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Reference data for hop tests used in pediatric ACL injury rehabilitation: A cross-sectional study of healthy children

Susan Warming[1] | **Tine Alkjær**[2,3] | **Robert Bennike Herzog**[1] | **Mathilde Lundgaard-Nielsen**[1] | **Mette Kreutzfeldt Zebis**[4]

[1]Department of Physical and Occupational Therapy, Bispebjerg and Frederiksberg Hospital, Copenhagen, Denmark

[2]Department of Biomedical Sciences, University of Copenhagen, Copenhagen, Denmark

[3]The Parker Institute, Bispebjerg and Frederiksberg Hospital, Copenhagen, Denmark

[4]Department of Midwifery, Physiotherapy, Occupational Therapy and Psychomotor Therapy, Faculty of Health, University College Copenhagen, Copenhagen, Denmark

Correspondence
Susan Warming, Department of Physical and Occupational Therapy, Bispebjerg and Frederiksberg Hospital, Copenhagen, Denmark.
Email: susan.warming@regionh.dk

In rehabilitation, four single-leg hop tests are frequently used for evaluation of ACL-injured children. However, reference values on single-leg hop performance and the corresponding limb symmetry indexes (LSIs) of healthy children younger than 15 years of age are lacking. Thus, the purpose was to describe hop performance and LSIs in healthy Danish children, and to quantify the proportion of participants passing LSI values of ≥85% as well as ≥90%. Healthy children aged 9–15 years were invited to participate in the study. Hop performance (single hop, 6-m timed hop, triple hop, and cross-over hop) was assessed for each leg for each hop test and expressed as absolute, normalized (to body height), and LSI values. Descriptive statistics were applied to calculate mean ±SD for all outcomes within age and gender groups. Further, the 95% reference interval was calculated for each age and gender group. A total of 531 healthy children (52% girls) were included in the study, representing seven age groups (9-15 years). The LSI group means across all participants for the four hop tests ranged between 84 and 95%. Between 70 and 83% of the children had an LSI of ≥85%, while 50 to 65% of the children had an LSI of ≥90%. The present reference material can be used in clinical practice when evaluating hop performance in pediatric ACL patients.

KEYWORDS
children, injury, knee, normative data, performance, rehabilitation, return to sport

1 | INTRODUCTION

Epidemiological studies stress that the incidence of anterior cruciate ligament (ACL) injury among children and adolescents is increasing.[1,2] Consequently, rehabilitation after pediatric ACL injury is an important clinical issue. However, consensus on how to treat ACL-injured children is lacking.[3,4] Motivated by the lack of consensus, Ardern et al. (2018) formulated a consensus statement on how to treat pediatric ACL injuries.[3] The consensus statement recommends to include single-legged hop tests in the functional evaluation and an limb symmetry index (LSI) of ≥90% as part of the return to sport (RTS) decision-making.[3] LSI is quantified by the relationship between the jump length of the injured/non-injured limb multiplied by 100%.[5] A previous study reported that more than 90% of healthy adults demonstrate LSIs of ≥85% why this level has been considered as "normal function".[5] However, the use of LSI as an indicator for functional deficiency and RTS is debated.[6-8] Therefore, assessment of functional performance among the ACL-injured population may benefit from comparisons to reference data of healthy controls.[9] A variety of single-legged hop tests are used to objectively assess function and ability to

resume sports activities in ACL-injured people but the most frequently used are (a) single hop, (b) 6-m timed hop, (c) triple hop, and (d) cross-over hop.[5,10] The reproducibility in an inter-tester reliability and test/retest design of these hop tests has been proven to be satisfactory within ACL-injured adults [11] and healthy children.[12] A reference material on these hop tests and LSI values is available for healthy sports active adults and adolescents,[5,13,14] but not for children younger than 15 years of age.

Both the absolute hop distance and the LSI are valuable functional performance outcomes.[13] However, since hop length improves with age during childhood due to growth,[15] normalizing hop performance to body height may also be relevant when evaluating hop performance in ACL-injured children.[16] Thus, comprehensive reference data on hop performance in healthy children including absolute and normalized values as well as the LSI may benefit the rehabilitation of the ACL-injured children. Accordingly, the purpose of the present study was to describe the hop performance and LSI of four clinically relevant single-leg hop tests in a group of healthy Danish children between 9 and 15 years of age. An additional purpose was to investigate the proportion of participants who demonstrated LSI values equal to or above 85% and 90%, respectively.

