investigated RSI_{mod} in combat athletes [3]. James et al. [3] demonstrated that athletes of higher competitive level present superior RSI_{mod} than athletes of lower competitive caliber, but this difference was only explained by a greater jump height, since no difference ($p = 0.17$) was observed in TTT. Furthermore, it is lacking evidence that this measure can be reliable in combat athletes as well as in non-athletic populations (*e.g.* physically active individuals). By monitoring RSI_{mod}, researchers, coaches and exercise enthusiasts could be provided with an indication of the individual reactive strength, explosiveness, and ability to use the stretch-shortening cycle [7, 15], improving the ability to prescribe and monitor training effects.

Therefore, the main purpose of this study is to verify and compare the test-retest reliability of RSI_{mod} and its associated variables (*i.e.* JH and TTT) in combat athletes and physically active men. A secondary purpose of this study is to compare RSI_{mod}, JH, and TTT between combat athletes and physically active men. A tertiary purpose of this study is to examine which of its constituent variables (JH and TTT) express a stronger relationship with RSI_{mod} and whether this may be different between athletes and non-athletes. It was hypothesized that athletes would demonstrate superior values of RSI_{mod} than physically active men. It was also hypothesized that athletes would demonstrate better scores of reliability in all measured variables, and that they might show some difference in the strength of the relationship of RSI_{mod} with its constituent variables.

MATERIALS AND METHODS

Participants

Thirty-eight males participated in this study: combat fighters ($n = 20$) and physically active males ($n = 18$) (demographics in Table 1). The sample size was established using GPower® software considering the following assumptions: combat fighters would have greater performance than physically active men ($d = 1.19$, when comparing the impulse produced during CMJ by athletes and non-athletes) [18]; and $\alpha = 0.05$; power ($1-\beta$) = 0.90. These assumptions indicated that a sample size of at least 32 individuals would reach sufficient power to avoid type II error.

The inclusion criteria adopted for combat fighters required that they were engaged in any modality of combat sport at least three days per week for a minimum of two years. This sample included eight Brazilian jiu-jitsu, five karate, three taekwondo, two wrestling, and two judo athletes. The inclusion criteria for physically active men (*i.e.* non-athletes) required that they were engaged in at least 75 min-

utes of vigorous activity three days per week or 150 minutes of moderate intensity aerobic activities five days per week. The sample of the participants filled out the IPAQ Questionnaire, which verified that 67% of them were classified as highly active and the remaining 33% as moderately active. All participants were free from any chronic diseases or injuries that could compromise jump performance. They were instructed to avoid any vigorous exercise 48 hours before testing days and were informed about the risks and benefits of the research. The study was performed in accordance with the ethical standards of the Helsinki Declaration and that the participants signed an informed consent form. The research was approved by the local Ethical Committee (number 2.878.364).

Table 1. Participant characteristics

Variable	Combat Fighters	Physically Active	<i>p</i> -value
Age (years)	25.1 ± 5.2	21.5 ± 2.0	0.01
Body mass (kg)	79.5 ± 10.4	76.6 ± 17.1	0.53
Height (cm)	177 ± 4.7	176 ± 8.9	0.68
BMI (kg·m ⁻²)	25.4 ± 3.2	24.6 ± 3.9	0.48

Data are reported as mean ± SD. BMI, body mass index.

Study design

The participants visited the laboratory three times. The first session served as a familiarization session where participants performed as many practice trials as needed, filled out the forms (*e.g.* health and IPAQ questionnaires), and completed height and body mass measurements. In the following two sessions, CMJ data collection occurred (test-retest design) under the supervision of a single rater. Testing was performed at the same time of day (± 1 hour), and the interval between each visit was 2–7 days.

