TITLE: Are single limb hopping scores the same when performed in a physical education class versus a laboratory setting in uninjured adolescents?

Implications for future rehabilitation guidelines for adolescents with knee injuries.

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ABSTRACT

This study compared the performance of adolescents (11-13 years old) in two environments with five single-limb hopping tasks. The purpose was to assess the reproducibility and responsiveness of single-limb hop tests in two environments (gymnasium and laboratory) for uninjured adolescents, and determine whether there are differences in baseline measures between males and females. Thirty-four participants (12 ± 0.3 years) were randomly assigned the gymnasium during a regularly scheduled physical education class or the laboratory and completed five single-limb hop tasks. Two weeks later, participants completed the tasks in the other location. The performances were evaluated for reproducibility (intra-class correlation coefficients [ICC], and standard errors of measurement [SEM]), and responsiveness (Bland-Altman analyses [BA], and smallest real difference [SRD]). Limb symmetry indices (LSI) were also calculated for each task. Two-way mixed ANOVAs examined location and sex differences. All hops were reproducible (ICC = 0.62-0.88) with SEMs ranging between 6.7-13.0% of the mean of the group. BA showed location differences for the triple hop on the dominant limb (d = -13.3 cm, p=0.03). SRDs ranged between 18.5-35.9% of the mean of the group for all hops. Males scored higher (percent difference (%D) = 9.9-21.4%, p<0.05) for all hops except the anterior hop on both limbs, the 6-meter timed hop and lateral hop on the non-dominant limb. LSIs were 93.5-102.6% and 94.4-101.7% for all hopping task for females and males, respectively. In conclusion, this battery of single-limb hop tests offer a reliable method for clinicians and researchers to assess the functional capacity of uninjured adolescents in various environments.

1. INTRODUCTION

Approximately 75% of children and adolescents in North America participate in some form of organized sport [1]. Unfortunately, more sports-related injuries are being reported and account for approximately 66% of all injuries in this population [2]. Of those injuries, more than 50% occur in the lower extremities, with the knee and ankle accounting for many of these injuries that often lead to rehabilitation and, in some cases, surgical intervention [3]. Moreover, the risk for a subsequent injury is higher after a primary injury [4]. Despite the impact of these injuries, and considering adolescent females have a 1.5 time higher risk of a season-ending lower extremity injury compared to boys [5], there is surprisingly very limited sex-specific research on functional testing in an adolescent population.

Single-limb hop testing is one of the most common assessments to determine post-injury, post-surgical, and post-recovery/rehabilitation return-to-activity readiness in the lower extremities [6–8]. Four single-limb hop tests were developed and have been shown to be sensitive indicators of post-injury deficits in adult males [9,10]. Multiple authors have also established reliability [11,12]; however, these single-limb hop tests have yet to be evaluated in an adolescent population and between sexes. It is also crucial to consider the environment in which functional performance is assessed during physical activities. Current testing is based in a closed environment such as a laboratory or clinician's office. These closed environments may not challenge the patient in the same way as an open environment, which is especially important when considering the environmental context within which actual activities and sports take place [13]. Several laboratory-based experiments have confirmed an increased injury risk when movements are performed with additional cognitive or visual stimuli [14,15]; however, typical functional testing does not incorporate different environments, which may limit a true assessment of the patient's performance. It is therefore important to ensure these tests can be performed outside a laboratory setting by measuring and establishing the reproducibility due to the varying locations and responsiveness of the scores within adolescent males and females to detect real and potentially clinically important changes over time.

Although limb symmetry indices (LSI) are commonly used to assess the functional capacity in adults with and without injuries [6,16]; there is limited evidence for its use in adolescent populations. Most studies calculate the LSI by dividing the dominant limb by the non-dominant limb's score with an accepted threshold of 0.90 indicating symmetry [17,18]. However, some studies have begun reporting lower thresholds in adolescents [19], and differences in asymmetry direction based on the task [20]. This highlights the need to further examine this population's performance during functional testing.

Injury recovery among adolescents differs from adults, given the complex multifactorial nature of puberty [21]. As such, when evaluating an adolescent patient's recovery from injury, it is important to have insight into the functional capacity with respect to their age, sex, maturation state, and activity-matched cohort since it is with those individuals that they will be returning to full activity once they have recovered from their lower extremity injury. It is also important to ensure these tests can be performed outside the laboratory in a less controlled environment such as a gymnasium during a physical activity class and provide similar results. Therefore, the purpose of this study was to: i) assess the reproducibility and responsiveness of a battery of single-limb hop tests in two environments (open: physical activity class; and, closed: laboratory) for an uninjured adolescent population, and ii) determine whether there are differences in baseline measures between adolescent males and females. Once test-retest reproducibility has been established in an adolescent population, these measures can be used in various environments by clinicians, strength and conditioning professionals, and researchers alike.