2 | METHODS

2.1 | Participants

Healthy Danish children from 11 different primary schools in Greater Copenhagen, Denmark, were invited to participate in the study. The data collection was initiated in 2012 and ended in 2017. The inclusion criteria were age between 9 and 15 years, healthy and no injuries or pain symptoms of the lower extremities. The children and their families were carefully provided with oral and written information about the study before the written informed consent to participate was obtained from the children's parents (or legal guardian). The study was approved by the local ethics committee (H-4–2012-FSP (50)) and was performed in accordance with the Helsinki II declaration.

2.2 | Procedures

2.2.1 | Testers

In the test period (2012–2017), 25 physiotherapist students were enrolled as testers. The testers were thoroughly educated in the test protocol and hop test instructions by a physiotherapist (RBH) with more than 12 years of clinical experience.

2.2.2 | Intra-day inter-tester reliability

As a part of the protocol, the intra-day inter-tester reliability of the four single-legged hop tests was investigated. This included twenty healthy school children with an average age of 12.3 years (range 12–13) and two testers. The testers followed the test procedures as described below and recorded the results of the four hop tests. The order of the testers was randomized, and the children were tested twice at the same day. The testers were blinded to the test results of each other.

2.2.3 | Test protocol

The participants were asked to perform four single-legged hop tests described by Noyes et al. (1991) [10] : 1) single hop (SH), 2) 6-m timed hop (6 m-timed), 3) triple hop (TH), and 4) cross-over hop (COH). The hop test instructions were given in accordance with standard procedures used for ACL-injured children treated at Bispebjerg-Frederiksberg Hospital, Copenhagen, Denmark. The test course was marked at a level floor by a 6-m-long and 15-cm-wide tape. In addition, a tape mark was placed at each end of the course to indicate the start and end line. A manual stopwatch was used for the 6 M-timed hop test.

Each hop started with the big toe of the tested leg placed at the start line. After landing, a line was drawn from the heel to the start line and the distance was tape measured. Prior to testing, the children were given a demonstration followed by a practical trial. For each of the tests, the children were given the following instructions: (a) “On one leg hop as far as possible” (SH), (b) “On one leg hop forward as quickly as possible along the 6-m test course” (6 m-timed), (c) “On one leg do three consecutive hops along the taped line as far as possible” (TH), (d) “On one leg do three hops across the taped line as far as possible” (COH). A hop was considered valid if the body was stable and balanced for 2 seconds during the final landing. The best result (longest distance or shortest time) out of two hops on each leg was recorded.[12] If the children did not reach a valid result within the two trials, they continued until one valid result was reached within a maximum of five repetitions. To avoid fatigue, the children rested for 2 minutes between each hop test. All hop tests were done with shoes on and no arm movements restrictions. All tests took place at the local schools where the children were enrolled.

2.2.4 | Limb symmetry index

To resemble the LSI used in clinical practice, that is, injured limb/non-injured limb multiplied by 100%,[5] the results of

each of the four single-leg hop tests for this normal population were divided into "best leg" representing the longest or fastest hop and "contralateral leg." Subsequently, the LSI was calculated as contralateral leg/best leg × 100%, except for the 6 m-timed hop test where it was the best leg/contralateral leg × 100%.[13]

2.3 | Statistical analyses

Before applying any statistical analyses, normal distribution of data was checked by visual inspection of boxplots. In case of non-normal distribution, data were logarithm transformed.

Descriptive statistics were applied to calculate mean ±SD for all hop performance outcomes within each individual age/gender group. For clinical purposes, 95% reference intervals were calculated (mean ±1.96 × SD on appropriate scale) for each age group.

The four hop performance test results are presented as the absolute mean ±SD values for hop length distance (cm) or time (s). In addition, the absolute hop length values of the three hop tests for distance were normalized according to body height: hop length/body height. The 6 m-timed hop test was not normalized as this performance score is independent of body size.[17] If data needed to be log transformed, before calculating mean and SD, the results were subsequently back transformed to the original scale.

