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A Single-Leg Vertical Hop Test Is an Effective Tool to Measure Functional Performance after Anterior Cruciate Ligament (ACL) Reconstruction

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Abstract: This study evaluated the single-leg vertical hop test (SLVHT), using digital sensor technology, for the functional assessment of rehabilitation progress in patients after ACL reconstruction (ACL-R). Between January 2019 and June 2022, 143 patients (26.6 (8.9) years, m/f 66/34%) completed return-to-sport testing at 3 and 6 months after ACL-R. The jump height during SLVHT was quantified with a digital motion sensor, containing a three-axis acceleration gyroscope sensor, and the limb symmetry index (LSI) (injured/non-injured leg ratio) was calculated. Three months postoperatively, the jump height of the injured leg was 59.6% (13.5 (5.5) cm) that of the non-injured leg (22.9 (6.2) cm; $p < 0.01$). After 6 months, the jump height of the injured leg (18.4 (6.9) cm) improved by 44.1% compared to that at the 3-month follow-up but was still lower than the non-injured leg jump height (23.2 (7.0) cm, $p < 0.001$; LSI = 79.6%). Men jumped higher than women, but their LSI was not different at 3 (59.6 vs. 59.5%) and 6 months (80.6 vs. 77.8%). Regression analysis identified the non-injured leg jump height as the primary independent predictor of the jump height of the injured leg (β = 0.776, T = 51.506, $p < 0.001$). SLVHT, using digital sensor technology, is a simple and cost-effective functional test to assess rehabilitation progress after ACL-R, with the potential for multi-centre data analysis.

Keywords: ACL reconstruction; functional testing; return to sport; motion sensor; rehabilitation; digitisation; inertial measurement units

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1. Introduction

The anterior cruciate ligament (ACL) is a key stabilising ligament of the knee joint. It is vulnerable to injury amongst athletes involved in high-intensity sport activities, even though most injuries occur due to noncontact activities [1,2]. The treatment options include ACL reconstruction (ACL-R) followed by intensive rehabilitation. The process of returning to activity after surgery is multifaceted, requiring individual rehabilitation protocols while considering recovery milestones. The main goal of current rehabilitation concepts is not only to restore function but also to provide specific training interventions to avoid functional valgus knee movement [3], which has been shown to be a relevant risk factor for reinjury [4–7].

There are various approaches to evaluate and monitor knee function after injury. Traditionally, clinical tests such as ligament laxity measurements, subjective data acquisition using standardised patient-reported outcome measures (PROMs) [8] and a static timeframe of 9–12 months have been used as monitoring tools during rehabilitation. In order to better assess the biomechanical integrity, neuromuscular capacity and resilience of the knee joint, functional testing has become central to current rehabilitation protocols [9–11].

Several functional tests have been designed and introduced in recent years to identify deficits and asymmetries in movement patterns, joint function and body control after ACL-R with high validity [12]. However, there is still debate about how these tests should be combined in different patient cohorts, when they should be executed in the course of rehabilitation, and how they should be interpreted when making return-to-play decisions for athletes. These tests may include a single-leg vertical hop, a single-leg horizontal hop for distance [13,14] and various modifications such as the triple jump test and the triple jump crossover test [9,15,16]. Each test targets specific functional domains and varies in complexity. Therefore, different environments, personnel and equipment may be required. The single-leg vertical hop test (SLVHT) has been recommended as a measure of functional performance due to its safety and feasibility and the possibility of implementation during early rehabilitation [17,18]. The performance in vertical hop tests is usually quantified by video analysis (elevation of the centre of the body, e.g., pelvic bone) or by contact mats [17,19,20]. However, these methods are time-consuming, person-dependent, and material- and cost-intensive [17].

In recent years, wearable inertial measurement units (IMUs) (i.e., digital sensors) have been introduced as an alternative tool to monitor athletic performance [21,22]. An IMU is a small portable device equipped with sensors that measures and records motion-related data based on movement biomechanics, joint kinetics and performance metrics such as height, width, angular velocity and acceleration. The compact size and wireless capabilities make it a versatile and practical tool in clinical and research settings. Only a few of these have been used in rehabilitation settings following injury or surgery and have been able to measure the hop height, width and sagittal plane angles reliably [23–25]. One of these IMU systems (OPED Corp., Valley, Germany) was validated and shown to be highly correlated with well-established measurement devices [26]. Using an associated mobile software application (Orthelligent, OPED Corp., Valley, Germany; used in the latest version; https://www.o-dhs.com/de/produkte-und-loesungen/orthelligent-pro), data can be derived from the sensor, displayed to the user and stored for later application and comparison. Thus, it is possible to monitor test results over time, compare gender- and sport-specific performances and determine individual deficits by the limb symmetry index (left–right comparison) [27].

