Reactive strength index during single-leg vertical

Abstract

After an ACLR, jump height during single-leg vertical continuous jumps (SVCJs) is a parameter that can detect lower limb asymmetry in the single-leg jump performance of an athlete who is at the stage of potentially returning to sport [10]. Unlike the single-leg hop tests, SVCJs are not forward jumps; they involve continuous vertical jumps at the fastest pace possible [10, 11]. Myer et al. reported that the jump height during SVCJs of the involved limb of athletes was lower than that of the uninvolved limb over 8 months after ACLR [10]. Vertical jumps are frequently required in movements such as rebounding in basketball or blocking in volleyball [12, 13]. However, no generalized measurement protocol has been established to evaluate an athlete's vertical jumping ability in the return to sport criteria after ACLR [14, 15].

In the study by Myer et al., one of the analyzed parameters was the jump height during SVCJs [10]. In their study, ground contact time was not analyzed although it is typically analyzed in SVCJs in addition to jump height when assessing jumping ability [16]. During tasks such as SVCJs, the duration of the contact time is related to the ground reaction force produced during the task [17]. Analyzing both the contact time and jump height in SVCJs will increase the likelihood of detecting asymmetry in the single-leg jumping ability.

In previous studies on healthy athletes, the reactive strength index (RSI), which is calculated using jump height and contact time, was used as a parameter for determining jumping ability in SVCJs [18, 19]. However, no studies have investigated the RSI during SVCJs in athletes who have undergone an ACLR. Moreover, no studies have compared the LSI of the RSI during SVCJs between post-ACLR and healthy athletes. In addition, the association of the LSI of the RSI during SVCJs with the LSI of the single-leg hop tests in athletes after ACLR is unclear.

Thus, this study aimed to confirm the properties of the RSI during SVCJs to detect asymmetry in the single-leg jumping performance of post-ACLR athletes to determine the appropriate time to return to sport. Our hypotheses were as follows: (1) the RSI scores during SVCJs and single-leg hop tests of the ACL-reconstructed limb will be significantly lower than that of the contralateral limb. (2) The LSI scores of the RSI during SVCJs and single-leg hop tests will be significantly lower in post-ACLR athletes than in healthy athletes. (3) The LSI scores of the RSI during SVCJs and single-leg hop tests are related; however, among those with ≥90% score in the LSI of single-leg hop tests, some will have <90% score in the LSI of the RSI during SVCJs.

Methods

Healthy athletes were included in the study if they participated in a team sport that required multidirectional movements and jump-landing (e.g., basketball, soccer, and lacrosse) with a modified Tegner activity scale score of > 6. Healthy athletes with a previous ACL injury that required reconstruction and an injury that affected the physical function of the lower back or limb were excluded.

Surgical technique

For the SHD, participants were instructed to stand on the limb to be tested, hop forward as far as possible, and land on the same limb [5, 6]. The distance from the starting line to the point of heel contact of the participant's test limb upon completing the single hop was measured and recorded [8, 21]. For the THD, participants were instructed to stand on the limb to be tested, perform three consecutive maximal forward hops, and land on the same limb [5, 6]. For the CHD, participants were instructed to stand on the limb to be tested, perform three consecutive maximal forward hops while alternately crossing over a 15-cm marking strip on the floor [6]. When measuring the right limb, participants began the test by standing on the right limb on the right side of the line [21]. For the THD and CHD, the distance from the starting line to the point of heel contact of the participant's test limb after completing the third hop was measured and recorded [21].

For each hop test, participants were initially given a verbal description of the test, and they were allowed to perform practice trials until they were confident to perform the test. Two trials were measured and recorded; the largest of the two was used for analysis.

SVCJs for measuring the RSI

All power analyses were performed using G*power statistical software. For within-subject analyses, a priori power analysis using data from a pilot test (n = 10; involved limb RSI, 0.43 ± 0.14; uninvolved limb RSI, 0.52 ± 0.13; effect size, Cohen's d = 0.665; alpha = 0.05; power = 0.80; two-tailed) revealed that at least 20 post-ACLR athletes were required to achieve an alpha of 0.05 and a power of 0.80. To compare the LSIs of the post-ACLR and healthy athletes, a power analysis using data from a previous study [26] with single-leg hop tests (SHD, THD, and CHD) revealed that at least 16 participants were required to achieve an alpha of 0.05 and a power of 0.80.

Results

Table 1
Participants' demographics

In this study, 75–80% of the post-ACLR athletes had been judged “satisfactory” based on the LSIs from the single-leg hop tests. By contrast, only 25% (5/21) had been judged “satisfactory” based on the LSI from the RSI during the SVCJs test (Table 4). Recovery of satisfactory RSI during the SVCJs test was associated with the symmetry of the single-leg hop tests. Of the patients who had an LSI ≥ 90% from the RSI during the SVCJs test, 100% (5/5), 80% (4/5), and 60% (3/5) also had an LSI ≥ 90% for SHD, THD, and CHD, respectively.

Recovery in the single-leg hop tests was associated with the RSI during the SVCJs test. However, only 29.4% (5/17), 23.5% (4/17), and 18.8% (3/16) of the athletes who had satisfactory recovery for SHD, THD, and CHD, respectively, had satisfactory recovery for RSI during the SVCJs test.

Table 2

Side-to-side differences for each test

Statiscally significant difference: $p<0.05$

Table 3
Limb symmetry index for each test

those with LSIs above 90% in the single-leg hop tests had LSIs above 90% in the RSI during SVCJs. These results support our hypotheses, except for the difference in the LSIs between the groups in the single-leg hop tests.

