# A comparison of vertical and horizontal reactive strength index variants and association with change of direction performance

**Running head:** Reactive strength index variants.

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## ABSTRACT

This study sought to investigate the inter-relationship between different vertical and horizontal variants of reactive strength index (RSI) and change of direction performance. Thirty-one male volleyball players (age: 22.4 ± 3.9 years), performed bilateral drop jumps (DJ), bilateral and unilateral countermovement jumps (CMJ), and triple hops for distance. The RSI was calculated as the ratio of jump height and contact time (DJ), jump height and time to take off (CMJ), and flight time or hop distance and contact time (triple hop), and 505 change of direction test. RSI obtained from DJ and CMJ tasks exhibited excellent trial-to-trial reliability (ICC = 0.91-0.94), while triple hop based RSI had only moderate reliability (ICC = 0.67-0.74). The relationships among different RSI variants were moderate to high (i.e. DJ to CMJ: $r = 0.57$-$0.69$; $p \leq 0.004$; DJ to triple hop: $r = 0.54$-$0.66$; $p \leq 0.021$ and CMJ to triple hop: $r = 0.42$-$0.63$; $p \leq 0.037$). For the triple hop, the associations between RSI based on hop flight time and RSI based on hop distance were high for hop 1-2 ($r = 0.77$-$0.83$; $p < 0.001$) and very high for hop 2-3 ($r = 0.91$-$0.92$; $p < 0.001$). All RSI variants were in small to moderate negative correlation with 505 test performance ($r = -0.38$ to $-0.45$; $p \leq 0.042$). The agreement in inter-limb asymmetry direction between in RSI from unilateral CMJ and triple hop RSI variables was slight to moderate (Kappa coefficient = 0.06-0.36). In conclusion, although inter-relationships between RSI variants were moderate to high, the direction of inter-limb asymmetry was inconsistent, highlighting the notion of movement variability in limb dominance.



**Keywords:** explosiveness, agility, power, rapid strength, speed.

## INTRODUCTION

Reactive strength is the ability to rapidly and efficiently transition from an eccentric to a concentric muscle contraction in a stretch-shortening cycle (SSC) movement (42). The ability to use SSC during sprinting, jumping and change of direction (CoD) tasks is considered an important determinant of athletic performance (18,39). Reactive strength index (RSI), which is defined as the ratio between jump height and ground contact time, is used to assess vertical reactive strength and has been shown to be reliable both within (2,20,26,29) and between sessions (10). Moreover, RSI may be used to design individually tailored plyometric training (36). Recent studies have introduced a modified version of the RSI ($RSI_{mod}$), that can be used during the countermovement jump (CMJ), replacing the ground contact time by the time to take off (15,27,40). Similar to RSI, the $RSI_{mod}$ is considered a reliable measure (15,40) and is sensitive to sex (15,40) and sport differences (40). According to the classification suggested by Schmidtbleicher (38), the RSI in DJ is considered to represent fast SSC ability (as long as the ground contact is < 250 ms), whereas the $RSI_{mod}$ represents slow SSC ability. Therefore, coaches may use either (or both) depending on the physical demands of the sport.

A possible limitation of RSI and $RSI_{mod}$ is that they evaluate reactive strength only in the vertical direction, while horizontal movements, such as sprinting and CoDs are of paramount importance in many sports. For example, it has been shown that horizontal force production is the primary determinant of sprint acceleration (30). In addition, performance in horizontally directed movements (e.g., horizontal jumping) has shown greater associations with sprint performance compared to vertically directed movements (14). This evidence, together with insights from intervention studies (11), has led to the development of the force-vector theory. In short, it is postulated that vertical and horizontal exercises are more specific to vertical and horizontal sports skills, respectively (11). Therefore, current RSI and $RSI_{mod}$ measures could lack specificity to horizontal movements. The findings from studies evaluating force-velocity relationships indicate very limited relationship between horizontal and vertical force and velocity capacities (25). One study showed only a moderate correlation ($r = 0.53$) between RSI calculated from vertical and horizontal DJ (2). However, the reader should note that for the horizontal DJ condition, this still involved falling vertically from a box first. The evidence indicates a limited specificity of the vertical RSI for assessing reactive strength in the horizontal direction. In addition, RSI and $RSI_{mod}$ have recently been reported to share only 22% of common variance (28), which indicates they should not be used interchangeably.