The purpose of this study was to evaluate the jump height in the SLVHT as a functional parameter to assess the rehabilitation progress in patients after ACL-R when measured with digital sensor technology in a clinical setting. We hypothesised that a limb symmetry index (LSI) of the SLVHT jump height could both detect functional deficits after ACL-R and respond to improvements over the course of rehabilitation, independently of gender and age differences. Functional testing after ACL-R is complex, often time-consuming, and therefore difficult to implement in the daily routine of practitioners. The results might provide a simple option to reliably test functional capability after ACL-R and present a useful setup to monitor rehabilitation progress.

2. Materials and Methods

2.1. Study Design and Patient Population

Patients (men and women, ≥16 years old) after primary ACL-R with an ipsilateral autologous tendon graft (quadrupled hamstring, quadriceps or patellar tendon graft) underwent return-to-sports testing (containing an assessment of knee function, range of motion, ligament laxity, IKDC SKF and KOOS, functional hop tests such as the SLVHT and hop for distance) three and six months postoperatively at a single institution between January 2019 and June 2022. Only patients who had completed the single-leg vertical hop test as part of the return-to-sports testing at both timepoints were included in this retrospective data analysis. The study population also included patients with or without concomitant meniscus surgery (partial meniscectomy or meniscal repair). The main exclusion criteria were concomitant medial or lateral ligament repair or reconstruction and revision surgery. All patients received the German standard of care, including physiotherapy with a total of at least 36 sessions consisting of manual therapy (joint mobilisation, soft tissue mobilisation, myofascial release, manual traction, etc.) and rehabilitation training depending on the individual progress. Written informed consent was obtained from all participants (including legal guardians for minor participants) prior to their inclusion in the study, and the retrospective data analysis was approved by the ethical committee of the University of Witten-Herdecke (Chart# 56/2022).

2.2. Assessment of Single-Leg Vertical Hop Test with Sensor-Based Digital Medical Device

A single-leg vertical hop test (SLVHT) was performed three times in a row under standardised testing conditions using an insertional digital sensor (Orthelligent®, OPED GmbH, Valley, Germany) attached by a rubber strap to the proximal tibia of the respective leg (Figure 1A). The best attempt was recorded. This digital sensor, also technically called an IMU, contains a three-axis acceleration sensor and a three-axis gyroscope sensor capable of detecting and measuring different movement patterns on the basis of pre-installed algorithms [26]. The calculations consist of detecting two time points: the take-off moment and the landing. For these detections, combined values of position (angle) and acceleration are considered and calculated, and the exceedance of threshold values is derived from this. The reliability of hop tests was previously shown [28], and assessments by the digital sensor used herein were examined previously [26,27].