Jump test

Before testing, the participants performed a warm-up, including a series of barbell squats on a Smith machine with 50% of body mass, and five CMJs with progressive levels of effort (20, 40, 60, 80 and 100% of maximal perceived jumping). Participants stood still on a force platform for approximately three seconds and performed the CMJ with hands akimbo after hearing the verbal command “3, 2, 1, jump”. The initial period of data collection was used for body weight determination (vertical force averaged over 1-s). Participants were free to choose the depth of the countermovement, but they were

instructed to minimize the duration of transition between the descending and ascending phases of the jump. They were instructed to jump “as fast and as high as possible”. Participants performed four CMJs (1-min apart) with maximal effort, and the highest jump was used in the subsequent analyses.

Data processing

Jumps were performed on a force platform (AMTI, Accupower Portable Force Plate, Watertown, MA, EUA) sampling at 1000 Hz. Force-time characteristics of the CMJ was analyzed in a custom-made spreadsheet (Microsoft Excel) [19]. The reactive strength index-modified (RSImod) and its associated variables (jump height [JH] and time to take-off [TTT]) were calculated as following: $RSImod = JH \div TTT$; $JH = v^2/2g$, where v = vertical velocity at take-off and g = gravitational acceleration; and TTT = movement duration, which includes the entire countermovement unweighting phase, braking, and propulsive phase of the CMJ jump [19, 20]. The vertical velocity was determined by integrating the vertical acceleration and time, whereas TTT identified as the time lapse between the start and the end of movement (*i.e.* instant of take-off) both using the well-established recommendation of five standard deviations from body weight minus 30 ms as the threshold [20].

Statistical analyses

Data normality was verified by the Shapiro-Wilk test. Then the mean and 95% confidence intervals were used to report RSImod and its associated variables. Percentage change in performance ($\Delta\%$) and within-participant coefficient of variation (CV) were described as median and interquartile ranges since these variables were not nor-

mally distributed. The student’s t-test for paired samples was used to identify potential systematic error in the test-retest measurements. Effect sizes (ES) for repeated measures designs were used to express the magnitude of the differences, and the intraclass correlation coefficient (ICC2,1) was determined for relative reliability [21, 22], while the within-participant CV and the typical error (TE) for absolute reliability [23, 24]. The CV comparisons were performed by using the CV ratio (CV ratio = CV from combat fighters \div CV from physically active), and the CV ratio was established as important only when equal to or less than 0.87 [24]. In addition, independent samples t-tests were performed, and Hedges’ g were calculated to measure the magnitude of the between-group differences. Pearson’s r was used to measure the linear correlation between RSImod and its associated variables; magnitudes of correlations of < 0.1 , $0.1-0.3$, $0.3-0.5$, $0.5-0.7$, $0.7-0.9$, > 0.9 are interpreted qualitatively as trivial, small, moderate, large, very large, and almost perfect correlations, respectively. The Statistical Package for the Social Sciences (SPSS version 23.0) was used for statistical analyses, while a custom-made spreadsheet (Microsoft Excel) was used for within-participant CV (SD \div mean) and TE calculations.

RESULTS

As shown in Table 1, combat fighters were 3.6 years older than physically actives, on average, but no other significant differences were observed in participants’ characteristics.

The test-retest reliability of RSImod, JH, and TTT in both groups are presented in Table 2 and Figure 1. The between-day changes in performance were trivial to small ($\Delta\% \leq 1.1\%$, $ES \leq 0.3$) and non-significant ($p \geq 0.25$). ICC values ranged from 0.49 to 0.83, which

TABLE II. Test-retest reliability of reactive strength index-modified (RSImod) and its associated variables in combat athletes and physically active men