2. METHODS

2.1 Study Design

A multi-center (open: physical education class and closed: laboratory) counter-balanced study was designed to compare the performance of uninjured adolescent males and females with a battery of single-limb hop tests on two separate occasions with a 2-week interval. The testing session occurred during a regularly scheduled physical education class in a gymnasium providing an open environment with visual and auditory distractions whereas the laboratory session provided a closed, controlled environment with a maximum of four participants rotating through stations of the single-limb hopping tasks at one time. Hop performances were evaluated by the same team of trained researchers in both locations.

2.2 Participants

Thirty-four adolescent participants, aged 11-13 years (18 females) were recruited from a local high school, and were randomly separated into two groups, with sex counterbalanced and began their first testing session either at the gymnasium or the laboratory. All participants provided informed consent, and approval for the study was obtained from the Institutional Research Ethics Board.

At the laboratory session, participants had their height and weight recorded and then completed two questionnaires: the Hospital for Special Surgery Pediatric Functional Activity Brief Scale (HSS Pedi-FABS) in English or French [22,23], to assess physical activity levels and the Tanner Stage self-assessment for indicating their developmental stage in puberty [24,25]. Limb dominance was established as the limb typically used for mobility (i.e. kicking a soccer ball) while the non-dominant limb contributes to support [26]. Participants were deemed eligible for the study if they were injury-free at the time of testing.

2.3 Procedure

The first group completed the series of hop tasks at the gymnasium and the second group completed the hops in the laboratory. Two weeks later, participants completed the protocol in the opposite location. Participants were instructed to perform single-limb hops in a randomized order on each limb as described in previous studies including the anterior- (ANT), triple- (TRP), cross- (CRS), and 6-meter timed hop test (6m) [9,10]; a maximal lateral hop (LAT) was also added (Figure 1A-E). A minimum of one-minute rest between trials was provided and all hop tests were performed at a self-selected pace. Each participant was provided a demonstration from the researcher before completing two practice trials on each limb. Participants were instructed to jump as far as they could for the ANT, LAT, TRP and CRS hops without pausing between jumps for the TRP and CRS, and to jump as fast as they could for the 6m hop test. Participants then completed a minimum of three good trials, consisting of using proper technique (hands on their hips throughout testing), being in control throughout the task and holding the landing for a minimum of two seconds. Standardized shoes were provided in the laboratory to control for variability in shoe type as part of a larger study, and the participants wore their personal footwear during their physical education class in the gymnasium setting. It was assumed that the different shoes would not have a significant effect on hopping performance.