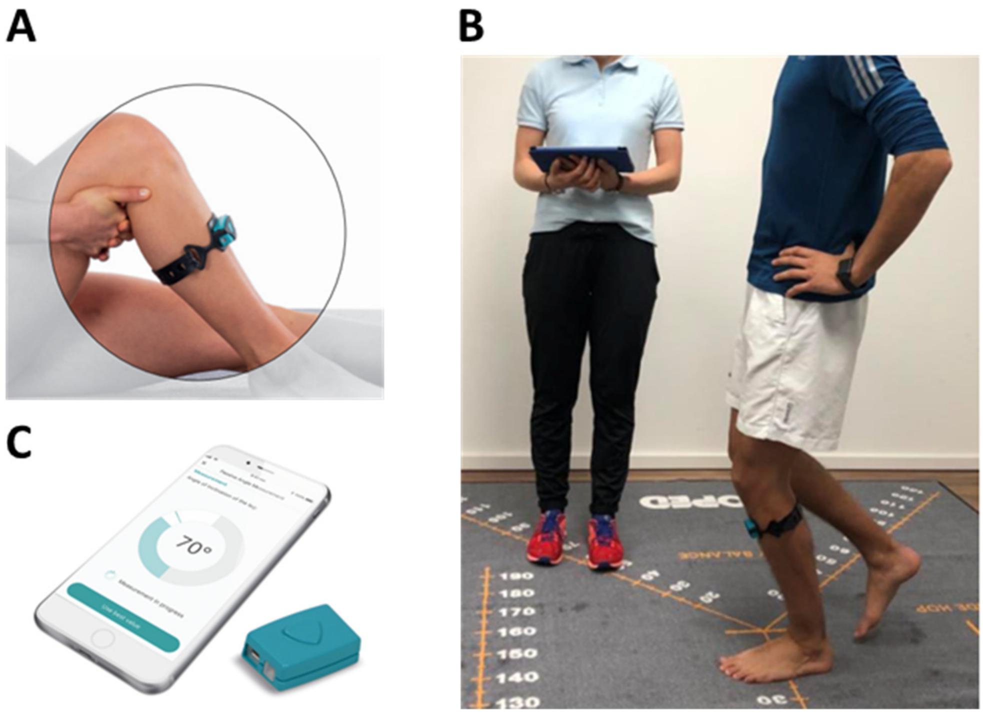

Figure 1. (**A**) Wearable sensor attached to the proximal tibia, containing an accelerometer transferring data via Bluetooth to a digital platform (tablet) (Orthelligent, OPED Inc., Valley, Germany). (**B**) Single-leg vertical hop test: trainer-administered, standardised test performance, barefoot on test carpet, both hands fixed to the hip, wearable sensor fixed to the proximal tibia via rubber strap. (**C**) Wearable sensor and mobile software application.

The SLVHT was trainer-administered and performed barefoot on a standardised surface (industrially manufactured carpet, OPED Inc.) with both hands attached to the hips (Figure 1B), since countermovements and arm swings have been shown to influence jump height significantly [29]. Jump height was determined in both the non-injured and injured limb by means of the time interval (foot off the ground) measured by the insertional sensor. Measurement values were transmitted via Bluetooth to a software application on a digital tablet (Figure 1C). The software (mobile application Orthelligent, OPED GmbH, Valley, Germany; used in the most current version; https://www.o-dhs.com/de/produkte-und-loesungen/orthelligent-pro) calculated the jump height and the limb symmetry index (LSI), which was used for intraindividual comparison of the injured with the non-injured leg (LSI = (jump height injured leg/jump height non-injured leg) × 100). The LSI is a common parameter used in ACL rehabilitation. As a side-to-side difference, the individual deficit can be expressed in a single term at different time points during the rehabilitation phase.

2.3. Assessment of Distance Hop, IKDC SKF and KOOS

In addition to the SLVHT, a single-leg hop test for distance was performed by the patients six months postoperatively as described elsewhere [19]. All patients were asked to complete the International Knee Documentation Committee subjective knee form (IKDC SKF) [14] and the Knee injury and Osteoarthritis Outcome Score (KOOS) questionnaires [30,31] at six months postoperatively. For the IKDC SKF, the individual items with a maximum of 87 points were transformed to a scaled number ranging from 0 to 100 (0 points: lowest level of function or highest level of symptoms, 100 points: highest level of function and lowest level of symptoms) [14].

2.4. Statistical Methods

All continuous variables were examined for a normal distribution with the Kolmogorov–Smirnov test. Normally distributed data are presented as the mean (±standard deviation) and non-normally distributed variables as the median (25–75). Age was categorised into ranges of five years. Group comparisons were performed using the paired or unpaired two-sided t-test. A further analysis of jump height was performed in relation to gender (male or female) and diagnosis (isolated ACL-R or ACL-R with meniscus involvement). Since an age of ACL-R patients of younger than 30 years is associated with a better postoperative rehabilitation success after 1 to 2 years [16], a cut-off at 30 years was chosen for the analysis and characterisation of the age subgroups (<30 years and above 30 years).

Nonparametric bivariate correlations (Spearman's rank correlation coefficients) were calculated for the vertical jump height (injured leg) and the results of other tests for rehabilitation progress (IKDC SKF, KOOS value, distance jump width (injured leg)) at 6 months postoperatively.