Within all four hop tests and age groups, the proportion of children passing the recommended criteria of ≥85% and ≥90% indicating "normal function" and "return to sport" was calculated.

The intra-day inter-tester reliability, the ICC estimates, and their 95% confidence intervals were calculated based on a single-rating (k = 1), absolute agreement, 2-way random-effects model, ICC (2,1).

3 | RESULTS

3.1 | Participants

Out of 896 invited, 531 healthy schoolchildren accepted to participate in the study and performed all four hop tests. Demographics are presented in Table 1. Body mass and body height were measured in 453 of the participants (Table 1).

3.2 | Intra-day inter-tester reliability

The ICC (2,1) for SH was 0.87 (95% CI: 0.67–0.95), 6 m-timed 0.77 (95% CI: 0.41–0.91), TH 0.92 (95% CI: 0.79–0.97) and for COH 0.87 (95% CI: 0.68–0.95), respectively.

3.3 | Hop performance

All hop performance data were normally distributed except the 6 m-timed hop test data. The absolute and normalized

TABLE 1 Participant characteristics divided into age and gender groups

Age (yrs.)	n	Gender	n[a]	Body height (cm)	Body mass (kg)	BMI
9	30	Boys	30	139.5 ± 6.3	31.9 ± 5.0	16.1 ± 1.6
	46	Girls	46	139.7 ± 6.7	32.6 ± 4.5	16.7 ± 2.4
10	44	Boys	44	145.1 ±5.3	36.9 ± 6.5	17.4 ± 2.4
	35	Girls	35	145.6 ± 6.5	36.2 ± 5.5	17.0 ± 2.1
11	36	Boys	36	151.7 ± 7.2	41.6 ± 6.9	18.0 ± 2.4
	46	Girls	46	151.2 ± 8.2	40.0 ± 7.3	17.4 ± 2.3
12	63	Boys	43	158.3 ± 7.0	45.7 ± 7.3	18.2 ± 2.6
	65	Girls	48	158.4 ± 6.5	47.0 ± 8.5	18.7 ± 3.1
13	25	Boys	18	160.4 ± 7.1	45.1 ± 6.9	17.5 ± 1.8
	47	Girls	31	164.0 ± 7.8	52.7 ± 8.5	19.5 ± 2.4
14	29	Boys	17	172.7 ± 8.6	60.5 ± 9.2	20.3 ± 2.5
	24	Girls	18	163.7 ± 9.3	53.1 ± 8.4	19.7 ± 1.5
15	26	Boys	26	178.8 ± 7.1	64.1 ± 9.5	20.0 ± 1.9
	15	Girls	15	167.0 ± 6.2	56.4 ± 4.5	20.2 ± 1.8
In total	531		453			

Note: Values are mean ±SD.

Abbreviation: BMI, Body mass index.

[a]n = 453 (as height and body mass were not assessed in all participants).

TABLE 2 Absolute and normalized values of the single hop (SH)

		SH absolute values (cm)			SH normalized values (hop length/body height)	
Age (years)	n = 531	Best leg	Contralateral leg	n = 453	Best leg	Contralateral leg
Boys						
9	30	93.6 ± 20.2	78.7 ± 21.8	30	0.67 ± 0.14	0.56 ± 0.15
10	44	99.9 ± 18.3	87.2 ± 22.5	44	0.69 ± 0.13	0.60 ± 0.16
11	36	99.4 ± 22.5	88.4 ± 20.1	36	0.65 ± 0.14	0.58 ± 0.13
12	63	117.5 ±29.4	105.7 ± 29.1	43	0.70 ± 0.14	0.63 ± 0.14
13	25	120.8 ± 22.8	111.8 ± 23.2	18	0.73 ± 0.13	0.68 ± 0.13
14	29	134.8 ± 26.1	114.5 ± 22.7	17	0.82 ± 0.15	0.70 ± 0.12
15	26	148.0 ± 24.4	135.1 ± 22.3	26	0.83 ± 0.13	0.76 ± 0.13
Girls						
9	46	89.4 ± 19.3	76.8 ± 19.5	46	0.64 ± 0.14	0.55 ± 0.14
10	35	101.1 ± 20.7	86.2 ± 21.5	35	0.70 ± 0.15	0.60 ± 0.15
11	46	92.9 ± 21.5	81.5 ± 20.0	46	0.61 ± 0.14	0.54 ± 0.14
12	65	108.6 ± 26.6	97.5 ± 26.1	48	0.63 ± 0.14	0.57 ± 0.14
13	47	109.2 ± 23.6	97.0 ± 23.7	31	0.61 ± 0.10	0.54 ± 0.12
14	24	113.5 ± 20.3	100.5 ± 19.6	18	0.72 ± 0.13	0.64 ± 0.11
15	15	109.6 ± 20.2	99.8 ± 18.5	15	0.66 ± 0.12	0.60 ± 0.11

