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ORIGINAL RESEARCH

NORMATIVE DATA FOR HOP TESTS IN HIGH SCHOOL AND COLLEGIATE BASKETBALL AND SOCCER PLAYERS

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ABSTRACT

Purpose/Background: Objective, reliable, and valid functional tests may assist with the decision-making process for rehabilitation as well as assist in pre-participation screening for targeted interventions to prevent noncontact lower extremity injuries. The purpose of this study was to determine normative values in high school and college basketball and soccer players for four hop tests: the single hop for distance, the triple hop for distance, the crossover hop for distance, and the 6-m timed hop.

Methods: A sample of convenience of 372 (185 females, 187 males) healthy high school and collegiate student-athletes were included in the study (mean age 17.37 years, range 14-24): 200 were soccer players and 172 were basketball players. Limb dominance was determined based on which extremity participants would choose to kick a ball for distance. A coin flip was used to determine which limb was tested first. Hop test order was randomized using a Latin square design. Participants performed one practice hop and three measured hops for each hop test on each limb. The average hop score for each limb was used for calculations.

Results: Significant differences in test performance were found between sexes and levels of competition, $p < 0.0005$, with males performing better than females and collegiate athletes performing better than high school athletes for all hop tests. There were no clinically relevant differences between dominant sports. There were also no clinically relevant differences between dominant and non-dominant limbs. Normative values for each hop test were proposed, based on sex and level of competition.

Conclusions: These findings indicate that separate hop test standards should be used based on participant sex and level of competition. While some statistically significant differences were found between limbs, these differences did not appear to be functionally relevant. Further studies are needed to determine if sport-specific normative hop test values should be utilized and to examine normal limb symmetry indices in specific populations.

Levels of Evidence: 2A

Key Words: ACL, return to sport, hop test, functional performance testing

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INTRODUCTION

More than 7.4 million U.S. high school students participate in competitive athletics today.[1] The overall injury rate per 1,000 hours of athletic exposure was 1.97 for high school athletes[1] and 12 for collegiate athletes.[2] Fifty-seven to 70% of injuries occur in the lower extremity.[1,3-8] Some sports have an inherently higher risk for injury, such as football and ice hockey, where collision-related injuries are common. However, many injuries occur without contact.[5-8] The most common, and the most severe, non-contact injury in terms of time lost from competition is an anterior cruciate ligament (ACL) rupture. Many non-contact ACL injuries may be preventable[9,10] through improvements in athlete neuromuscular control, skill performance, and conditioning.

An ACL rupture can be devastating to an athlete's competitive career. While one study noted that 65 - 80% of athletes who sustain an ACL tear returned to play within one year of ACL reconstruction (ACLR),[11] a more recent study[12] revealed that only 34% of athletes returned to full competition, while another 33% were only able to partially return to competition. Thirteen percent of athletes discontinued training due to their ACL injury. The risk of a repeat ACL injury or contralateral ACL injury in returning athletes ranges from 3-15%.[13-17] Last, many athletes report their ACL injury was the reason for their eventual early retirement.[18]

Given these high rates of ACL injuries, repeat injuries, and persisting functional deficits, there is a need for better athlete preparation, rehabilitation, and safer return to sport.[16] In their recent systematic review of the literature, Barber-Westin and Noyes illustrated this knowledge gap by noting that 40% of investigators failed to use any criteria to determine when an athlete may be ready to return to sport after ACLR.[19] Another 32% of investigators noted time post-surgery as the sole criteria.[19]

When choosing criteria, clinicians must choose tests that are objective, reliable, and valid. In addition, tests need to be practical in terms of the equipment and time required. The tests should also entail little or no risk to the rehabilitating athlete. Criteria should also have accepted normative values in order to allow relevant comparisons.[20] Historically, impairment-based testing has been the norm. However, it is now known that impairments such as knee joint range of motion,[21] manually tested joint laxity,[21-23] proprioception testing,[24] and isotonic[25,26] or isokinetic[21,27-29] strength testing have little correlation with successful return to sport.

Functional performance tests are meant to simulate a portion of the competitive environment in a controlled fashion. While many authors support the use of functional testing to determine functional performance,[27-30] the question of what functional tests are most appropriate remains unanswered. Given current knowledge that the uninvolved side can compensate for the involved extremity,[31,32] bipedal tasks may mask the impairments and functional deficits that occur after unilateral lower extremity injuries.[33-35] Hop tests, the single hop for distance, the triple hop for distance, the crossover hop for distance, and the 6-m timed hop, are unilateral functional performance tests with extensive research supporting their reliability and/or validity.