Subsequently, a multivariate linear regression analysis for various factors was performed to identify independent determinants of the jump height.

The level of statistical significance was set at $\alpha = 0.05$. For the statistical analysis, R was used, and regression analysis was performed with SPSS, both in their latest versions.

3. Results

During the study period, of the 502 patients who had performed an SLVHT at at least one time point, n = 143 patients had completed the test at both 3 and 6 months after ACL-R and were included in further analysis. Of the study population, 68 patients had also completed the IKDC SKF and n = 66 had completed the KOOS questionnaire at the 6-month follow-up. The distance jump was performed by 142 patients at 6 months postoperatively.

The demographics of the study population are summarised in Table 1. The patient population included was young (predominant age group <25 years), practiced mainly ball sports, and had both isolated ACL-R and ACL-R with meniscal involvement. Thus, the patient population reflected the typical target population for ACL-R.

3.1. Single-Leg Vertical Hop Test

Three months postoperatively, the jump height of the injured leg was only 59.6% that of the contralateral side (non-injured leg: 22.9 (6.2) cm vs. injured leg 13.5 (5.5) cm, $p < 0.001$; Figure 2, Table 2). At 6 months postoperatively, the jump height of the injured leg was significantly higher by 44.1% percent when compared to the 3-month value (13.5 (5.5) cm vs. 18.4 (6.9) cm, $p < 0.001$, Figure 1, Table 2). However, the LSI at 6 months postoperatively was still only about 79.6% (Table 2). The jump height of the non-injured leg did not change significantly from 3 months to 6 months postoperatively. There were no adverse events related to the SLVHT.

Table 1. Demographic data of the study population.

Characteristic	Study Population
Total [n]	143
Gender (male/female [n (%)])	94:49 (66%:34%)
Age [years]	26.6 (8.9)
Height [cm]	177.4 (8.3)
Weight [kg]	76.8 (13.7)
BMI [kg/m²]	24.3 (3.3)
Injury due to the main sport practiced [n (%)]	
Soccer	66 (46%)
Handball	22 (15%)
Other ball sports	16 (11%)
Tennis	6 (4%)
Winter sports	8 (6%)
Other sports	5 (4%)
No sports-related injury	20 (14%)
Injured leg [n (%)]	
Right	65 (45%)
Left	78 (55%)
Diagnosis [n (%)]	
ACL-R isolated	59 (41%)
ACL-R with meniscus involvement	84 (59%)

Data are presented as the mean (standard deviation). Abbreviations: ACL-R, anterior cruciate ligament reconstruction; BMI, body mass index; n, number.

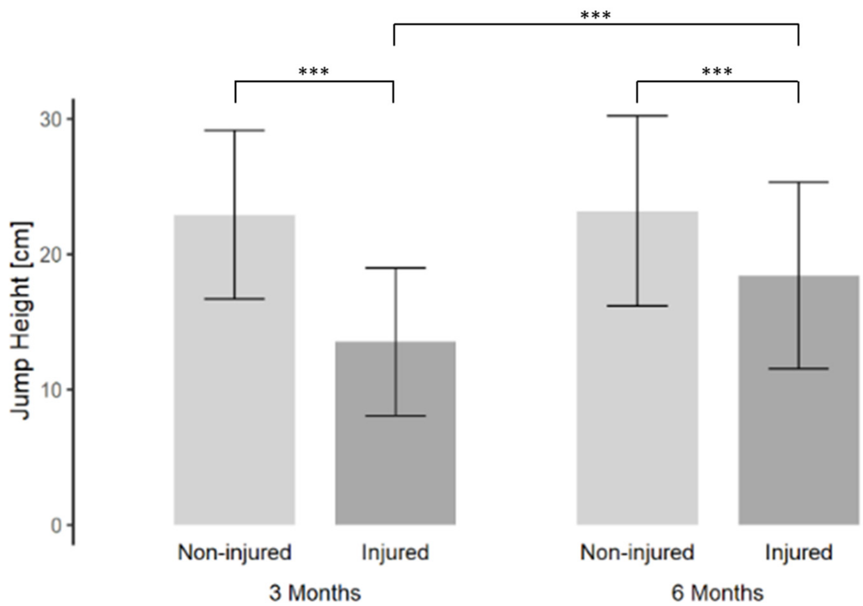

Figure 2. Jump height for the single-leg vertical hop test with the injured and non-injured leg at 3 and 6 months postoperatively in the total ACL-R population. Data are presented as the mean (standard deviation); n = 143; statistics: ***, $p < 0.001$.