With some exceptions (4,6), RSI and $RSI_{mod}$ have been evaluated mainly for bilateral tasks. However, when unilateral tests are used, they enable the calculation of inter-limb asymmetries whereby values ranging from 5-15% have been shown to be detrimental to jumping and sprinting performance (7,8,34). Moreover, specificity of adaptations following unilateral and bilateral exercises are well documented (32). It has been reported the kinetic and kinematic measures from unilateral jumps (horizontal and vertical CMJ and DJ) tend to have a stronger relationship to sprint performance than bilateral jumps (14). Thus, it would be logical to assume that RSI variants computed from unilateral tests (e.g., unilateral CMJ or DJ) would be more specific to unilateral tasks. Based on the abovementioned aspects of specificity, unilateral hops for distance could be suggested as a viable alternative to DJ and CMJ for calculating RSI. Triple hop distance has already been shown to be a reliable outcome (31). However, the potential to obtain additional information regarding reactive strength (by calculating the ratio between hop distances/flight times and contact times), remains largely unexplored. Recently, RSI derived from the unilateral triple hop test was suggested as an alternative metric that can be used to identify limb deficits during rehabilitation of anterior cruciate ligament injury rehabilitation

(22). A recent pilot study suggested high inter-session reliability and moderate to excellent within-session reliability for RSI during the triple hop test (13). The mean contact times (0.29-0.35 s) in the available studies (13,22) suggest that unilateral hops represent slower SSC actions compared to DJ (contact times < 0.25 s), but faster than CMJ (time to take off = 0.6-0.9 s; (27,35,40)). To this end, the inter-relationships between these different RSI variants has not been explored. A recent meta-analysis reported small to moderate associations between RSI in DJ and proxies of athletic performance (18), whereas such information seems to be lacking for $RSI_{mod}$ and triple hop RSI.

Therefore, the purpose of this study was: a) to explore the inter-relationships among RSI in DJ, bilateral and unilateral $RSI_{mod}$, and the RSI derived from the triple hop test, b) to assess the relationship between all RSI variants and proxies of sports performance (10-m linear sprint and 505 CoD tasks) and, c) to assess the agreement between unilateral $RSI_{mod}$ and horizontal hop RSI in relation to the direction of inter-limb asymmetry. We hypothesized that: a) the inter-relationships among the RSI variants will be moderate (2), b) horizontal and unilateral RSI variants will show greater associations with the proxies of sports performance compared to vertical and bilateral RSI variants (14) and, c) there will be a small or moderate agreement between unilateral $RSI_{mod}$ and horizontal hop RSI for the direction of inter-limb asymmetry (5).

## METHODS

### Experimental approach to the problem

This was a cross-sectional study, with all measurements conducted in a single visit. To study the inter-relationships between different RSI variants, we recruited 31 male volleyball players. Participants had been performing bilateral and unilateral hopping exercises as well as DJs and CMJs as part of their regular training and assessments. The participants performed a standardized warm-up, comprised of 10 min of self-pace jogging, 5 min of dynamic stretching and 5 min of bodyweight resistance exercises. Then, they completed assessments of vertical jumps on a force plate (DJ, bilateral CMJ, unilateral CMJ), triple hop test, and a CoD performance tests (505 test, with an additional 10m spring for CoD deficit calculation). The order of the tasks was randomized across participants. For all tasks, three trials were performed, and the average of the three trials was taken for further analysis.

### Subjects

For this study, we recruited 31 male volleyball players (age: 22.4 ± 3.9 years; body height: 188.5 ± 6.3 cm; body mass: 79.2 ± 6.9 kg). All the players have been competing in the national league and reported to be involved in regular volleyball training for 10.6 ± 4.0 years and to regularly perform full body resistance exercises at least twice a week. The subjects were also regularly performing various vertical and horizontal jumps as part of their training, including but not limited to CMJ, DJ, long jumps and repeated single-leg vertical and horizontal jumps. The exclusion criteria were the presence of musculoskeletal injuries in the previous 6 months. The participants were informed about the experimental procedures and were required to sign an informed consent before participating in the experiment. The experiment was approved by Republic of Slovenia National Medical Ethics Committee (approval no. 0120–99/2018/5) and was conducted in accordance to the latest revision of the Declaration of Helsinki.

## Procedures

### *Drop and Countermovement Jump Tests*

DJs and CMJs were performed on a piezoelectric force plate (Kistler, model 9260AA6, Winterthur, Switzerland). Ground reaction force data were recorded at sampling rate of 1000 Hz. Participants performed 3 warm-up trials for each jumping task at 50, 75 and 90 % of the perceived maximal effort. Each task was performed twice, with a 60-second rest between trials. The hands were placed on the hips at all times. For the DJ, the participants stood on a solid 40 cm high wooden box. This height was chosen as it was previously reported to elicit the most reliable RSI (26). The participants stepped off the box and performed a vertical jump immediately after the landing. They were instructed to try to achieve maximal jump height whilst minimizing the ground contact time, and to maintain upright posture. For the CMJ, the participants were instructed to start from the standing position and use an explosive countermovement to a self-selected depth and to jump as high as possible. Recent evidence shows that using a self-selected depth for CMJ results in more reliable $RSI_{mod}$ estimation compared to fixed depths (35). For the unilateral CMJ, the non-tested leg was slightly flexed at the knee and was not allowed to touch the tested leg. Performing the swing with the non-tested leg was not allowed. Both legs were tested unilaterally in an alternating order.