Note: Values are mean ±SD.

TABLE 3 Absolute values of the 6-m timed hop (6 m-timed)

		6 m-timed absolute values (sec.)	
Age (years)	n = 531	Best leg	Contralateral leg
Boys			
9	30	2.5 ± 0.3	2.8 ± 0.8
10	44	2.5 ± 0.5	2.8 ± 0.6
11	36	2.5 ± 0.5	2.8 ± 0.6
12	63	2.4 ± 0.5	2.7 ± 0.5
13	25	2.1 ± 0.4	2.4 ± 0.5
14	29	2.0 ± 0.3	2.2 ± 0.3
15	26	1.9 ± 0.3	2.1 ± 0.3
Girls			
9	46	2.6 ± 0.4	2.9 ± 0.5
10	35	2.5 ± 0.4	2.7 ± 0.4
11	46	2.7 ± 0.5	2.9 ± 0.5
12	65	2.5 ± 0.4	2.8 ± 0.5
13	47	2.3 ± 0.4	2.6 ± 0.5
14	24	2.3 ± 0.6	2.5 ± 0.5
15	15	2.4 ± 0.3	2.6 ± 0.4

Note: Values are mean ±SD.

mean ±SD hop performance values of the four hop tests for each leg (best and contralateral) for boys and girls in all seven age groups are presented in Tables 2-5. The corresponding 95% reference intervals for all hop performance results within each individual group are presented in the Appendix S1.

3.4 | Limb symmetry index

The LSI group means across all participants within the four hop tests ranged between 84 and 95% (Table 6). In total, between 70 and 83% of the children had an LSI of ≥85%, while 50 to 65% of the children had an LSI of ≥90% (Table 7, Figure 1).

4 | DISCUSSION

The present study has provided a reference material of healthy children between the age of 9 and 15 years which has not previously been available for clinical practice. The reference material that comprises hop performance and limb symmetry index of four single-leg hop tests frequently used in the rehabilitation of ACL-injured children will enable the

TABLE 4 Absolute and normalized values of the triple hop (TH)

		TH absolute values (cm)			TH normalized values (hop length/body height)	
Age (years)	**n = 531**	**Best leg**	**Contralateral leg**	**n = 453**	**Best leg**	**Contralateral leg**
Boys						
9	30	308.0 ± 60.6	278.0 ± 60.5	30	2.21 ± 0.41	1.99 ± 0.42
10	44	313.9 ± 52.0	289.7 ± 54.5	44	2.16 ± 0.36	2.00 ± 0.38
11	36	338.7 ± 61.1	309.6 ± 53.6	36	2.24 ± 0.41	2.04 ± 0.36
12	63	379.4 ± 84.4	351.4 ± 79.5	43	2.34 ± 0.48	2.15 ± 0.47
13	25	393.4 ± 70.4	359.7 ± 74.6	18	2.33 ± 0.42	2.10 ± 0.42
14	29	436.2 ± 74.0	391.8 ± 61.8	17	2.56 ± 0.44	2.30 ± 0.34
15	26	492.5 ± 60.9	467.5 ± 72.2	26	2.76 ± 0.37	2.62 ± 0.44
Girls						
9	46	291.8 ± 47.0	258.2 ± 52.0	46	2.10 ± 0.34	1.85 ± 0.36
10	35	312.2 ± 64.7	288.1 ± 64.7	35	2.16 ± 0.45	1.99 ± 0.45
11	46	304.2 ± 54.6	272.8 ± 45.4	46	2.01 ± 0.36	1.80 ± 0.31
12	65	350.8 ± 73.5	317.1 ± 83.3	48	2.08 ± 0.41	1.87 ± 0.48
13	47	362.9 ± 66.2	331.0 ± 57.7	31	2.10 ± 0.38	1.91 ± 0.32
14	24	363.5 ± 50.0	332.2 ± 55.0	18	2.21 ± 0.27	2.06 ± 0.25
15	15	353.6 ± 62.5	334.5 ± 65.7	15	2.12 ± 0.37	2.00 ± 0.38