Variables	Groups	Day 1	Day 2	$\Delta\%$	CV	ICC	TE	SWC	p-value	ES
RSImod (ratio)	Combat athletes	0.59 (0.54, 0.63)	0.60 (0.55, 0.64)	1.09 (10.99)	5.40 (9.43)	0.69 (0.36, 0.86)	0.05	0.02	0.53	0.15 (-0.47, 0.77)
	Physically active	0.54 (0.48, 0.60)	0.55 (0.49, 0.62)	0.50 (12.44)	6.74 (9.72)	0.64 (0.26, 0.85)	0.07	0.03	0.52	0.17 (-0.49, 0.82)
Jump height (m)	Combat athletes	0.42 (0.40, 0.44)	0.43 (0.40, 0.46)	1.02 (5.62)	4.29 (6.87)	0.71 (0.42, 0.88)	0.03	0.01	0.25	0.30 (-0.32, 0.92)
	Physically active	0.37 (0.33, 0.40)	0.38 (0.35, 0.42)	0.31 (5.87)	4.92 (5.02)	0.62 (0.25, 0.84)	0.04	0.01	0.33	0.24 (-0.41, 0.90)
TTT (s)	Combat athletes	0.72 (0.69, 0.75)	0.72 (0.70, 0.75)	0.40 (5.75)	3.35 (4.83)	0.49 (0.06, 0.76)	0.05	0.01	0.75	0.08 (-0.55, 0.70)
	Physically active	0.69 (0.64, 0.74)	0.70 (0.65, 0.75)	0.90 (7.71)	3.74 (5.87)	0.83 (0.59, 0.93)	0.04	0.02	0.64	0.12 (-0.54, 0.77)

Data are presented as mean and 95% confidence interval, except $\Delta\%$ and CV which are presented as median and interquartile range; TTT, time to take-off; $\Delta\%$ change in percentage; CV, within-participant coefficient of variation; ICC, intra-class correlation coefficient; TE, typical error; SWC, smallest worthwhile chance; ES, effect size.

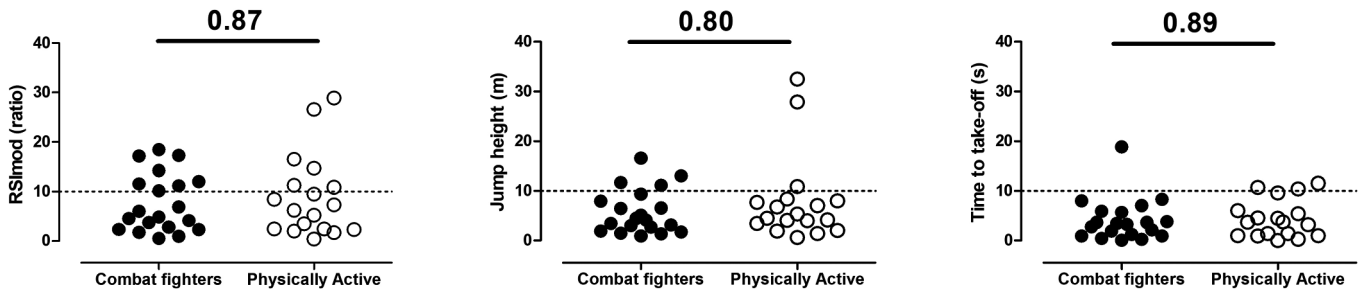


FIG. 1. Individual data for coefficient of variation (%) of jump performance variables in combat athletes and physically active men. The comparison (i.e. CV ratio = CV from combat fighters ÷ CV from physically active) values are presented above each variable.