### *Triple Hop Test*

The participants also completed three repetitions of the triple hop test per leg in an alternating order, with 2 warm-up trials performed at 50 and 75 % of maximal self-perceived effort. The assessment was completed on a concrete floor, right next to line markers that were placed at every 5 cm. Participants started the test in unilateral stance, with their toes behind the start line, and hopped forward as far as possible repeatedly for three hops. The trials were filmed in slow-motion at 240 fps, using a smartphone (iPhone SE). Both legs were tested unilaterally in an alternating order.

*Change of Direction (CoD) Speed Test*

CoD performance was assessed by the means of 505 test, using laser timing gates (Brower Timing Systems, Draper, UT, USA), which were positioned at a height of 1-m. Briefly, the 505 test involves a 10-m sprint which is not recorded, an additional 5-m of sprinting, a 180° turn and further 5-m sprint. Three trials for each side were performed in an alternating order. According to the recent recommendations, CoD deficit was also calculated as the difference between 505 times and 10-m linear sprint time to obtain a more isolated measure of CoD ability (33). The 10-m sprints were recorded separately from the 505 test, using the same timing gates.

**Data processing and outcome measures**

The force signals were automatically processed by the manufacturer's software (MARS, Kistler, Winterthur, Switzerland) by a moving average filter with a 5 ms window. The jump heights for CMJ and DJ was calculated based on take-off velocity. For the DJ, contact times were also calculated, and subsequently, the RSI was calculated as the ratio between the jump height and the contact time. Ground contact time was defined as the time during which the force signal was > 10 N. For the bilateral and unilateral CMJs, we calculated the $RSI_{mod}$, by dividing the jump height by the time to take off (15). Time to take off was determined as the time between the countermovement initiation (defined as the decrease in force signal larger than 3 standard deviations of the baseline signal) and the take-off (defined as the first instant of force < 10 N). The trials were additionally inspected offline, and potential software errors in phase detection were manually corrected.

Video recordings of the triple hop were uploaded into a motion analysis software (Kinovea®, version 0.8.24). The timestamps at each touchdown and toe-off of each hop were determined manually using the software. Flight time and ground contact time for each hop were calculated from the number of frames between the timestamps and the recording frequency. In addition, hop distances were visually estimated to the nearest 1-cm. RSI was computed between hops 1-2 and hops 2-3 for each limb, once based on flight time (i.e., flight time divided by contact time) and once based on hop distance (i.e., hop distance divided by contact time). Thus, 4 different outcomes per leg were considered for further analysis: RSI based on flight time between hops 1 and 2 ($RSI\text{-}12_{FT}$) and between hops 2 and 3 ($RSI\text{-}23_{FT}$), as well as RSI based on hop distance between hops 1 and 2 ($RSI\text{-}12_{DIST}$) and between hops 2 and 3 ($RSI\text{-}23_{DIST}$).

**Statistical analysis**

Statistical analyses were done with SPSS (version 25.0, SPSS Inc., Chicago, USA). Descriptive statistics are reported as mean ± standard deviation. The normality of the data distribution was verified with Shapiro-Wilk tests. Trial-to-trial reliability was assessed with two-way random model intra-class correlation coefficients (ICC) for absolute agreement, with respective 95% confidence intervals. The reliability according to ICC was interpreted as poor (< 0.5), moderate (0.5-0.75), good (0.75-0.90) and excellent (> 0.90) (21). Moreover, typical errors (17) were calculated and divided by the mean values to obtain coefficient of variation (CV), which was acceptable < 10%. Correlations among different RSI outcomes, and between RSI outcomes and CoD performance were assessed with Pearson's correlation coefficients and interpreted as negligible (< 0.1), weak (0.1-0.4), moderate (0.4-0.7), strong (0.7-0.9) and very strong (> 0.9) (1). To control for the Type 1 error, we applied Holm-Bonferroni sequential correction of p-values. Additionally, we assessed agreement between triple hop RSI and single-leg RSImod in terms of inter-limb asymmetry direction using Kappa coefficients. The agreement according to Kappa scores was interpreted according to previous studies (6,7) as: 0.01-0.20 = slight; 0.21-0.40 = fair; 0.41-0.60 = moderate; 0.61-0.80 = substantial; 0.81-0.99 = nearly perfect. The threshold for statistical significance was set at $p < 0.05$.