TABLE 5 Absolute and normalized values of the cross-over hop (COH)

		COH absolute values (cm)			COH normalized values (hop length/body height)	
Age (years)	**n = 531**	**Best leg**	**Contralateral leg**	**n=453**	**Best leg**	**Contralateral leg**
Boys						
9	30	248.1 ± 60.4	208.8 ± 53.9	30	1.78 ± 0.42	1.49 ± 0.36
10	44	259.6 ± 47.1	235.6 ± 51.5	44	1.79 ± 0.34	1.62 ± 0.36
11	36	273.8 ± 61.9	240.7 ± 56.0	36	1.80 ± 0.40	1.58 ± 0.36
12	63	322.4 ± 87.8	292.2 ± 88.1	43	1.97 ± 0.52	1.78 ± 0.53
13	25	345.9 ± 77.8	309.7 ± 78.8	18	2.00 ± 0.41	1.77 ± 0.38
14	29	366.8 ± 71.6	335.9 ± 60.9	17	2.12 ± 0.42	1.96 ± 0.38
15	26	427.9 ± 79.8	395.8 ± 78.9	26	2.40 ± 0.45	2.22 ± 0.44
Girls						
9	46	228.9 ± 62.9	203.0 ± 54.1	46	1.64 ± 0.44	1.45 ± 0.38
10	35	256.3 ± 55.6	230.9 ± 55.2	35	1.77 ± 0.38	1.59 ± 0.39
11	46	251.6 ± 56.5	216.3 ± 47.3	46	1.66 ± 0.38	1.43 ± 0.32
12	65	285.4 ± 75.0	257.3 ± 73.8	48	1.72 ± 0.43	1.53 ± 0.43
13	47	298.5 ± 67.3	276.3 ± 69.8	31	1.74 ± 0.33	1.60 ± 0.38
14	24	293.5 ± 58.3	271.5 ± 50.2	18	1.81 ± 0.29	1.71 ± 0.25
15	15	277.9 ± 62.7	261.3 ± 62.7	15	1.67 ± 0.36	1.56 ± 0.35

Note: Values are mean ±SD

TABLE 6 Limb Symmetry Index (LSI) in percentage for the four hop tests presented as mean ± SD

Age (yrs.)	Gender	n	SH	6 m-timed	TH	COH
9	Boys	30	84.0 ± 11.8	89.5 ± 9.3	90.4 ± 9.6	84.8 ± 10.9
	Girls	46	86.1 ± 12.1	91.7 ± 7.9	88.3 ± 8.4	89.2 ± 9.2
10	Boys	44	86.6 ± 11.7	91.5 ± 6.2	92.4 ± 7.6	90.3 ± 7.5
	Girls	35	85.3 ± 11.1	91.9 ± 6.9	92.1 ± 5.6	90.2 ± 9.1
11	Boys	36	89.5 ± 8.9	91.0 ± 6.8	91.8 ± 7.0	88.5 ± 10.0
	Girls	46	87.7 ± 7.8	92.1 ± 6.9	90.1 ± 6.7	86.6 ± 9.8
12	Boys	63	89.7 ± 8.1	90.9 ± 6.7	92.7 ± 6.0	90.1 ± 8.5
	Girls	65	89.7 ± 8.9	90.5 ± 7.7	91.7 ± 6.7	89.7 ± 8.8
13	Boys	25	92.4 ± 6.7	89.5 ± 7.1	91.2 ± 6.8	89.4 ± 8.2
	Girls	47	88.5 ± 9.3	92.5 ± 6.0	91.6 ± 6.1	92.4 ± 7.6
14	Boys	29	85.3 ± 10.1	93.1 ± 6.3	90.3 ± 6.8	92.0 ± 6.4
	Girls	24	88.9 ± 9.9	91.7 ± 7.8	91.3 ± 8.3	92.9 ± 6.0
15	Boys	26	91.4 ± 5.8	92.0 ± 6.4	94.6 ± 4.5	92.4 ± 6.3
	Girls	15	91.4 ± 7.2	89.2 ± 8.0	94.5 ± 5.6	93.9 ± 4.6

Note: Contralateral leg against the best leg except for the 6-m timed hop where it is opposite.