Gokeler et al. reported a significant difference in SHD measurements between the involved and uninvolved limbs of post-ACLR athletes [27]. Herrinton et al. reported similar findings for the THD and CHD measurements with a moderate effect size [28]. These studies have reported a duration of 6.7–7.8 months since reconstruction in post-ACLR athletes. Our study contradicts these findings and reports a mean duration of 11.6 (6.7–31.2) months. The LSIs of the single-leg hop tests that measure distance increased as duration increased after reconstruction [29]. The longer duration after reconstruction in our study may have influenced the difference observed in the results between the present study and previous studies. The LSIs of the single-leg hop tests showed that post-ACLR athletes who had undergone reconstruction approximately 11 months earlier recovered to the same level as healthy athletes.

In this study, the RSI during SVCJs was significantly lower on the involved limb than on the uninvolved limb of post-ACLR athletes and had a large effect size. Their corresponding LSIs were significantly lower than that of healthy athletes, and the effect size was large. Myer et al. reported that the mean LSI of the jump height of post-ACLR athletes was 89% [10]. Similarly, the mean jump height and RSI during SVCJs in the present study was 86% and 81%, respectively. The study findings show that greater lower limb asymmetry can be detected by calculating the RSI with the jump height and contact time. In many previous studies that have assessed jump with landing and leaping for healthy athletes, the contact time and RSI have been used as parameters of jump performance [30, 31]. The RSI for continuous vertical jumps in post-ACLR athletes is not known. Our study results therefore provide new insights into the RSI during SVCJs in post-ACLR athletes who are determining the appropriate timing to return to sport.

Less than 30% of the post-ACLR athletes with an LSI of 90% or above in the single-leg hop tests had an LSI over 90% in the RSI during SVCJs. The results of this study showed that the symmetry of single-leg forward hop performance was restored in post-ACLR athletes more than 6 months after surgery, but asymmetry remained in their reactive continuous vertical jump performance. According to a study that analyzed the LSIs of the jump height during SVCJs, SHD, and THD in post-ACLR athletes 54 weeks after reconstruction, the LSI of the jump height during SVCJs was the lowest, which is similar to our study findings [32]. The present results support our hypothesis. For post-ACLR athletes at the phase of determining the timing of their return to sport, the RSI during SVCJs was shown to detect lower limb asymmetry more easily than the single-leg hop tests.

In our study, a side-to-side difference was found in the single-leg hop tests and RSI during SVCJs in both post-ACLR and healthy athletes. In healthy athletes, the LSI for each test ranged from 91.9–96.5%. Several studies have reported no or small side-to-side differences in single-leg hop tests in healthy athletes [33, 34]. A difference was found in the methods of LSI calculations, and various definitions were used to categorize the lower limbs between the studies. Some studies mostly analyzed the differences and ratios between the dominant and non-dominant limbs separately in healthy athletes [33, 35, 36]. Our study divided the lower limbs of healthy athletes into poor-performing and well-performing limbs. Therefore, we observed a greater difference when comparing the dominant and non-dominant limbs. In our study, the LSI was calculated using results of the poor-performing limb as the numerator and results of the well-performing limb as the denominator, which was effective in identifying the asymmetry in the limbs.

Single-leg hop tests are a forward jumping test, but SVCJs are continuous jumps in the vertical direction. Vertical jumps are frequently required in sports such as basketball, handball, and volleyball, which record a high incidence of ACL injuries [37–39]. A pre-return to sport vertical jump performance assessment may be useful for post-ACLR athletes participating in these sporting events. However, vertical jumping tasks are less frequently used than horizontal jumping tasks such as the single-leg hop tests in assessing post-ACLR athletes [40]. To ensure return to sport in post-ACLR athletes participating in sports that require frequent vertical jumps, evaluations related to vertical jumps would need to be included in the return to sport criteria.

A recent systematic review identified the need for modification of return to sport criteria for adequate decision making regarding the timing of return to sport in post-ACLR athletes [40, 41]. Even if a test is able to accurately capture an athlete's recovery status, generalization is difficult if it is not feasible in a clinical setting. Recent advances in technology have made it possible for relatively inexpensive devices such as mat switches [42] and smartphone applications [43] to accurately measure flight time and RSI for vertical jumps involving landing and leaping. The RSI during SVCJs employed in this study has the following advantages as a functional assessment of post-ACLR athletes. First, similar to the single-leg hop tests, this is a single-legged task; therefore, the asymmetry of the lower limb function can be confirmed. Second, SVCJs can be performed in a relatively space-saving manner. The results of this study indicate that the RSI during SVCJs may serve as a new indicator for detecting lower extremity asymmetry in post-ACLR athletes at the phase of determining the timing of their return to sport.

This study has several limitations. First, although sex influences the effect of lower body explosiveness on jump landings as assessed by the RSI [44], it was not included in the analysis. Approximately 70% of the study participants were female. Second, the surgical technique for inclusion was not limited. Third, because the study included post-ACLR athletes who were within 6 months to 2 years after surgery, the return to sport status varied, but it was not analyzed separately for timing or return to sport status. Finally, we only used the Optojump™ system for the RSI during SVCJs measurements. In RSI measurements, fixed bias may occur due to differences in measurement equipment [19]. Therefore, careful attention is needed when comparing the data from this study with studies that have used different measuring instruments.

Conclusion

Limb symmetry index (LSI)

Single hop for distance (SHD)

Triple hop for distance (THD)

Crossover hop for distance (CHD)

Limb symmetry index (LSI)

Declarations

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