Table 2. Jump heights in the single-leg vertical hop test with the non-injured and injured leg in the total ACL-R population and different subgroups (gender, age groups, injury severity).

			Jump Height 3 Months Postoperatively			Jump Height 6 Months Postoperatively			Change in Jump Height (3 to 6 Months)	
		n	Non-Injured Leg [cm]	Injured Leg [cm]	LSI [%]	Non-Injured Leg [cm]	Injured Leg [cm]	LSI [%]	Non-Injured Leg Absolute [cm] (Relative [%])	Injured Leg Absolute [cm] (Relative [%])
Total		143	22.9 (6.2)	13.5 (5.5)	59.6 (17.7)	23.2 (7.0)	18.4 (6.9) [a]	79.6 (17.7) [a]	0.3 (2.7%)	4.9 (44.1%)
Gender	male	94	25.7 (4.8) [#]	15.2 (5.4) [#]	59.6 (17.5)	26.4 (5.6) [#]	21.1 (6.3) [#,a]	80.6 (18.5) [a]	0.7 (3.5%)	5.9 (47.8%)
	female	49	17.5 (5.0) [#]	10.2 (3.8) [#]	59.5 (18.0)	17.1 (5.0) [#]	13.3 (4.9) [#,a]	77.8 (16.0) [a]	−0.5 (−1.0%)	3.1 (36.8%)
Age group	<30 years	106	23.7 (6.2) [§]	14.3 (5.5) [§]	61.0 (18.0)	24.0 (7.1) [§]	19.5 (6.9) [§]	81.0 (17.4) [a]	0.3 (3.0%)	5.2 (44.2%)
	>30 years	37	20.7 (5.7) [§]	11.4 (4.9) [§]	55.4 (15.9)	20.9 (6.2) [§]	15.5 (6.0) [§]	75.6 (18.0) [a]	0.2 (1.8%)	4.1 (43.5%)
Injury severity	ACL-R isolated	59	22.3 (6.2)	13.3 (5.5)	59.6 (17.0)	22.1 (6.8)	17.8 (6.9)	79.8 (17.1)	−0.2 (−0.4%)	4.5 (41.3%)
	ACL-R with meniscus involvement	84	23.4 (6.2)	13.7 (5.4)	59.6 (18.1)	24.0 (7.1)	18.9 (6.9)	79.5 (18.2)	0.6 (4.3%)	5.2 (46.0%)

Data are presented as the mean (standard deviation); Statistics: a: 3 months postoperatively vs. 6 months postoperatively (respective leg), $p < 0.001$; #: male vs. female (respective leg), $p < 0.01$; §: comparison of age groups (respective leg), $p < 0.01$. Abbreviations: LSI, limb symmetry index.

3.2. Differences in Jump Heights in the Single-Leg Vertical Hop According to Age, Gender and Injury Severity

To examine whether age, gender and severity of injury had an effect on jump height, the jump height was comparatively analysed in the corresponding subgroups.

Female patients had a lower jump height with the injured leg than did male patients at both 3 months and 6 months postoperatively (males vs. females: 3 months, 15.2 (5.4) cm vs. 10.2 (3.8) cm; 6 months, 21.1 (6.3) cm vs. 13.3 (4.9) cm; $p < 0.001$; Table 2). Even though the increase in jump height from 3 to 6 months was higher in males than females, the LSI did not differ significantly at both timepoints (LSI: 3 months, 59.6% (males) vs. 59.5% (females); LSI: 6 months, 80.6% (males) vs. 77.8% (females); $p > 0.5$). An analysis of jump height in the SLVHT according to age indicated that the jump heights of the injured leg after 3 and 6 months of rehabilitation were higher in younger patients than in the older study group (age ≤30 years vs. >30 years: 3 months, 14.3 (5.5) cm vs. 11.4 (4.7) cm; 6 months, 19.5 (6.9) cm vs. 15.5 (6.0) cm; $p < 0.001$, Table 2). The LSI differed between both age groups at both timepoints postoperatively (age <30 years vs. >30 years: LSI: 3 months, 61.0% vs. 55.4% ($p < 0.05$); LSI: 6 months, 81.0% vs. 75.6%). To our surprise, the jump height in the SLVHT with the injured leg did not differ between patients with isolated ACL-R and those with ACL-R with meniscal involvement, at both 3 and 6 months (Table 2).