Abbreviations: 6 m-timed, 6-m timed hop; COH, cross-over hop; SH, single hop; TH, triple hop.

TABLE 7 Percentages of healthy children (across all age groups (Total) and within each individual age group) with LSI ≥85% and LSI ≥90%

	Total	Age 9 (n = 76)	Age 10 (n = 79)	Age 11 (n = 82)	Age 12 (n = 128)	Age 13 (n = 72)	Age 14 (n = 53)	Age 15 (n = 41)
LSI ≥85%								
SH	70% (n = 373)	58%	62%	65%	76%	79%	68%	90%
6 m-timed	81% (n = 432)	79%	78%	82%	80%	83%	89%	80%
TH	83% (n = 438)	71%	81%	82%	87%	82%	83%	95%
COH	74% (n = 392)	50%	56%	44%	77%	86%	85%	90%
LSI ≥90%								
SH	50% (n = 263)	47%	38%	46%	55%	60%	45%	54%
6 m-timed	65% (n = 347)	71%	59%	70%	61%	67%	72%	61%
TH	65% (n = 346)	58%	59%	60%	70%	61%	57%	80%
COH	57% (n = 304)	50%	56%	44%	59%	60%	70%	73%

Abbreviations: 6 m-timed, 6-m timed hop; COH, cross-over hop; SH, single hop; TH, triple hop.

clinician to evaluate ACL-injured children in relation to their healthy peers. In addition, the normalized data add information about the relationship between hop length and body height when growing up, which may be taken into consideration by the clinician when evaluating ACL-injured children. The hop tests were found to have moderate to excellent intra-day inter-tester reliability.[18] These findings concur with previous inter-tester reliability observed among healthy children performing the exact same hop tests as in the present study.[12]

The present results indicate that using LSI as a single parameter for evaluating "normal function" or RTS may not be sufficient. Overall, 3/4 of the healthy children reached "normal function" whereas only ~60% passed the RTS criterion. Thus, asymmetry in hop performance between legs appears to be relatively pronounced even in healthy children. Limb symmetry in hop performance is complex, and in case of ACL injury, this may be further complicated. Several studies have questioned the usability of LSI in hop tests as a single indicator of RTS as the leg symmetry may be influenced by either reduced strength of the uninjured leg,[19] or the injured leg.[6] Further, a recent systematic review found only weak evidence that LSI of ≥90% would reduce the risk of a secondary ACL injury after RTS in an adult population.[19] To accommodate some of these concerns, Wellsandt et al. (2017) suggested to use the estimated preinjury capacity (EPIC) of the non-injured limb (test of the non-injured limb before reconstruction) instead of the LSI.[7] However, hop performance on the non-injured limb prior to surgery may be influenced by fear avoidance or lack of motivation, especially among children.[19] Thus, normative data and the corresponding reference intervals divided into gender and age groups, as presented in this study, could be a more appropriate way of assisting the clinician in the evaluation of the child with an ACL injury. It is, however, important to