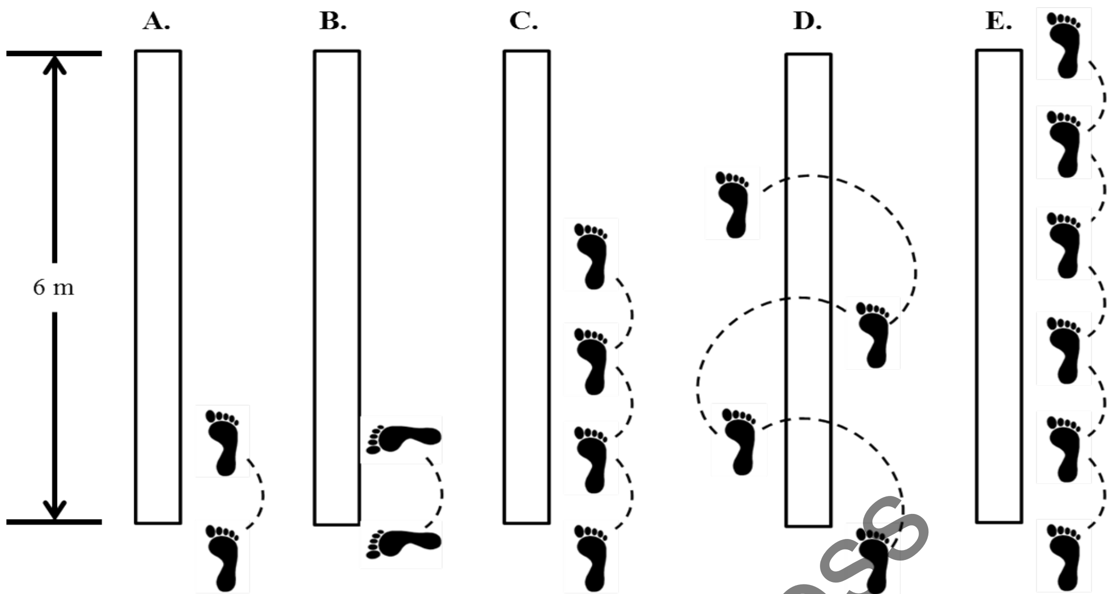

FIGURE 1. Single-limb hop tests on the right foot: A) anterior hop; B) lateral hop; C) triple hop; D) cross hop; and E) 6-meter timed hop.

2.4 Statistical Analyses

All variables were assessed for skewness/kurtosis and normality (Shapiro-Wilks tests). All statistical analyses were performed using SPSS (V25, IBM Corporation, Armonk, NY, USA) with the level of statistical significance set at alpha = 0.05. Independent t-tests (or the non-parametric equivalent, Mann-Whitney U-tests) were used to evaluate group differences (female vs male) on the following variables: demographics and anthropometrics, questionnaires, and LSIs for all single-limb hop tests. Dependent t-tests (or the non-parametric equivalent, Wilcoxon tests) were used to evaluate between limb differences within each group for the spatiotemporal variables.

2.4.1 Reproducibility

Test-retest reproducibility. Test-retest reproducibility was defined as the degree to which the measurement error is related to the variability between the participants' performance on each single-limb hop test in both locations [27]. The test-retest reproducibility of each single-limb hop test was examined using the intra-class correlation coefficients (ICC), a two-way random-effects model with absolute agreement. The ICC calculated the ratio of the variance between participants and the total variance by assuming that the participants formed a random sample of a population [27]. ICC values less than 0.40 were deemed poor, between 0.40 and 0.75 were moderate, 0.75-0.90 were good and greater than 0.90 were excellent [28]. The assessors remained the same between sessions for each task reducing the potential for measurement error.

Agreement. Agreement quantifies the relationship between two measurements made on the same participant during the first and second sessions of hop tests and was expressed on the measurement scale (i.e., meters or seconds) [27]. The standard error of measurement of agreement (SEM) represented the error variance [27]. SEM% was also calculated as a measure of reproducibility percentage against the mean scores [29]. Systematic differences between the two limbs measured in the gymnasium and at the laboratory were investigated with Bland & Altman (BA) analysis [30], by plotting the mean difference found between the limbs in each location against the standard deviation (SD) of the calculated difference. The limits of agreement (LOA) were calculated as the mean difference ± 1.96 times the SD of the differences [30].

2.4.2 Responsiveness

The ability to detect clinically relevant changes of the within-participant test-retest differences over time was defined as responsiveness [31]. BA plots were used to visualize variations around the zero line if the mean difference between the two measures was significantly different from 0.0 cm [30]. If BA analyses indicated no large systematic differences regarding the LOA, the smallest real difference (SRD) was calculated as $1.96 \times \sqrt{2} \times SEM$ and responsiveness as a percentage of the mean was calculated as $(SRD/mean) \times 100$ to represent the smallest measurement change and could be interpreted as a real (clinical) difference for a single individual based on the LOA [32].

2.4.3 Limb Symmetry Index

The hop distances and times of the dominant and non-dominant limbs were compared at both sessions with paired *t*-tests. LSIs were then calculated for each test by dividing the score of the non-dominant limb by the dominant limb's score, multiplied by 100 [33].

An analysis of variance (ANOVA) was performed to assess the ICCs, SEMs, and SRDs. To determine whether there were location and sex differences, a mixed ANOVA was used with locations being the within-subject factor and sex, the between-subject factor. Dependent *t*-tests were also performed to examine the learning effect between visit 1 and visit 2.

3. RESULTS

Participants' demographics including age, height, body mass and puberty stage did not differ ($p > 0.05$) between sexes and were (mean ± SD): 12.0 ± 0.3 years, 1.58 ± 0.08 m, 50.1 ± 12.6 kg, and 3 ± 1, respectively. All participants were physically active (16 ± 6 and 23 ± 5 for females and males respectively). Male participants scored on average higher than females on the HSS/FR Pedi-FABS questionnaire ($p < 0.01$) and were more active ($p < 0.001$) while no other differences existed in the population's demographics. As such, hop performances (Table 1) were not normalized to the participants' height.