3.3. Correlations and Regression Analysis

Only the jump height during the SLVHT of the healthy leg and the LSI were associated with the jump height in the SLVHT with the injured leg (Table S1, Supplementary Materials). Using the regression model including all variables (see above), these correlations were confirmed, revealing that only the jump height with the healthy leg was the independent predictor of the jump height with the injured leg 6 months postoperatively (Table S2, Supplementary Materials). In order to test which of the possibly influencing factors causally affect the jump height of the healthy leg and the LSI, a stepwise regression analysis was performed. After excluding the variables age, leg length, height, body weight and injured side, only gender could be identified as an influencing factor for the absolute jump height with the healthy leg (Table S3, Supplementary Materials). None of the investigated factors (age, leg length, height, body weight, gender, age, injury severity, injured side) had a significant influence on the LSI.

3.4. Correlation of Jump Height in SLVHT with Distance Hop, IKDC SKF and KOOS

In order to externally validate the digitally measured SLVHT, the jump height in the SLVHT with the injured leg at 6 months was tested against established measurement variables. The SLVHT results for the injured leg correlated significantly with the jump distance of the distance hop (r = 0.680, $p = 2 \times 10^{-16}$, y = 46.249 + 2.743 × x; Figure 3A), while the jump height of the injured leg at 6 months significantly correlated with the IKDC SKF (r = 0.280, $p = 0.0129$, y = 67.563 + 0.507 × x, Figure 3B) and the KOOS value (r = 0.200, $p = 0.062$, y = 71.120 + 0.505 × x, Figure 3C).

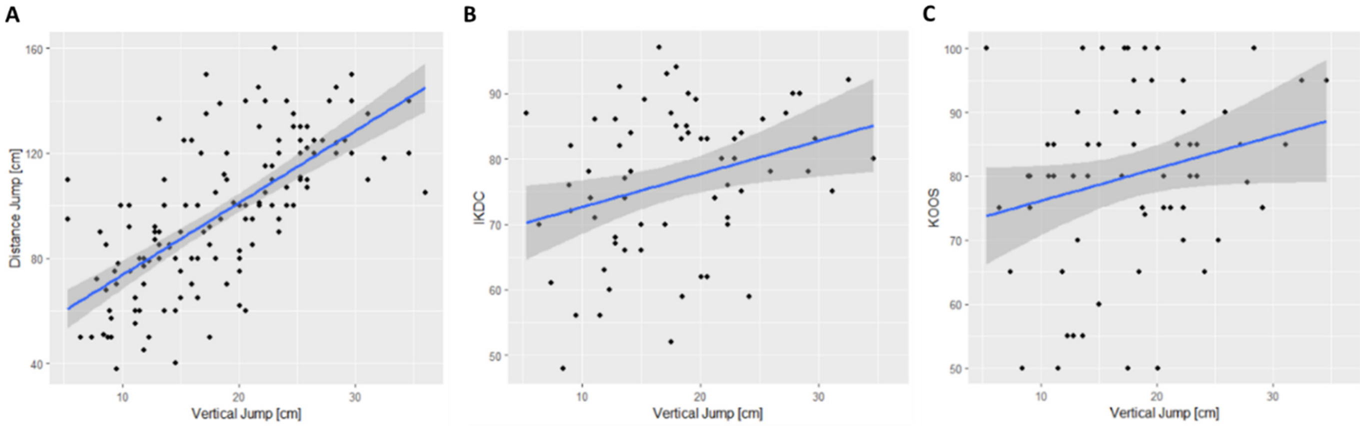

Figure 3. Correlation of the jump height of the single-leg vertical jump test with the injured leg with (**A**) the distance jump, (**B**) the IKDC SKF and (**C**) the KOOS value at 6 months postoperatively.