Because of the disproportionate percentage of female athletes with ACL injuries, it is important to identify if there are any differences in hop test performance between sexes. Maturation has been found to lead to sex differences in landing forces,[36] vertical jump performance,[36-38] and cutting.[39] Barber-Westin's study[40] demonstrated an interaction between age and sex for both drop landing and crossover hopping. Therefore, it would appear wise to compare hop tests results with individuals of similar age and sex.

It is also unclear if athletes from different sports would be expected to achieve similar hop test scores. For example, basketball and soccer are both high-risk sports for ACL injuries. Both sports require quick stops/starts and cutting maneuvers. However, when compared with soccer, basketball requires significantly more jumping and significantly less running. It is unclear whether sport specific demands lead to different hop test scores or if all athletes perform similarly.

Hop tests are typically scored by computing a limb symmetry index (LSI) by comparing the involved lower extremity to the uninvolved. However, there are some concerns regarding the use of the uninvolved limb as the sole standard for the involved limb with any objective testing. The uninvolved

limb's abilities may decline during the rehabilitation process and may be affected by prior injury or surgery.[29,41] Additionally, an athlete may have perfect limb symmetry and yet be underprepared to compete because both extremities are much weaker or more poorly controlled than the "average" individual.[34,41] Unfortunately, with the exception of DeCarlo and Sell's 1997 study[42] of the single hop for distance in high school athletes (average age 14 years, sports unknown), there are no normative data available for hop test performance.[20]

The purpose of this study was to determine normative values in high school and college basketball and soccer players for four hop tests: the single hop for distance, the triple hop for distance, the crossover hop for distance, and the 6-m timed hop. Two secondary purposes were to assess test-re-test reliability and to assess differences between dominant and non-dominant limbs.

METHODS

A total of 372 high school and collegiate (Division I and Division II) student-athletes were included in the study (mean age 17.37 years, range 14-24): 200 soccer players and 172 basketball players comprising eight main groups defined by sex, level of competition, and sport (Table 1). A sample of convenience was recruited from high school and college soccer and basketball leagues. Inclusion criteria for the study were: voluntary participation; signed participant consent or signed parental consent and participant assent; 14 – 25 years of age; member of a competitive soccer or basketball team; and currently participating in practices/games without restriction. Participants were excluded if they had prior ankle, knee, or hip surgery.

All testing was performed at team facilities by a single examiner. Testing was performed on dry, level, debris-free surfaces, such as a basketball court, weight room floor, or artificial turf. Participants wore athletic shoes of their choosing. Due to the potential for surface irregularities, testing was not performed on grass. Two 15m fiberglass measuring tapes (Champion Sports, Winston-Salem, NC) were fixed to the test surface 15 cm apart. A start line and a 6-meter line were taped to the surface.

Table 1. *Participants age data*

	Female		Male		Total Sample	
	n	Age*	n	Age*	n	Age*
High school basketball	50	15.20 (14,17)	50	15.96 (14,18)	100	15.58 (14,18)
High school soccer	50	15.00 (14,18)	50	15.58 (14,17)	100	15.29 (14,18)
Collegiate basketball	35	19.14 (17,22)	37	19.68 (17,23)	72	19.42 (17,23)
Collegiate soccer	50	19.48 (18,22)	50	19.78 (18,24)	100	19.63 (18,24)
Total	185	17.05 (14,22)	187	17.62 (14, 24)	372	17.33 (14,24)

n = number, * = Mean in years (range)

Informed consents/assents were obtained prior to testing. Participants were verbally asked about their surgical history. Limb dominance was determined by asking participants which limb they would use to kick a ball for distance.[43] All athletes performed at least a 10 minute warm-up of basic lower extremity stretching[25] and a general warm-up exercise (e.g. jogging, agility drills, or sport-specific activities). A coin flip determined which limb was tested first.[44] Test order was randomized using a Latin square design, which was repeated every four test groups.

Hop tests were conducted according to previously described methods.[45] Participants were asked to perform one submaximal trial of the first hop test to familiarize himself/herself with the task.[46] Participants then performed three maximal trials that were recorded on one limb followed by the other. The average of the three trials was used for statistical analysis.[47] Participants repeated this format for each of the three remaining tests. Distance was recorded to the nearest cm.[45] The timed hop was recorded to the nearest hundredth of a second using a stopwatch (NB Coach Digital 30-Lap Chronograph stopwatch, Brighton, MA).[45] Participants had approximately 30 seconds rest between trials and approximately one minute rest between tests.[48] Because upper extremity movement is a usual component of hop performance, there were no restrictions on arm motion during testing.[47,49] To establish reliability, 15 participants were retested 48-72 hours after initial testing.[50] The study was approved by the Institutional Review Board of the University of Indianapolis.