Table 1: Means and standard deviations of performance for each single-limb hop test in the two test locations for males and females for the dominant (D) and non-dominant limbs (ND).

	Gymnasium (mean ± SD)				Laboratory (mean ± SD)			
Limb	D		ND		D		ND	
Sex	Male	Female	Male	Female	Male	Female	Male	Female
Anterior hop (cm)	110.1 ± 23.7	96.0 ± 20.2	107.4 ± 25.8	93.8 ± 22.3	109.4 ± 18.6	99.1 ± 15.2	106.3 ± 20.3	93.0 ± 19.2
Lateral hop (cm)	101.4* ± 19.6	83.5* ± 14.4	96.7 ± 17.0	83.3 ± 19.4	99.5* ± 14.5	87.9* ± 12.4	94.9 ± 14.5	88.3 ± 18.2

Triple hop (cm)	377.0*† ± 62.8	316.2*† ± 71.	378.6* ± 76.3	307.6* ± 66.3	388.5*† ± 55.6	331.1*† ± 52.6	376.6* ± 63.3	327.1* ± 61.5
Cross hop (cm)	307.0* ± 60.2	250.1* ± 67.9	291.1* ± 79.9	243.9* ± 70.9	305.0* ± 58.9	246.4* ± 58.9	304.8* ± 63.6	247.4* ± 58.9
Timed 6-meter hop (s)	2.70* ± 0.47	2.99* ± 0.47	2.71 ± 0.54	2.98 ± 0.57	2.60* ± 0.46	2.95* ± 0.47	2.64 ± 0.56	3.02 ± 0.52

[1] Statistically significant sex differences evaluated using dependent t-tests and Wilcoxon (* and §, respectively) and location differences (†) are identified ($p < 0.05$).

3.1 Reproducibility

ICC scores were moderate between locations for both limbs for ANT and LAT (0.62-0.70). The rest were all good between locations for both sexes (>0.75). SEM for dominant and non-dominant limbs had differences of less than 1.3 cm for ANT, 1.1 cm for LAT, 0.02 s for 6m, 0.5 cm for TRP, and 4.6cm for CRS between limbs for all jumps and the absolute values for the five tests are shown in Table 2. The SEM% ranged between 6.7-13.0% (Table 2).

Table 2: Test-retest reproducibility, agreement, and responsiveness for all participants in the laboratory versus gymnasium for the dominant (D) and non-dominant (ND) limbs.

	ICC (95% CI)		SEM (SEM%)		SRD (SRD%)		*p-value*	
Limb	*D*	*ND*	*D*	*ND*	*D*	*ND*	*D*	*ND*
Anterior hop (cm)	0.70 (0.47-0.84)	0.70 (0.47-0.84)	11.10 (10.7)	12.40 (12.4)	30.75 (29.8)	34.38 (34.4)	0.62	0.77
Lateral hop (cm)	0.65 (0.40-0.81)	0.62 (0.36-0.79)	9.96 (10.8)	11.04 (12.2)	27.60 (29.8)	30.60 (33.8)	0.56	0.52
Triple hop (cm)	0.85 (0.71-0.93)	0.88 (0.77-0.94)	26.13 (7.4)	25.64 (7.4)	72.44 (20.6)	71.07 (20.6)	0.03*	0.13
Cross hop (cm)	0.80 (0.63-0.89)	0.77 (0.59-0.88)	30.38 (11.0)	35.03 (13.0)	84.22 (30.6)	97.10 (35.9)	0.70	0.34
Timed 6-meter hop (s)	0.81 (0.65-0.90)	0.86 (0.73-0.93)	0.19 (6.7)	0.21 (7.4)	0.52 (18.5)	0.59 (20.7)	0.13	0.82

[1] Statistically significant differences ($p < 0.05$) between locations are identified (*).

3.2 Responsiveness

The BA analysis mean (*d*) and LOA values are shown in Table 3. There was a significant location bias for the laboratory for the dominant limb's TRP scores (d = -13.3 cm; LOA = -81.9 – 55.3 cm; $p < 0.05$). Higher biases were found in the laboratory for the dominant ANT, dominant and non-dominant LAT, non-dominant TRP, and non-dominant CRS. Higher biases were found in the gymnasium for the non-dominant ANT, dominant and non-dominant 6m, and dominant CRS. Absolute values in SRD for the five tests are shown in Table 2. The SRD% ranged between 18.5-35.9% (Table 2).