4. Discussion

Functional testing after ACL-R is a complex field and has become more common in recent years, serving as a valuable tool for assessing and monitoring patients' progress throughout the recovery process. It is still under debate as to which return-to-sport testing battery or combination of tests can provide a reliable predictive value for return-to-sport decision making. Furthermore, differences in test standardisation, measuring techniques and interpretation make it difficult to implement tests in clinical practice.

Previous research has demonstrated that the SLVHT is sensitive to functional deficits at the knee joint, and it is better able to detect asymmetries when compared to horizontal hop tests, suggesting it as a useful tool for global evaluation [32]. To our knowledge, the SLVHT has not been monitored during rehabilitation over time in bigger cohorts to investigate whether it can measure progress in joint function accurately and independently over time.

The main finding of this study was that three months after ACL-R, the SLVHT jump height was significantly lower in the injured leg compared to the non-injured leg. The jump height of the injured leg increased significantly from three to six months after surgery. In common rehabilitation protocols after ACL-R and also in this study, patients start with running activities, plyometric training and jumping exercises after 3 months. Consequently, a change in knee function and muscle force between these two time points could be expected. The significant increase in jump height can therefore be explained by the bigger training load and neuromuscular adaption. The SLVHT seems to display this change objectively.

Return-to-sport test batteries differ throughout sports and age groups, and it is debatable whether the results might be affected by gender-specific characteristics such as body composition and other factors influencing knee movement. Our study population represented a typical group of ACL patients, with a wide age range and about one-third of them being female patients. Subgroup analysis showed that the female patients had a lower absolute jump height compared to males. This is expected, since muscle strength is generally higher in men than in women. However, the LSI did not differ between men and women. In addition, the regression analysis showed that gender was not an independent factor influencing the jump height of the injured leg. Therefore, the LSI of the vertical jump height may be independent of gender, and changes throughout the rehabilitation process might not be influenced by this. We therefore hypothesise that the SLVHT may be a suitable tool for assessing rehabilitation progress for both men and women.

Moreover, younger patients (under 30 years of age) had a higher jump height during the SLVHT with the non-injured leg, and the LSI values at 3 and 6 months differed between younger and older patients. This difference may reflect faster rehabilitation progress in the younger age group and quicker adaption to the training load [16]. It is commonly known that younger athletes tend to be involved in higher levels of sport than older patients [33,34]. Hence, a better neuromuscular basis and functional status might be assumed in younger patients, and the LSI of the SLVHT seemed to reflect these differences reliably.

To verify our hypothesis, regression analyses was performed, and it showed that the jump height during the SLVHT with the injured leg was determined solely by the jump height of the non-injured leg, and the LSI was independent of other potentially confounding factors, as discussed above.

Rehabilitation outcomes after knee joint surgery are often recorded with subjective measurement instruments such as the IKDC SKF and KOOS-QoL questionnaires [14,30]. Higher values of these scores parallel the course of rehabilitation after ACL-R [35]. In the present study, the SLVHT jump height correlated with these established scores at 6 months postoperatively, demonstrating that subjective perception is well represented by the objectively measurable jump height.

To objectively measure functional performance during rehabilitation after ACL-R in clinical settings, the single-leg hop for distance is an alternative test that is widely used and has also been included in the International Knee Documentation Committee (IKDC) objective form [11]. A jump distance of 90% that of the non-injured side (LSI) was used as a criterion for a return to contact sports [13,14]. It is under debate as to whether horizontal or vertical hop tests provide better functional information on the joint status and how these tests should be combined in different settings. Interestingly, in our study, the jump height in the SLVHT with the injured leg correlated with the jump width during the distance hop at 6 months postoperatively. Conclusively, both tests tend to represent similar muscle activation patterns and neuromuscular demands and are responsive to functional improvement. However, it was shown previously that the vertical jump height is more sensitive than the horizontal jump value in detecting functional deficits [17] and that the SLVHT is more reliable in detecting functional asymmetries after ACL-R [32,36]. Furthermore, in our experience, the SLVHT can be performed earlier after surgery than distance hops. In our study, most patients did not have sufficient confidence in their injured leg to perform a maximal single-leg distance hop after three months. In contrast, none of the patients who came for follow-up after three months refused to perform an SLVHT.