Statistical Analysis

Data was analyzed using SPSS version 21 for Macintosh. As some of the hop tests in the reliability study were not normally distributed (Shaprio-Wilk $p < 0.05$), Friedman's ANOVA was used to determine the differences between day 1 and day 2 scores for

each leg. The Wilcoxon Signed Rank test, with an $\alpha = 0.025$, was performed to determine within group differences between dominant and nondominant limbs for each of the eight main groups. The Mann Whitney test, with an $\alpha = 0.0125$, was performed to determine main effect differences between sex, level of competition, and sport. In all cases, a Bonferroni adjustment was applied to decrease the risk of a type I error.

RESULTS

There were no statistically significant differences between day 1 and day 2 hop test scores, $p > 0.05$, indicating good test-retest reliability.

Because the Wilcoxon Signed Rank test indicated significant differences between dominant and non-dominant limbs for three of the 32 hop tests (Table 2), dominant and non-dominant limb scores were analyzed separately. The Mann Whitney test indicated that males performed significantly better than females, $p < 0.0005$, for both dominant and non-dominant limbs on all four hop tests. This was true overall and for both levels of competition.

The Mann Whitney test indicated that collegiate athletes performed significantly better than high school for both dominant and non-dominant limbs, $p < 0.0005$, on all four hop tests. This was true for the whole sample and for both sexes. The Mann Whitney test indicated that overall male basketball players performed significantly better than male soccer players on all distance hop tests, $\alpha = 0.0125$ (all ps < .01), but there were no significant differences (dominant limb $p = .34$, non-dominant limb $p = .05$) between sports for the two timed hop tests (Table 3). Effect sizes for overall males on the distance hops were small to medium, ranging from $d = .38$ to $d = .66$. Effect sizes for all males on the 6-m timed hop were negligible to small, $d = .14$ for the dominant limb and $d = .29$ for the non-dominant limb. For female athletes, the Mann Whitney test indicated no significant differences between basketball and soccer players for all four hop tests at the $\alpha = 0.0125$ level, with p-values ranging from .28 to .89. Effect sizes for female athletes were negligible to small, $d = .02$ to $d = .20$. When examined by level of competition, the Mann Whitney test indicated no significant differences between sports on any hop test at the $\alpha = 0.0125$ level, p- values ranging from .016 to .134 for high school athletes and .055 to .711 for college athletes. Effect sizes for level of competition were negligible to small, $d = .03$ to $d = .19$.

Table 2. *Statistically Significant Dominant versus Non-dominant Lower Extremity Hop Tests*

Group	Hop Test	Mean Differences	p-value	Literature Reported SEM
Male high school	Single hop*	2.76 cm	p=0.005	4.56 – 7.93 cm
Female college	6-m hop	0.04 sec	p=0.041	0.08 – 0.21 sec
Female college	Triple hop	8.42 cm	p=0.009	15.44 - 23.18 cm

SEM = standard error of measurement
*= Non-dominant limb superior to dominant limb

Table 3. *Male Soccer versus Male Basketball Player Results*

Hop Test	Median Differences	p-value	Literature SEM
Single hop			
Dominant	3.34 cm*	p=.011	4.56 – 7.93 cm
Nondominant	6.17 cm*	p<.0001	
6-m timed hop			
Dominant	0.025 sec*†	p=.338	0.08 – 0.21 sec
Nondominant	0.015 sec*†	p=.053	
Triple hop			
Dominant	26.83 cm	p<.0001	15.44 - 23.18 cm
Nondominant	23.66 cm	p<.0001	
Crossover hop			
Dominant	24.17 cm	p=.0001	15.95 – 21.16 cm
Nondominant	14.83 cm	p=.002	

SEM = standard error of measurement
* = median difference < SEM in the literature
†= no significant difference between sports

DISCUSSION

Significant differences in hop test performance were found between sexes and levels of competition. The differences between sexes and levels of competition were several times greater than the SEM cited in the literature. Therefore, these differences appear functionally relevant with male athletes performing better than female athletes and college athletes performing better than high school athletes for all hop tests.

The findings of differences between sexes are similar to previous studies in which males performed better than females.[42,51-55] The consistent differences between sexes across all comparisons are in contrast with two studies. The interaction between age and sex with functional testing noted in these two

studies[36,38] was in younger athletes and specifically examined pre-post pubescent changes, whereas the current study examined a cross-section of two more mature age groups. Therefore, it would be unwise to compare the results of the present study with studies involving pre-pubescent athletes.