Table 3: Bland-Altman analysis summary with the mean and limits of agreement between the laboratory and gymnasium for the dominant and non-dominant limbs.

Limb	Dominant limb (*d*(LOA))	Non-dominant limb (*d*(LOA))
Anterior hop (cm)	-1.3 (-32.4 – 29.8)	0.9 (-34.0 – 35.8)
Lateral hop (cm)	-1.4 (-29.3 – 26.5)	-1.8 (-32.6 – 29.1)
Triple hop (cm)	13.3 (-81.9 – 55.3)*	-9.4 (-79.1 – 60.3)
Cross hop (cm)	2.9 (-105.4 – 89.0)	-8.2 (-105.4 – 89.0)
Timed 6-meter hop (s)	0.88 (-0.02 – 0.68)	0.01 (-0.59 – 0.60)

[1] Statistically significant differences ($p < 0.05$) between locations are identified (*).

3.3 Limb Symmetry Index

No statistical location differences were found between LSIs. The mean LSIs were 96.3±8.9% for ANT, 97.7±9.2% for LAT, 101.1±9.5% for 6m, 98.4±9.2% for TRP, and 98.2±12.8% for CRS with the scores for each sex and location displayed in Table 4. The percent of participants who had LSI above 100% for the different hops ranged between 22.2-66.7% and 25.0-62.5% in either location for females and males, respectively (Table 4).

Table 4: Limb symmetry indices (LSI) and number of participants who scored above 100% between locations (laboratory vs gymnasium) for the battery of single-limb hop tests for males and females.

Sex	Single-limb hop test	Laboratory		Gymnasium	
		LSI (%) (mean ± SD)	# participants > 100 LSI	LSI (%) (mean ± SD)	# participants > 100 LSI
Females	Anterior hop (cm)	93.5 ± 9.1	4	97.3 ± 7.6	6
	Lateral hop (cm)	99.8 ± 11.9	12	99.0 ± 7.8	6
	Triple hop (cm)	98.7 ± 9.1	11	97.8 ± 10.1	11
	Cross hop (cm)	100.6 ± 12.1	7	97.7 ± 12.3	5
	Timed 6-meter hop (s)	102.6 ± 8.6	8	100.0 ± 10.6	7

Males	Anterior hop (cm)	97.2 ± 8.8	6	97.4 ± 10.3	5
	Lateral hop (cm)	95.7 ± 8.0	5	95.9 ± 8.2	6
	Triple hop (cm)	96.9 ± 8.4	10	100.1 ± 9.6	7
	Cross hop (cm)	100.1 ± 9.7	4	94.4 ± 16.6	8
	Timed 6-meter hop (s)	101.7 ± 10.0	7	100.2 ± 9.4	6

3.4 Baseline Measures and Sex Differences

The mean distances and times were 101.5 ± 21.3 cm, 91.6 ± 17.3 cm, 348.6 ± 69.6 cm, 272.8 ± 69.8 cm, and 2.83 ± 0.52 s respectively for ANT, LAT, TRP, CRS, and 6m. A significant main effect of sex for LAT, $F(1, 32) = 9.918$, $p < 0.05$, 6m, $F(1, 32) = 4.302$, $p < 0.05$, TRP, $F(1, 32) = 8.599$, $p < 0.05$, and CRS, $F(1, 32) = 8.522$, $p < 0.05$ was found on the dominant limb; and TRP, $F(1, 32) = 7.351$, $p < 0.05$, and CRS, $F(1, 32) = 5.564$, $p < 0.05$ on the non-dominant limb, where males jumped significantly farther and faster than female participants (Table 1). Furthermore, significant improvements in scores were found over the two sessions except for the 6m on both limbs. The mean differences between the second and first visits for the dominant and non-dominant limbs respectively were 8.0 ± 13.7 cm and 8.8 ± 15.4 cm for ANT, 10.4 ± 9.6 cm, and 12.0 ± 10.1 cm for LAT, 18.1 ± 32.7 and 15.4 ± 33.3 cm for TRP, and 28.9 ± 32.3cm and 33.3 ± 37.18 cm for CRS ($p < 0.01$). Finally, a significant effect of location was found for the TRP ($p < 0.05$), where both groups jumped significantly farther in the laboratory than during their physical education class in the gymnasium on their dominant limb.