# RESULTS

## Reliability and descriptive statistics

All triple hops RSI showed moderate relative reliability (ICC = 0.63-0.74). Moreover, most CV were < 10 % for triple hop RSI variables (Table 1). In contrast, DJ RSI (ICC = 0.94; CV = 6.51%) and bilateral $RSI_{mod}$ (ICC = 0.94; CV = 6.85%) were more consistent across trials. Single-leg $RSI_{mod}$ had excellent relative reliability (ICC = 0.91-0.92), however, the absolute reliability was acceptable only for the right leg (CV = 9.57 %), but slightly elevated above the 10% for the left leg (CV = 10.08%).

[TABLE 1]

The mean time to complete the 505 test was 2.30 ± 0.11 s on the left side and 2.27 ± 0.10 on the right side. The mean 10-m sprint time was 1.71 ± 0.16. The CoD deficits were calculated to be 0.55 ± 0.12 s for the left side and 0.53 ± 0.11 s for the right side. All performance measures showed acceptable absolute reliability (CV = 3.31-4.43%). However, 505 times and CoD deficits for the left side showed only moderate relative reliability (ICC = 0.66-0.71), while the outcomes on the right side showed high relative reliability (ICC = 0.79-0.81).

Table 2 displays the descriptive statistics for variables underlying RSI calculations. DJ height and contact time (ICC = 0.85-0.94; CV = 5.25-5.51%), as well as all CMJ heights and contact times (ICC = 0.77-0.96; CV = 4.71-6.77%) showed high or excellent relative reliability and acceptable absolute reliability. All triple hop variables showed acceptable absolute reliability (CV = 3.85-8.73%). Relative reliability was also high for most variables, with the exception of both contact times for the left leg (ICC = 0.55-0.64), flight time for hop 1-2 for the left leg (ICC = 0.63), both flight times for the right leg (ICC = 0.70-0.72) and contact time for the hop 1-2 for the right leg (ICC = 0.68).

[TABLE 2]

**Associations among different RSI variants**

DJ RSI was in a moderate to high association with bilateral and single-leg $RSI_{mod}$ ($r = 0.57$-$0.69$; $p \leq 0.004$). The $RSI_{mod}$ variables were in high association with each other ($r = 0.71$-$0.78$; $p < 0.001$). DJ RSI was in moderate to high association with triple hop RSI variables ($r = 0.54$-$0.66$; $p \leq 0.021$). All $RSI_{mod}$ variables were in moderate or high association with all triple hop RSI variables ($r = 0.42$-$0.63$; $p \leq 0.037$). The associations between single-leg $RSI_{mod}$ and triple hop RSI were slightly higher when considering the same leg ($r = 0.44$-$0.63$) compared to the associations between opposite legs ($r = 0.42$-$0.51$).

Within the triple hop test, the associations between RSI based on hop flight time and RSI based on hop distance were high for hop 1-2 ($r = 0.77$-$0.83$; $p < 0.001$) and very high for hop 2-3 ($r = 0.91$-$0.92$; $p < 0.001$). The associations between the RSI on left and right leg for the same outcome were high for hop 1-2 ($r = 0.60$-$0.67$; $p \leq 0.002$) and hop 2-3 ($r = 0.72$-$0.76$; $p < 001$). Finally, all associations between hop 1-2 and hop 2-3 were high ($r = 0.76$-$0.87$; $p < 0.001$)

**Agreement in inter-limb asymmetries between triple hop RSI and single-leg $RSI_{mod}$**

The agreement in terms of inter-limb asymmetry direction between $RSI_{mod}$ and triple hop RSI variables was mostly slight (κ = 0.06-0.18), with an exception of moderate agreement between $RSI_{mod}$ and RSI-$23_{DIST}$ (κ = 0.36; p = 0.036). Agreement between asymmetries in RSI based on flight time and RSI based on hop distance was moderate for hop 1-2 (κ = 0.54; p = 0.001) and substantial for hop 2-3 (κ = 0.66; p = 0.001). The agreement between asymmetries in hop 1-2 and hop 2-3 was moderate when RSI was calculated based on the flight time (κ = 0.44; p = 0.014), and fair when RSI was calculated based on hop distance (κ = 0.24; p = 0.048).