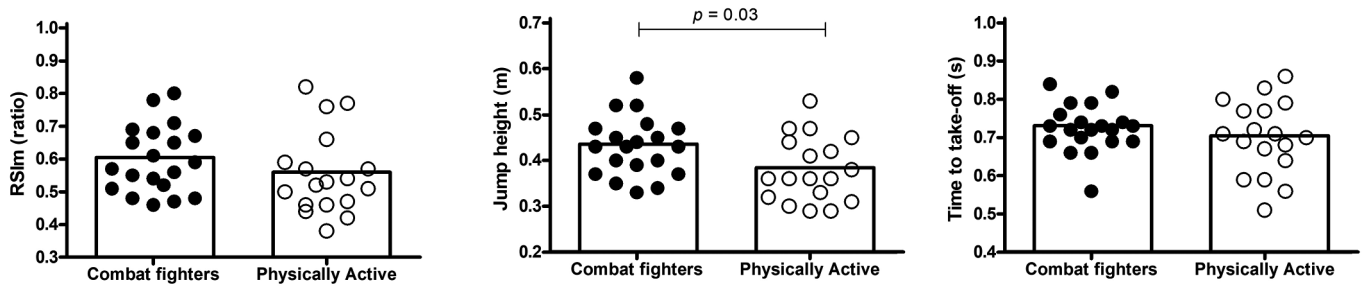


FIG. 2. Mean (bars) and individual data for comparisons between reactive strength index-modified (RSImod), jump height and time to take-off in combat fighter athletes and physically active men.