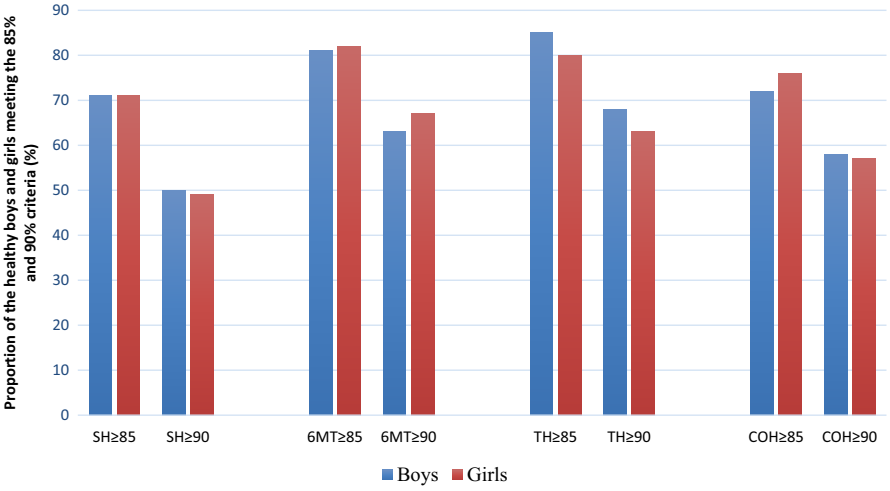

FIGURE 1 Proportion of healthy boys and girls meeting the LSI of ≥85% and ≥90% criteria representing "normal function" and return to sport, respectively, for the four hop test. Abbreviations: 6MT, 6-m timed hop; COH, cross-over hop; SH, single hop; TH, triple hop

emphasize that in clinical practice, hop tests and LSI do not stand alone. Outcome measures such as knee laxity, range of motion (ROM), muscle strength and patient-reported outcome measures (PROMs) also form an important part of the evaluation and decision-making for RTS.[4]

The importance of dividing normative data of children into both gender and age groups is based on studies of biological maturity. Golle et al. (2015) assessed longitudinal data on age- and sex-specific physical fitness percentiles in healthy children aged 9–12 years and found that the hop test performance increased with increasing age.[20] Gender divergence in athletic performance has been reported to begin at the age of 12 with the timing and tempo closely related to the rise in circulating testosterone in boys during puberty.[21] Seger et al. (2000) found that until the age of 11, boys and girls exhibit equal anthropometric measures and strength performance.[22] In both genders, body measures and muscle strength increased significantly during a following 5-year period, however, with larger increases being recorded for the boys.[22] The maximum growth rate (peak height velocity) during the adolescent growth spurt occurs around 12 years of age in girls and 14 years of age in boys.[23]

As the purpose of the present study was purely descriptive, no analyses of differences in hop performance between the groups were applied. However, the mean values presented in Table 1 point toward that girls were taller and heavier than the boys at the age of 13 years while the boys aged 14–15 years appeared to be taller and heavier than their female peers supporting the reported difference in the timing of growth spurt in boys and girls. Inspection of the normalized hop for distance test values indicates that body height largely evens out the hop performance across the age groups within the girls suggesting that an increase in anthropometric measures is not necessarily followed by neuromuscular adaptations (eg, increased power, strength, and coordination). In contrast, normalization did not seem to equalize hop performance across age groups within the boys as much as in the girls (see eg, normalized SH performance of the 15 years old boys versus the 9-year-old boys, Table 2). To fully confirm these potential age/gender differences, application of appropriate statistical analyses is needed, which would be relevant to conduct in a future study.

4.1 | Limitations

This study is subject to limitations. The present study is a cross-sectional study whereas the strongest study design would have been a longitudinal study with repeated measurements to follow changes in individual growth, maturation, and hop performance. However, the present reference values follow similar trends as reported in previous longitudinal work.[20]

The present study included a random sample of healthy schoolchildren but did not use a stratified sample design and may therefore not be representative of the entire population of Danish children and adolescents. However, the study included healthy schoolchildren irrespectively of their engagement in different sport activities or physical activity levels and thus represent a random sample of both sport active and more sedentary children. That is in contrast to previous published reference materials where focus has been on sport active adolescents.[9,10]

5 | PERSPECTIVES

We suggest that this reference material may be used by clinicians for evaluation of hop performance in the pediatric ACL patient. With this, it is possible to estimate if hop performance of ACL-injured children is within the normal range of their healthy peers, and with the possibility to monitor this over time.

DATA AVAILABILITY STATEMENT

Data available on request from the authors—that is, the data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Susan Warming https://orcid.org/0000-0002-4108-8008
Tine Alkjær https://orcid.org/0000-0002-9105-3882
Mette Kreutzfeldt Zebis https://orcid.org/0000-0001-5301-3241

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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