**Associations between different RSI variants and CoD performance**

The 505 test with right turn showed small associations with left leg RSI-$12_{DIST,}$ RSI-$23_{FT}$, RSI-$23_{DIST}$, DJ RSI, bilateral $RSI_{mod}$ and left single-leg $RSI_{mod}$ (r = -0.38 to -0.45; p ≤ 0.042) (Table 3). The 505 test with left turn was in moderate association with left leg RSI-$12_{DIST}$ (r = -0.41; p = 0.028) and small association with RSI-$23_{DIST}$ (r = -0.39; p = 0.040). No associations were found between RSI variables and CoD deficit (Table 3). Moreover, there were no statistically significant associations between any of the RSI variables and 10-m sprint performance. Finally, we found no association between CoD or 10-m sprint performance with inter-limb asymmetries in unilateral $RSI_{mod}$ or triple hop RSI (all r ≤ 0.27; all p > 0.05).

[TABLE 3]

## DISCUSSION

The purpose of this study was to investigate the inter-relationships between RSI, bilateral and unilateral $RSI_{mod}$, triple hop RSI and proxies of sport performance, as well as the agreement between unilateral $RSI_{mod}$ and triple hop RSI in relation to the direction of inter-limb asymmetry. Our results show predominantly moderate relationships among different RSI variants, which is in accordance with our hypothesis. Associations within the tasks (i.e., unilateral to bilateral $RSI_{mod}$, and among different triple hop RSI) were mostly high. The 505 test times were associated with several triple hop RSI, as well as with DJ RSI, bilateral $RSI_{mod}$ and left single-leg $RSI_{mod}$. Since the associations were similar across different RSI variants, our second hypothesis was rejected. With an exception of moderate agreement between unilateral $RSI_{mod}$ and RSI-$23_{DIST}$ ($\kappa = 0.36$), only slight agreements were observed between unilateral $RSI_{mod}$ and triple hop RSI in regard to inter-limb asymmetry direction.

This study was one of the first to include RSI calculation for horizontal unilateral hops. The observed mean contact times (0.29-0.33 s) and flight times (0.26-0.43 s) are in agreement with a previous studies (13,22). Our results indicate that the relationships among different RSI variants are moderate. This is consistent with a previous study that found a moderate relationship ($r = 0.53$) between RSI obtained from vertical and horizontal DJ (2), and with another study reporting a moderate correlation between vertical RSI and $RSI_{mod}$ (28). Therefore, it appears that different RSI share some common variance, but also provide some independent information. The associations between different RSI variants can be explained by the fact that they are all underpinned by the same physical capabilities, such as maximal strength and speed-strength (3,19). However, the differences among RSI variants could be explained by different muscle contributions. For example, DJ performance is predominantly determined by the strength and stiffness of the ankle joints (16,24), whereas a higher contribution of knee and hip joints is typical for the CMJ (41). Moreover, movement velocity is lower while the forces are larger in unilateral compared to bilateral jumps (37). This means that the relationships between unilateral and bilateral RSI are reduced because individuals with higher maximal strength could perform comparably better in unilateral tasks, while individuals with superior speed-strength may perform better in bilateral tasks. While further research of the utility of different RSI variants is needed, the principle of specificity would suggest that coaches should choose tasks that best resemble the demands of the sport (e.g., unilateral or bilateral actions, horizontally or vertically oriented task, actions involving short or fast SSC). At the same time, it currently remains unknown which RSI variant is the best performance indicator.

Previous research has shown that inter-limb asymmetries in strength and power are associated with reduced athletic performance (8). However, given the task-specific nature of asymmetry (4,5,6), these associations are not always consistent (8). In this study, we found no association between inter-limb asymmetries in unilateral $RSI_{mod}$ or triple hop RSI and CoD or 10-m sprint performance. Similarly, no association was reported between jumping performance and inter-asymmetries in vertical stiffness, assessed through unilateral DJ (24). In contrast, unilateral DJ inter-limb asymmetries have been reported to be associated with slower 10 m and 30 m sprint times, as well as slower 505 test times (7). Caution should be exercised when assessing the direction of inter-limb asymmetry in RSI, as the agreement between $RSI_{mod}$ and triple hop RSI outcomes was poor, and even asymmetries within the triple hop tasks were only in moderate agreement. This is consistent with previous studies (6,7), showing that inter-limb asymmetries are task-specific, precluding the use of a single test for a comprehensive evaluation of inter-limb differences. Even functionally similar tasks, such as bilateral vertical hopping and bilateral DJ can exhibit substantially different inter-limb asymmetries (23). As such, when profiling inter-limb differences, practitioners should consider test-retest designs to determine whether levels of agreement in the direction of asymmetry are consistent for the same measure, as opposed to between separate tasks (6,9,12).