4. DISCUSSION

The objectives of this study were to: i) determine whether a battery of single-limb hop tasks could be reproducible and responsive in an adolescent population, and ii) determine whether sex differences existed. This study demonstrated that this battery of single-limb hop tasks is a highly reproducible and responsive method to assess the functional capacity of adolescents and their performances in both a laboratory and during a regularly scheduled physical education class. This study also found important sex differences that must be considered when evaluating functional capacity in adolescents.

This is the first study to determine the test-retest reproducibility of the anterior, lateral, triple, cross and 6-meter timed hop tests in an adolescent population. In line with previous studies on adults, the test-retest reproducibility coefficients for each of the single-limb hop tests were moderate to good (> 0.60) [12]. In addition, the 95% CI for all tests was narrow [34], indicating good agreement. The ICC provides information about the reproducibility between two or more locations [28], and includes the variance term for individuals and is therefore affected by sample size heterogeneity, meaning that high correlations can still mean unacceptable measurement error [35]. In the present study, we further analyzed the absolute agreement, which is unaffected by the range of measurements using the SEM [29,32]. The smaller the SEM, the more reliable and reproducible the measurement, often used to interpret the results of a true improvement after an intervention. The SRD also allows clinicians to determine whether a change in hop distance or time reflects a true change, rather than irrelevant variations when repeatedly testing an individual. The SRDs in Table 2 were 18.5-35.9% of the mean of the group, and similar across the different hop tests. This suggests that an improvement between 18.5-35.9% reflects a true change in performance when retesting an adolescent individual. These percentages are slightly higher than previous studies evaluating the test-retest of the anterior, triple, cross and timed hop [11,12,17]. Our study population is however comprised of recreationally active adolescents performing in both a closed and open environment suggesting a higher variability in SEMs and SRDs may be more reflective of this population.

When establishing baseline measures for an uninjured adolescent population, the LSI, typically used as an outcome measure in return-to-activity guidelines following an injury to the lower extremity [36–38], must be examined. Most studies calculate LSI in uninjured individuals by dividing the score of the dominant limb by the non-dominant limb's score and obtain an average of >90% [17,39]. Munro and colleagues (2011) found a mean LSI between 98.4-101.6% for the original set of four single-limb hop tests [17], which is in line with the results of our study (93.5-102.6% and 94.4-101.7% for females and males, respectively). However, a mean LSI of 100% or greater may mask the asymmetries of adolescents within an uninjured group as the dominant limb used in tasks requiring both limbs such as kicking a ball, may not be the same in unilateral tasks such as jumping and landing [26]. Approximately 44% (range of 22-66.7% depending on jumping task) of adolescents scored higher on their self-reported non-dominant limb compared to their dominant limb on any given single-limb hop task

To further establish baseline measures for an adolescent population, it is important to ensure that the number of practice and test trials, and location do not influence the results. Ross and colleagues (2002) examined the test-retest reliability of the anterior, triple, cross and 6-meter timed hops in eighteen adult cadet males and had three practice trials followed by three test trials with a four-week interval between testing days [12]. Others had 1-3 practice trials and 2-4 test trials with a one-week interval between testing days [11,17]. All studies consistently revealed significant improvements in scores between sessions that could be attributed to a learning effect. Our study used two practice trials and three test trials with a two-week interval between sessions and found significant improvements in all hops except for the 6-meter timed hop on both limbs. However, no significant differences in distances or times were found between locations except for the triple hop on the dominant limb. Although significant improvements from the first to the second testing session were found, we believe the lack of significance between locations in our adolescent population suggests that the battery of hop tests can be performed within acceptable limits of error in a gymnasium and laboratory. This learning effect should be taken into consideration within this population and further examined over repeated monthly intervals for 6-12 months or the length of a rehabilitation program for a serious lower extremity injury such as an anterior cruciate ligament injury. The repeated testing of these hopping tasks in adolescents would be beneficial since many rehabilitation programs use the patient's performance at different phases of rehabilitation to determine readiness to return to full activity.

Finally, the results of our study indicated there were sex differences within the scores of the hop tasks regardless of location. Female participants improved their performance in the laboratory compared to the gymnasium except for the cross-hop, whereas male participants scored higher for all hopping tasks except the timed 6-meter hop in the gymnasium. While it is difficult to speculate on why males and females responded differently, factors that may contribute include the psychosocial and physical nature associated with participation in different sports and activities. For example, females are more likely to engage in individual sports and activities, whereas males typically engage in team sports or group activities [40], and the data collections done in the gymnasium were conducted in a group setting. These results suggest that the functional capacity of males and females should be evaluated separately when applying scores from one environment to another.