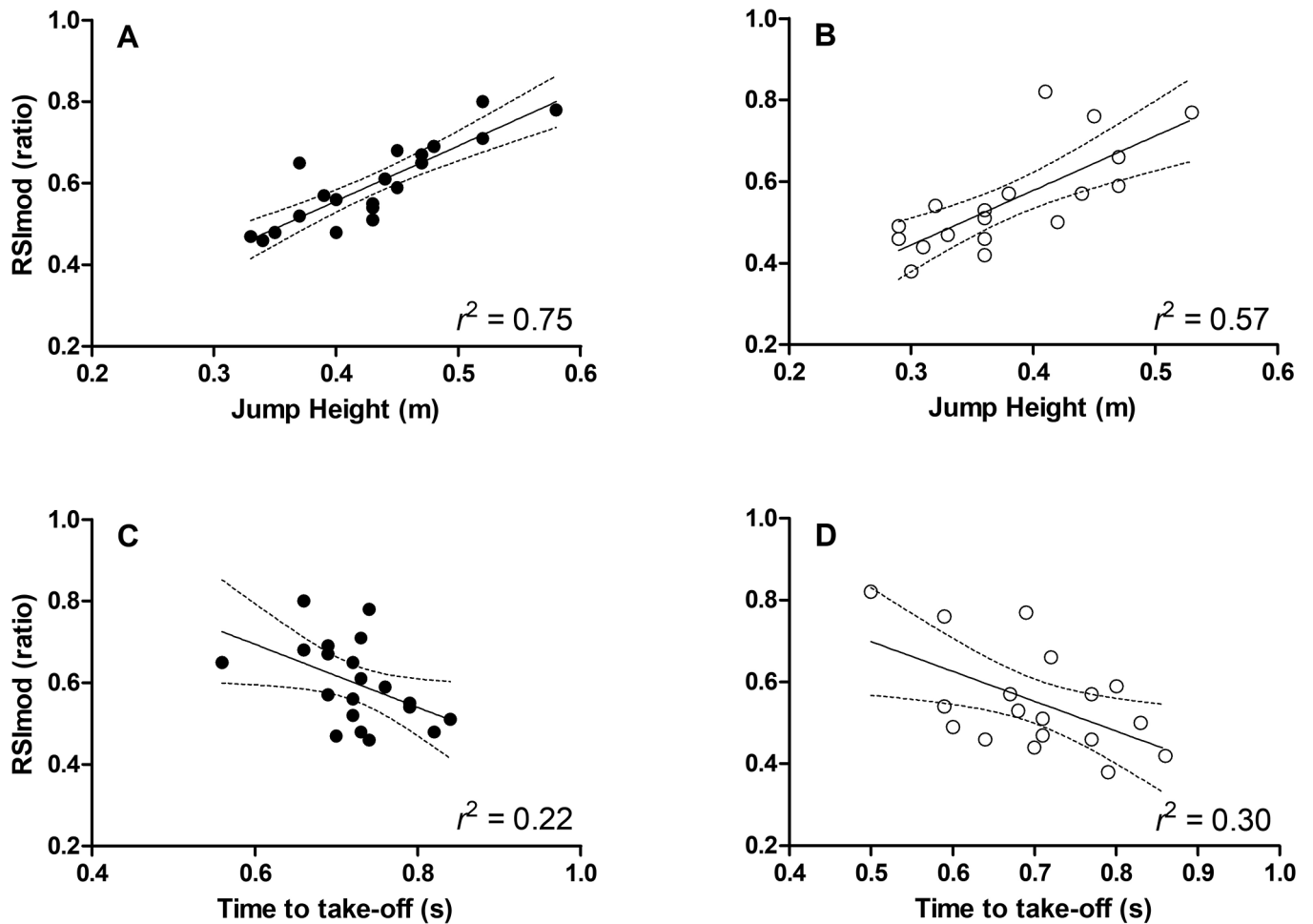


FIG. 3. Pearson correlations between reactive strength index-modified (RSImod) and jump height (A and B), and between RSI mod and time to take-off (C and D) in combat fighters (●) and physically active men (○).

can be considered as moderate to very large. The CV comparisons (*i.e.* CV ratio) demonstrated that combat athletes had a lower test-retest variation for RSI_{mod} (0.87) and JH (0.80) than non-athletes (Figure 1).

The comparisons of RSI_{mod}, JH, and TTT are shown in Figure 2. Combat fighters demonstrated a greater JH than physically active men ($p = 0.03$, $g = 0.73$), but small and non-significant differences were observed for RSI_{mod} ($p = 0.24$, $g = 0.38$) and TTT ($p = 0.32$, $g = 0.33$).

In addition, RSI_{mod} was more positively correlated (very large) with JH ($r = 0.75$ to 0.87 ; $p < 0.001$) than negatively correlated (moderate and large for combat fighters and physically actives, respectively) with TTT ($r = 0.45$ to 0.54 ; $p < 0.001$) (Figure 3).

DISCUSSION

This study investigated the test-retest reliability of RSI_{mod} and its associated variables (*i.e.* JH and TTT), compared the obtained values between combat athletes and physically active men, and tested the strength of the relationship between RSI_{mod} and its variables. First, RSI_{mod}, JH, and TTT may be considered reliable variables obtained from CMJ performance since non-significant changes ($\leq 1.1\%$; $p \geq 0.25$; $ES \leq 0.3$) and acceptable CVs ($\leq 6.7\%$) were observed. It also seemed that combat athletes demonstrated lower CV for RSI_{mod} and JH than physically active men. Second, the between-group comparisons revealed that combat athletes jumped higher than physically active men (0.43 vs 0.38 m, $p = 0.03$, $ES = 0.73$), but no other significant differences were observed. Finally, RSI_{mod} was more related to JH than TTT, and this relationship was more evident for combat fighters (75% vs 57%), which is a unique finding to this study.

The present results partially corroborate with previous studies indicating that RSI_{mod} and its constituent variables might reach acceptable levels of test-retest reliability, which have been arbitrarily advocated as $ICC > 0.7$ and $CV < 10\%$ [7, 13, 14]. In the present study, all variables for both groups presented $CV < 10\%$ (for JH and TTT were $< 5\%$), but only JH for combat fighters and TTT for physically actives presented $ICC > 0.70$. In this regard, some points need to be highlighted. First, RSI_{mod} is a constitute variable sharing variance from the other two variables (JH and TTT). Thus, it may explain the higher CV for RSI_{mod} (5.4 and 6.7%) compared to JH (4.3 and 4.9%) and TTT (3.4 and 3.7%) independently. Second, for a variable be considerate reliable and meaningful, other scores of reliability beyond ICC and CV are required [11, 23]. While the vast majority of studies have presented solely ICC and CV to represent reliability [7–9, 15, 16, 26, 27], this study presents several scores of reliability from RSI_{mod} in both combat athletes and nonathletes.