Triple hop RSI outcomes were calculated separately from flight time and hop distance. Using the flight time method does not require marking the floor for distance, which is advantageous from the practical point of view. For vertical jumps, the flight time and the jump height provide essentially the same information. However, our results suggest that in the triple hop (notably for the hop 1-2), the flight time and hop distance should not be used interchangeably. Further research is needed to determine which RSI variant is more relevant to specific aspects of sports performance. For now, we recommend that hop distance is preferred over flight time for two reasons. First, the associations with 505 test performance tended to be higher for the RSI computed from the hop distance. Second, the hop distances showed higher trial-to-trial reliability (ICC = 0.79-0.83) compared to flight times (ICC = 0.55-0.72). It should be noted that trial-to-trial reliability of all triple hop RSI variants was only moderate (ICC = 0.63-0.74), which warrants caution and further investigation regarding the use of this test for reactive strength evaluation. Further studies are needed to investigate how many trials are required to obtain a reliable triple hop RSI, and how many hops are needed, before flight time and distance performance plateaus.

Some limitations of the present study with consideration for further research need to be highlighted. The study sample consisted of well-trained male volleyball players. Previous studies have found significant differences in RSI among sports and between sexes (40), thus, our results cannot be generalized to other sports and females. In particular, our results could be significantly different if we studied athletes who perform predominantly horizontal movements (e.g., triple jumpers). Moreover, only DJ task from 40 cm height was included in the study. While some studies reported no differences in RSI computed from DJs of varying heights (20), others suggest that optimal DJ height exists that maximizes RSI (36). Future studies should consider to include multiple DJ with different heights. Finally, the triple hop metrics were determined manually in a video motion analysis software. A recent study has shown that RSI in DJ can be assessed within smartphone video applications with high reliability and validity (29). Nevertheless, somewhat lower trial-to-trial reliability was shown for triple hops in this study compared to DJ and CMJ, which warrants further investigations and caution in practical application.

## PRACTICAL APPLICATIONS

RSI has been used in practice as surrogate for reactive strength ability. This study has shown that the RSI variants form bilateral DJ, bilateral and unilateral CMJ and unilateral triple hops are moderately related, meaning that they provide somewhat different information that may be of interest to practitioners. We recommend that the coaches choose the task that best resemble the demands of the sport (e.g., unilateral or bilateral actions, horizontally or vertically oriented task, actions involving short or fast SSC). Measurements (especially the triple hop task) should be performed with caution, as the outcomes presented with only moderate reliability. Moreover, the practitioners need to be aware that a single test is insufficient for a comprehensive evaluation of inter-limb differences. Regarding the triple hop test, we suggest that the RSI is calculated as the ratio between hop distance and contact time.

**Conflict of interest:** The authors declare that they have no conflict of interest.

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# TABLES

**Table 1.** Descriptive statistics and trial-to-trial reliability of RSI variables

| | Mean | SD | ICC (95 % CI) | TE (95 % CI) | CV (95 % CI) |
|---|---|---|---|---|---|
| *Left triple hop* | | | | | |
| RSI-$12_{FT}$ ($ms^{-1}$) | 1.02 | 0.15 | 0.70 (0.52-0.82) | 0.09 (0.07-0.11) | 8.81 (7.4-11.0) |
| RSI-$12_{DIST}$ ($ms^{-1}$) | 5.35 | 0.92 | 0.67 (0.48-0.80) | 0.57 (0.48-0.71) | 10.68 (8.9-13.4) |
| RSI-$23_{FT}$ ($ms^{-1}$) | 1.42 | 0.26 | 0.83 (0.71-0.90) | 0.14 (0.12-0.17) | 6.08 (5.1-7.6) |
| RSI-$23_{DIST}$ ($ms^{-1}$) | 7.57 | 1.59 | 0.68 (0.50-0.81) | 0.16 (0.14-0.2) | 11.6 (9.7-14.5) |
| *Right triple hop* | | | | | |
| RSI-$12_{FT}$ ($ms^{-1}$) | 0.98 | 0.17 | 0.75 (0.60-0.86) | 0.09 (0.08-0.12) | 9.34 (7.8-11.8) |
| RSI-$12_{DIST}$ ($ms^{-1}$) | 5.24 | 0.96 | 0.63 (0.42-0.77) | 0.63 (0.53-0.79) | 12.1 (10.1-15.2) |
| RSI-$23_{FT}$ ($ms^{-1}$) | 1.34 | 0.29 | 0.73 (0.57-0.84) | 0.15 (0.13-0.19) | 11.55 (9.7-14.5) |
| RSI-$23_{DIST}$ ($ms^{-1}$) | 7.23 | 1.61 | 0.72 (0.55-0.83) | 0.90 (0.75-1.13) | 12.5 (10.5-15.7) |
| *Drop jump* | | | | | |
| RSI ($ms^{-1}$) | 1.77 | 0.47 | 0.94 (0.90-0.96) | 0.12 (0.1-0.14) | 6.51 (5.7-7.8) |
| *Counter-movement jump* | | | | | |
| $RSI_{mod}$ bilateral ($ms^{-1}$) | 0.57 | 0.12 | 0.94 (0.90-0.96) | 0.04 (0.03-0.04) | 6.85 (5.9-8.1) |
| $RSI_{mod}$ left ($ms^{-1}$) | 0.26 | 0.06 | 0.91 (0.86-0.94) | 0.03 (0.02-0.03) | 10.08 (8.7-12.0) |
| $RSI_{mod}$ right ($ms^{-1}$) | 0.27 | 0.07 | 0.92 (0.87-0.95) | 0.02 (0.02-0.03) | 9.57 (7.7-11.0) |