5. CONCLUSION

The battery of single-limb hop tests examined in this study offers clinicians, scientists and strength and conditioning experts a reliable method to assess the functional capacity of uninjured, adolescent males and females in various testing environments. This data and the methods can be used to guide LSI measures in adolescent males and females with lower extremity injury. Athletes participating in multidirectional sports often must multitask and providing an environment that more closely resembles an unplanned situation may provide a more accurate reflection of functional capacity and performance. Therefore, the performances obtained in a gymnasium during a regular physical education class may be an alternative option for patients to bring their scores directly to clinicians and health care providers to evaluate functional capacity compared to the traditional laboratory setting when such a facility is not available. These may also begin serving as baseline values for comparison of performance for adolescent individuals who have sustained a lower extremity injury.

REFERENCES

[1] The National Federation of State High School Association. 2018-19 High School Athletic Participation Survery. 2019.

[2] Werner BC, Yang S, Looney AM, et al. Trends in Pediatric and Adolescent Anterior Cruciate Ligament Injury and Reconstruction. J Pediatr Orthop. 2016;36:447–452.

[3] Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. J Athl Train. 2007:311–319.

[4] Salmon L, Russell V, Musgrove T, et al. Incidence and risk factors for graft rupture and contralateral rupture after anterior cruciate ligament reconstruction. Arthrosc J Arthrosc Relat Surg. 2005;21:948–957.

[5] Fernandez WG, Yard EE, Comstock RD. Epidemiology of Lower Extremity Injuries among U.S. High School Athletes. Acad Emerg Med. 2007;14:641–645. Doi: 10.1111/j.1553-2712.2007.tb01851.x.

[6] Cristiani R, Mikkelsen C, Edman G, et al. Age, gender, quadriceps strength and hop test performance are the most important factors affecting the achievement of a patient-acceptable symptom state after ACL reconstruction. Knee Surgery, Sport Traumatol Arthrosc. 2020;28:369–380.

[7] Mattacola CG, Perrin DH, Gansneder BM, et al. Strength, functional outcome, and postural stability after anterior cruciate ligament reconstruction. J Athl Train. 2002;37:262–268.

[8] Sharma N, Sharma A, Sandhu JS. Functional Performance Testing in Athletes with Functional Ankle Instability. Asian J Sports Med. 2011;2:249–258.

[9] Noyes FR, Barber SDS, Mangine RRE. Abnormal Lower Limb Symmetry Determined by

Function Hop Tests After Anterior Cruciate Ligament Rupture. Am J Sports Med. 1991;19:513–518.

[10] Barber SD, Noyes FR, Mangine RE, et al. Quantitative assessment of functional limitations in normal and anterior cruciate ligament-deficient knees. Clin Orthop Relat Res. 1990;255:204–214.

[11] Dingenen B, Truijen J, Bellemans J, et al. Test-retest reliability and discriminative ability of forward, medial and rotational single-leg hop tests. Knee. 2019;26:978–987.

[12] Ross MD, Langford B, Whelan P. Test-retest reliability of 4 single-leg horizontal hop tests. J Strength Cond Res. 2002;16:617–622.

[13] Davies GJ, McCarty E, Provencher M, et al. ACL Return to Sport Guidelines and Criteria. Curr Rev Musculoskelet Med. 2017;10:307–314.

[14] Borotikar BS, Newcomer R, Koppes R, et al. Combined effects of fatigue and decision making on female lower limb landing postures: Central and peripheral contributions to ACL injury risk. Clin Biomech. 2008;23:81–92.

[15] Brown TN, Palmieri-Smith RM, McLean SG. Sex and limb differences in hip and knee kinematics and kinetics during anticipated and unanticipated jump landings: Implications for anterior cruciate ligament injury. Br J Sports Med. 2009;43:1049–1056.

[16] Johnson MR, Stoneman PD. Comparison of a Lateral Hop Test Versus a Forward Hop Test for Functional Evaluation of Lateral Ankle Sprains. J Foot Ankle Surg. 2007;46:162–174.

[17] Munro AG, Herrington LC. Between-session reliability of four hop tests and the Agility T-test. J Strength Cond Res. 2011;25:1470–1477.