The statistically significant differences in hop performance between levels of competition is not surprising given that the athletes who continue beyond the high school level are more likely to have superior skill sets. The differences between high school and collegiate athletes may also be the result of physical maturation. The current findings are consistent with, and expand upon the work of Barber-Westin, Noyes, and Galloway,[40] who demonstrated that muscle strength increases with age in male and female athletes in a variety of youth sport leagues. The single hop test results of the current study for high school athletes are slightly greater than those from DeCarlo and Sell's study.[42] This difference may be due to the greater mean age of the high school participants or differences in sport participation within the subjects in the current study.

With regard to sport, basketball is more of a game of jumping and soccer more of a game of running, but both sports require speed and changes of direction. Intuitively, one would expect basketball players to perform better on the distance hops and for all athletes to perform similarly on the timed hop. However, this was not borne out in the analyses. The results of this study demonstrate an interaction between sport and sex. Female athletes of both sports performed similarly on all hop tests. In contrast, male basketball players performed statistically better on distance hops than soccer players. The mean differences between sports for male athletes were 4.76 cm for the single hop, 25.25 cm for the triple hop, and 19.5 cm for the crossover hop. These differences do not appear to be functionally relevant given the literature SEM (4.56 cm - 7.93 cm for the single hop, 15.44 cm - 23.18 cm for the triple hop, and 15.95 cm - 21.16 cm for the crossover hop). Additionally, these small differences between sports are well within the standard deviations of the proposed normative values, making them clinically irrelevant. While not specifically tracked, several participants were multi-sport athletes, which may have affected the results.

Table 4. *Proposed Normative Values*

Test	Male College	Female College
Single hop (cm)	192±20	149±17
6-m timed hop (sec)	1.74±0.21	2.13±0.20
Triple hop (cm)	632±72	470±53
Crossover hop (cm)	570±75	406±54
Test	**Male High School**	**Female High School**
Single hop (cm)	181±20	129±18
6-m timed hop (sec)	1.91±0.23	2.25±0.24
Triple hop (cm)	583±72	428±54
Crossover hop (cm)	522±77	375±60

At this time, there is not enough evidence to support the use of sport-specific standards for hop tests.

The authors agree that professionals should use caution when purely relying upon limb symmetry for the assessment of hop test performance.[20,34] Based on the results of this study, hop test scores should be evaluated based on normative data that are specific to the individual's sex and level of competition as well as the individual's limb symmetry index. Table 4 provides suggested normative data for the subjects of this study for each of the four hop tests. Normative values were determined by combining dominant and non-dominant data for each group of participants. Statistically significant differences were found between limbs in three of the 32 hop tests (mean differences between limbs were 2.76 cm for male high school single hop, 0.04 sec for female college 6-m timed hop, and 8.42 cm female college triple hop). These differences were not functionally relevant because all were within the SEM noted in the literature[46,48,52] (4.56 cm - 7.93 cm for the single hop, 15.44 cm - 23.18 cm for the triple hop, and 0.08 sec to 0.21 sec for the 6-m timed hop) and all were less than the standard deviations of the proposed normative values.

Limitations

There are three limitations to this study. Despite the adjusted alpha level, there is the potential for a type I error. Next, while the study included a much larger number of subjects and more well defined groups of athletes than previous studies in the literature, only high school and collegiate soccer and basketball players were included. Therefore, the findings may not be generalizable to broader groups such as recreational athletes, athletes who compete in other sports, or older athletes. Finally, the inclusion of

individuals with previous non-surgical injuries of the lower extremity may have affected the results of the study. However, it would be highly unlikely that a large study population of high school and collegiate athletes could be found without a prior ankle sprain or other minor injury. The inclusion/exclusion criteria chosen were meant to permit the prototypical athlete to participate in the study, improving the study's external validity.

There are three key areas for future research on hop tests. First, studies are needed to examine limb symmetry indices within large populations grouped by age, sex, activity level, and prior injury/surgery. Second studies should strive to determine if sport-specific or position-specific normative values are required. Third, studies are needed to determine if there are any correlations between hop test performance and future lower extremity injuries or athletic prowess (accolades received).

CONCLUSION

The results of this study demonstrated differences in hop test performance between sexes and between levels of competition. Therefore, hop test scores should be evaluated as *both* a comparison with known distance and time standards based on sex and level of competition and relative to an individual athlete's limb symmetry index.

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