It is important to note that ICC values may vary substantially depending on which version is used and also depending on the sample of participants. It is well known that a heterogeneous sample of participants may lead to an artificially high ICC [28]. Thus, it is not uncommon to observe high ICC values (> 0.90) when a heter-

ogenous sample of individuals (sometimes including both males and females) are reported [26, 29]. The ICC values in the present study ranged from 0.49 to 0.83, which may be considered inferior to the ICC values reported in other studies [26, 29]. However, this may be the result of the more homogenous sample of individuals included in the present study. Taking our TTT results as example, it can be noted that despite the similar results of reliability between combat athletes and physically active males (Table 1), the ICC values were higher for the physically active males than the combat athletes (0.83 versus 0.49) despite the sample of combat athletes being a bit more homogenous (95%CI = 0.69 to 0.75 s) than the physically active men (95%CI = 0.64 to 0.75 s).

The present study also examined single-measures ICC, which might present inferior values when compared to the average-measures expressed in other studies. It also worth mentioning that expressing CV for reliability allows for the changes in the target variable to be compared with the expected error, but CV does not provide information regarding the meaningfulness of the change [13]. Thus, a practitioner needs to know if the error of the measurement allows one to detect the smallest worthwhile change (SWC) in a specific group of individuals. In other words, it is required that a variable demonstrate a $TE < \text{the SWC}$ to increase the likelihood to detect a change [30]. The present study did not demonstrate TE lower than the SWC for any of the assessed variables or either of the groups, meaning that although the data were reliable, only moderate to large changes in performance can be detected [23]. To date, only a single study has included (beyond ICC and CV) both TE and SWC values for RSI_{mod}. Hershman et al. [29] assessed the test-retest reliability of 22 collegiate basketball players (men = 14 and women = 8). Interestingly, the authors reported that RSI_{mod} and its constituent variables demonstrated $TE < \text{SWC}$, while the CV values were slightly worse (10.4%, 5.4%, and 8.5% for RSI_{mod}, JH and TTT, respectively) than those observed in the present study. The discrepancy between the results of the present study and Hershman's study is probably due a more heterogeneous sample of participants in their study, since they recruited both male and female athletes. Since the SWC is the product of the between-subjects SD $\times 0.2$, a more heterogeneous sample of participants would theoretically provide a higher SWC. These results highlight that a variable may exhibit a high CV, but depending on the sample of participants, it would still be able to detect small changes in performance and vice-versa (*i.e.* a variable with low CV may not be able to detect small changes). Thus, a reliability study should report scores that allow the reader to observe both data reliability and its potential applications in practice.

The present study demonstrated that combat athletes presented less variation in RSI and JH compared to the physically active men. This result is in agreement with a previous study suggesting that athletes could demonstrate 30% less CV than non-athletes [31]. Furthermore, the present results may suggest that a single familiarization session is sufficient to reach an acceptable level of variance for the whole sample of participants (*i.e.* no between-days differ-

ences were found, $p \geq 0.25$). However, data from Figure 1 suggest that some individuals may require more than one session to be familiarized, which seems to be more evident for the RSI_{mod} in the physically active individuals. Thus, future studies using RSI_{mod}, especially in non-athletic populations, may find better results after applying more than a single familiarization session for those individuals exhibiting a large CV ($> 10\%$).