*SD – standard deviation; ICC – intra-class correlation coefficient; TE – typical error; CV – coefficient of variation; CI – confidence interval*

**Table 2.** Descriptive statistics and trial-to-trial reliability of variables underlying RSI calculations

| | Mean | SD | ICC | TE | CV |
|---|---|---|---|---|---|
| Left Hop12 Contact time (s) | 0.32 | 0.04 | 0.64 (0.44-0.79) | 0.02 (0.02-0.03) | 7.30 (6.1-9.2) |
| Left Hop12 Flight time (s) | 0.32 | 0.03 | 0.63 (0.43-0.78) | 0.02 (0.02-0.03) | 7.36 (6.2-9.2) |
| Left Hop12 Distance (m) | 1.69 | 0.18 | 0.79 (0.65-0.88) | 0.09 (0.07-0.11) | 5.26 (4.4-6.6) |
| Left Hop23 Contact time (s) | 0.31 | 0.04 | 0.55 (0.32-0.72) | 0.03 (0.02-0.03) | 8.73 (7.3-11.0) |
| Left Hop23 Flight time (s) | 0.43 | 0.05 | 0.82 (0.70-0.90) | 0.02 (0.02-0.03) | 5.06 (4.2-6.4) |
| Left Hop23 Distance (m) | 2.28 | 0.30 | 0.83 (0.71-0.90) | 0.14 (0.12-0.17) | 6.08 (5.1-7.6) |
| Left Total distance (m) | 5.95 | 0.54 | 0.85 (0.74-0.91) | 0.24 (0.20-0.29) | 3.98 (3.3-5.0) |
| Right Hop12 Contact time (s) | 0.33 | 0.04 | 0.68 (0.49-0.81) | 0.02 (0.02-0.03) | 6.40 (5.3-8.1) |
| Right Hop12 Flight time (s) | 0.32 | 0.03 | 0.70 (0.52-0.82) | 0.02 (0.02-0.03) | 6.55 (5.5-8.2) |
| Right Hop12 Distance (m) | 1.69 | 0.20 | 0.81 (0.68-0.89) | 0.09 (0.08-0.11) | 5.37 (4.5-6.8) |
| Right Hop23 Contact time (s) | 0.32 | 0.04 | 0.79 (0.64-0.88) | 0.02 (0.02-0.03) | 6.48 (5.4-8.2) |
| Right Hop23 Flight time (s) | 0.42 | 0.04 | 0.72 (0.56-0.83) | 0.02 (0.02-0.03) | 5.80 (4.9-7.3) |
| Right Hop23 Distance (m) | 2.25 | 0.29 | 0.80 (0.67-0.88) | 0.14 (0.11-0.17) | 6.09 (5.1-7.6) |
| Right Total distance (m) | 5.86 | 0.47 | 0.80 (0.68-0.89) | 0.22 (0.19-0.28) | 3.85 (3.2-4.8) |
| DJ Height (m) | 0.34 | 0.07 | 0.94 (0.90-0.96) | 0.02 (0.02-0.02) | 5.25 (4.6-6.3) |
| DJ Contact Time (s) | 0.20 | 0.03 | 0.85 (0.77-0.91) | 0.01 (0.01-0.01) | 5.51 (4.8-6.6) |
| Bilateral CMJ height (m) | 0.44 | 0.06 | 0.96 (0.93-0.97) | 0.02 (0.02-0.02) | 4.71 (4.1-5.6) |
| Bilateral CMJ time (s) | 0.79 | 0.09 | 0.81 (0.71-0.87) | 0.04 (0.03-0.05) | 5.27 (4.6-6.3) |
| Left CMJ height (m) | 0.23 | 0.04 | 0.95 (0.93-0.97) | 0.01 (0.01-0.02) | 6.24 (5.4-7.4) |
| Left CMJ time (s) | 0.90 | 0.10 | 0.77 (0.66-0.85) | 0.06 (0.05-0.07) | 6.77 (5.8-8.1) |
| Right CMJ height (m) | 0.24 | 0.04 | 0.96 (0.93-0.98) | 0.01 (0.01-0.02) | 6.19 (5.2-7.2) |
| Right CMJ time (s) | 0.89 | 0.12 | 0.79 (0.68-0.86) | 0.06 (0.05-0.07) | 6.57 (5.4-8.0) |