In addition, the landing phase of a distance hop may produce shear forces that increase the risk of re-injury [37]. Therefore, this jump is usually performed late in rehabilitation when sufficient stability of the knee can be expected. In this study, the SLVHT could be performed after only 3 months without adverse events. Previously, we showed that 80% of the patients after ACL-R were able to perform the SLVHT as early as 8 weeks post-surgery [38].

These results are supported by the fact that the SLVHT results with the injured leg did not differ between patients with isolated ACL-R and those with ACL-R with meniscal involvement in our study. Repair of the meniscus often requires a limitation on the range of motion and/or a prolonged time to partially bear weight on the injured leg. Even though we did not differentiate between meniscal repair and resection, additional restrictions in the first 6 weeks after surgery did not seem to affect the jump height after 3 or 6 months. We explain these differences with the fact that muscular status is mostly affected by partial weight bearing. Regardless of a meniscal repair, almost all our patients were allowed to bear full weight after 3 weeks, except for those with complicated buckle handle tears, which are rare. So, we assume that both groups started training at the same point, after 6 weeks, with only minor differences in neuromuscular status. Furthermore, the SLVHT applies mainly vertical forces to the joint, which do not stress the meniscus as torsional or shear forces, so the SLVHT seems to be a safe tool even after meniscal surgery.

Functional testing, in recent years, sometimes even with on-field testing for athletes, has high technical and personnel resource requirements that have made it only available for professional athletes and specialised institutions. With further developments in recent years, alternative techniques have been introduced to determine jump heights with less technical effort [22,23,39] to make such testing more clinician-friendly and available for a broader audience. Using sensor technology during an SLVHT, as used in this study, the jump height can be accurately measured in a clinical setting or at a routine follow-up visit without referring the patient to a specialised training facility that costs time and resources. The test can be performed with minimal set-up time, even in a space-constrained environment. As the digital sensor is connected to a tablet app, test values can be easily transferred to a digital database via Bluetooth and displayed immediately. This makes it possible to demonstrate and discuss the results immediately with the patient and provide other professions that are involved in the rehabilitation process, such as trainers and physiotherapists, with the data. Because of the central digital database, larger groups of patients could easily be enrolled in a multicentre setting. With such larger datasets, it would be possible not only to document and manage rehabilitation progress at an individual level, but also to compare the results of different surgical techniques, such as the choice of graft for ACL-R. Trainer-administered tests can also ensure standardisation of the test and high-quality data collection.

4.1. Limitations

This study had some limitations. In the subgroup analysis of jump height by gender and age, the number of patients in each group was lower, so the results of these comparisons must be interpreted with caution. Further analyses of the results with regard to aspects of surgical treatment such as the graft choice were not part of this analysis. Only patients not fulfilling the return-to-sport criterion of LSI > 90% at six months were recommended for further training and retesting, and most of these patients did not return to our clinic for testing at later time points. In addition, as is usual in clinical routine, no preoperative data were collected that would allow the calculation of other scores (e.g., EPIC [40]). Also, the IKDC SKF and KOOS-QoL parameters were only assessed at 6 months.

4.2. Clinical Implications

The SLVHT is a functional, sensitive and safe test that can easily assess rehabilitation progress in terms of lower limb strength. As the jump height measurement on the SLVHT have a strong correlation with isokinetic testing and various other hop tests [41], it can be used as a safe, low-cost and time-efficient alternative to traditional non-performance-based criteria such as the time to surgery and PROMS, even in patients after meniscal injury. Digital technology that offers pseudonymised data collection from various other tests may allow us to create a large-scale rehabilitation registry that could help surgeons and trainers to better evaluate various aspects of surgical techniques or rehabilitation protocols. Finally, patients must be counselled preoperatively that rehabilitation may take up to 12 months, and functional testing should be performed routinely to monitor their longitudinal progress.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14083143/s1, Table S1: Univariate correlations between jump heights during single-leg vertical hop test (SLVHT) at 6 months post-operatively and different parameters; Table S2; Multivariate linear regression analysis for the jump height with the injured leg during single-leg vertical hop test (SLVHT) 6 months postoperatively; Table S3: Stepwise multivariate linear regression analysis for the jump height with the healthy leg during single-leg vertical hop test (SLVHT); Figure S1: Univariate correlations between jump heights during single-leg vertical hop test (SLVHT) at 6 months post-operatively and (A) Jump Height with the healthy leg; (B) Limb Symmetry Index (LSI).

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