[18] Barber-Westin SD, Noyes FR. Factors Used to Determine Return to Unrestricted Sports

Activities After Anterior Cruciate Ligament Reconstruction. J Arthrosc Relat Surg. 2011;27:1697–1705.

[19] Girard CI, Warren CE, Romanchuk NJ, et al. Decision Tree Learning Algorithm for Classifying Knee Injury Status Using Return-to-Activity Criteria. Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS, vol. 2020- July: Institute of Electrical and Electronics Engineers Inc.; 2020: 5494–5497.

[20] Mulrey CR, Shultz SJ, Ford KR, et al. Methods of identifying limb dominance in adolescent female basketball players: Implications for clinical and biomechanical research. J Sports Med. 2020;30:279–281.

[21] Labella CR, Hennrikus WL, Hewett TE. Anterior Cruciate Ligament Injuries : Diagnosis , Treatment , and Prevention. Pediatrics. 2014;133:e1437–e1450.

[22] Fabricant PD, Robles A, Downey-Zayas T, et al. Development and Validation of a Pediatric Sports Activity Rating Scale. Am J Sports Med. 2013;41:2421–2429.

[23] DelBel MJ, Kemp LG, Girard CI, et al. Translation and Validation of the Hospital for Special Surgery Pediatric Functional Activity Brief Scale for French Paediatric Populations. Physiother Canada. 2020:e20190033.

[24] Marshall WA, Tanner JM. Variations in pattern of pubertal changes in girls. Arch Dis Child. 1969;44:291–303.

[25] Marshall WA, Tanner JM. Variations in the pattern of pubertal changes in boys. Arch Dis Child. 1970;45:13–23.

[26] van Melick N, Meddeler BM, Hoogeboom TJ, et al. How to determine leg dominance: The agreement between self-reported and observed performance in healthy adults. PLoS One. 2017;12:1–9. Doi: 10.1371/journal.pone.0189876.

[27] DeVet HCW, Terwee CB, Knol DL, et al. When to use agreement versus reliability measures. J Clin Epidemiol. 2006;59:1033–1039.

[28] Fleiss JL. The design and analysis of clinical experiments. vol. 73. John Wiley & Sons; 2011.

[29] Lexell JE, Downham DY. How to Assess the Reliability of Measurements in Rehabilitation The Sports-Related Injuries and Illnesses in Paralympic Sport Study (SRIIPSS) View project. Am J Phys Med Rehabil. 2005;84:719–723.

[30] Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;327:307–310.

[31] Guyatt G, Walter S, Norman G. Measuring change over time: Assessing the usefulness of evaluative instruments. J Chronic Dis. 1987;40:171–178.

[32] Beckerman H, Roebroeck ME, Lankhorst GJ, et al. Smallest real difference, a link between reproducibility and responsiveness. Qual Life Res. 2001;10:571–578.

[33] Abrams GD, Harris JD, Gupta AK, et al. Functional Performance Testing After Anterior Cruciate Ligament Reconstruction: A Systematic Review. Orthop J Sport Med. 2014;2:1–10.

[34] Lai K, Kelley K. Accuracy in parameter estimation for targeted effects in structural equation modeling: Sample size planning for narrow confidence intervals. Psychol Methods. 2011;16:127–148. Doi: 10.1037/a0021764.

[35] Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sport Med. 1998;26:217–238.

[36] Schmitt LC, Paterno M V., Ford KR, et al. Strength Asymmetry and Landing Mechanics at Return to Sport after ACL Reconstruction. Med Sci Sports Exerc. 2015;47:1426–1434.

[37] Toole AR, Ithurburn MP, Rauh MJ, et al. Young athletes cleared for sports participation after anterior cruciate ligament reconstruction: How many actually meet recommended return-to-sport criterion cutoffs? J Orthop Sports Phys Ther. 2017;47:825–833. Doi: 10.2519/jospt.2017.7227.

[38] Kivlan BR, Martin RL. Functional Performance Testing of the Hip in Athletes: A Systematic Review for Reliability and Validity. Int J Sports Phys Ther. 2012;7:402–412.

[39] van Grinsven S, van Cingel REH, Holla CJM, et al. Evidence-based rehabilitation following anterior cruciate ligament reconstruction. Knee Surgery, Sport Traumatol Arthrosc. 2010;18:1128–1144.

[40] Deaner RO, Geary DC, Puts DA, et al. A Sex Difference in the Predisposition for Physical Competition: Males Play Sports Much More than Females Even in the Contemporary U.S. PLoS One. 2012;7:e49168.

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