*SD – standard deviation; ICC – intra-class correlation coefficient; TE – typical error; CV – coefficient of variation; CI – confidence interval*

**Table 3.** Associations between change of direction ability and RSI variables (Pearson correlation)

| | **505 time (s) left** | **505 time (s) right** | **CoD deficit (s)** | **CoD deficit (s)** | **10-m sprint (s)** |
|---|---|---|---|---|---|
| *Left triple hop* | | | | | |
| RSI-$12_{FT}$ ($ms^{-1}$) | -0.31 (-0.68, 0.05) | -0.29 (-0.68, 0.08) | -0.16 (-0.52, 0.22) | -0.12 (-0.47, 0.17) | 0.03 (-0.40, 0.43) |
| RSI-$12_{DIST}$ ($ms^{-1}$) | -0.41* (-0.76, -0.06) | -0.41* (-077, -0.05) | -0.23 (-0.62, 0.12) | -0.20 (-0.51, 0.10) | -0.01 (-0.42, 0.37) |
| RSI-$23_{FT}$ ($ms^{-1}$) | -0.30 (-0.67, 0.06) | -0.39* (-0.72, -0.05) | -0.07 (-0.39, 0.31) | -0.14 (-0.48, 0.17) | -0.05 (-0.37, 0.29) |
| RSI-$23_{DIST}$ ($ms^{-1}$) | -0.39* (-0.76, -0.05) | -0.45* (-0.80, -0.11) | -0.17 (-0.45, 0.21) | -0.19 (-0.49, 0.15) | -0.07 (-0.44, 0.25) |
| *Right triple hop* | | | | | |
| RSI-$12_{FT}$ ($ms^{-1}$) | -0.15 (-0.53, 0.23) | -0.20 (-0.55, 0.23) | -0.04 (-0.38, 0.34) | -0.08 (-0.41, 0.23) | 0.06 (-0.29, 0.41) |
| RSI-$12_{DIST}$ ($ms^{-1}$) | -0.22 (-0.60, 0.15) | -0.35 (-0.70, 0.04) | 0.02 (-0.42, 0.45) | -0.10 (-0.43, 0.21) | -0.16 (-0.50, 0.12) |
| RSI-$23_{FT}$ ($ms^{-1}$) | -0.16 (-0.54, 0.21) | -0.24 (-0.55, 0.09) | 0.01 (-0.41, 0.44) | -0.05 (-0.37, 0.29) | 0.02 (-0.39, 0.41) |
| RSI-$23_{DIST}$ ($ms^{-1}$) | -0.29 (-0.66, 0.08) | -0.36 (-0.72, 0.01) | -0.08 (-0.51, 0.31) | -0.13 (-0.47, 0.18) | -0.06 (-0.42, 0.23) |
| *Drop jump* | | | | | |
| RSI ($ms^{-1}$) | -0.34 (-0.72, 0.02) | -0.38* (-0.73, -0.03) | -0.09 (-0.53, 0.30) | -0.12 (-0.47, 0.18) | -0.02 (-0.40, 0.32) |
| *Counter-movement jump* | | | | | |
| $RSI_{mod}$ bilateral ($ms^{-1}$) | -0.15 (-0.54, 0.08) | -0.32 (-0.69, 0.04) | 0.17 (-0.21, 0.50) | 0.01 (-0.47, 0.47) | -0.29 (-0.55, 0.11) |
| $RSI_{mod}$ left ($ms^{-1}$) | -0.16 (-0.51, 0.11) | -0.38* (-0.74, -0.04) | 0.11 (-0.27, 0.42) | -0.09 (-0.53, 0.21) | -0.15 (-0.51, 0.14) |
| $RSI_{mod}$ right ($ms^{-1}$) | -0.16 (-0.52, 0.11) | -0.22 (-0.61, 0.15) | 0.15 (-0.25, 0.48) | 0.11 (-0.27, 0.40) | -0.28 (-0.56, 0.12) |

* $p < 0.05$