The between-group comparisons demonstrated a small, but non-significant difference in RSI_{mod} (0.60 vs 0.55, $p = 0.24$, ES = 0.38). Some potential reasons may explain this unexpected result. The combat athletes jumped higher (0.43 vs 0.38 m, $p = 0.03$, ES = 0.73) without significantly extending the TTT compared to physically active men (0.72 vs 0.70 s, $p = 0.32$, ES = 0.33). It also can be observed that athletes were ~ 3 kg heavier than the physically active males ($p = 0.53$, ES = 0.21). Although the differences in TTT and body mass were not significant, it might have attenuated a possible between-group difference in RSI_{mod}. Previous studies also have demonstrated that athletes of superior competitive level were able to perform a higher jump with similar TTT [8, 26], which may also apply for studies comparing males and females [9, 16, 32]. For instance, Dos'Santos et al [26] compared 'stronger' with 'weaker' athletes of diverse modalities (e.g. rowing, soccer) and demonstrated that the stronger ones were able to jump higher (0.37 vs 0.29 m), while no difference in TTT was observed (0.71 vs 0.72 s). Similarly, Sole et al. [16] compared male ($n = 76$) and female ($n = 75$) collegiate athletes and demonstrated that male athletes jumped higher (0.36 vs 0.27 m), while TTT was similar between the genders (0.87 vs 0.87 s). In contrast, another study [3] found differences in both JH (0.51 vs 0.45 m) and TTT (0.82 vs 0.93 s) comparing combat athletes of higher versus lower competitive level. Similarly, others [7] found that professional rugby players performed shorter TTT (0.71 vs 0.82 s) than semi-professional players, but with similar JH (0.37 vs 0.36 m). All together, these studies highlight that RSI_{mod} and its constituent variables can provide a greater insight into one's neuromuscular capabilities, and reporting these variables separately may give an opportunity for a more individualized training prescription.

The present study investigated the strength of the relationship between RSI_{mod} and its constituent variables. Considering that RSI_{mod} is the quotient of JH over TTT, it would be easy to assume that both variables have equal contributions to RSI_{mod}. However, it was found that RSI_{mod} is more associated with JH than with TTT, and the strength of the association was greater for combat athletes (75%) than for physically active men (57%). Additionally, the association between RSI_{mod} with TTT was slightly stronger for physically active men (30% vs 22%). Although no significant between-group difference

was observed in RSI_{mod}, it could be noted that combat athletes had a greater mean value (0.60 vs 0.55, ES = 0.38). Previous studies have suggested that groups of individuals demonstrating superior RSI_{mod} rely more on JH than on TTT [8, 33]. Thus, it is possible that athletes jumped higher after performing a deeper countermovement (*i.e.* vertical displacement of their center of mass), but at a much faster pace than the physically active men, evidenced by similar TTT. According to this logic, the utilization of the stretch-shortening cycle may have favored the combat athletes, which would theoretically yield a greater take-off velocity and consequently, greater jump height.

Although the present study provides information regarding the reliability of RSI_{mod} and its constituent variables in both combat athletes and non-athletes, this study is not free from limitation. The sample of combat athletes included fighters from different modalities, and they were not distinguished by weight class. Therefore, future studies could examine the CMJ variables while considering athletes by modalities and weight class. Although acceptable scores of reliability were observed in both groups using data from a single jump (*i.e.* best jump performance), this may not be the best approach for managing the signal-to-noise ratio. Using the average between three or more trials will probably decrease TE, this increasing the likelihood of detecting small changes in performance such as those induced by training programs applied in highly trained individuals.

CONCLUSIONS

This study suggests that RSI_{mod} is a reliable variable obtained during CMJ tests in combat athletes and physically active men, with the scores being slightly better for the combat athletes than for non-athletes (*e.g.* lower CV). However, compared to RSI_{mod}, reliability scores were better for JH and TTT. In terms of performance, combat athletes jumped higher than physically active men, but no differences in RSI_{mod} or TTT were observed. Lastly, RSI_{mod} was more strongly related to JH than TTT, and this was more evident in the combat athletes than non-athletes. This indicates that the combat athletes were able to better utilize their (equal) time spent jumping (higher), possibly via greater utilization of the stretch shortening cycle, faster or more optimal motor unit recruitment, or an array of other factors.

Acknowledgements

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001.

Conflict of interest declaration

The authors have no conflicts of interest.

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