ASSESSMENT OF THE LOWER EXTREMITY FUNCTIONAL AND MUSCULAR PERFORMANCE IN YOUNG FEMALE HANDBALL ATHLETES

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Abstract:

A low physical fitness and incorrect technique could result in muscle strength imbalance and poor dynamic/static balance in handball players. This study aimed to evaluate the muscular and functional performance of lower limbs in female handball athletes. Twelve female handball athletes performed isokinetic tests at 60°/s, 120°/s, 180°/s, and 240°/s for the knee's extensor and flexor muscles and functional tests for lower limbs. Regarding the muscular performance, there were no differences between the limbs in the knee's muscles' peak torque, while the values of the conventional ratio were below the recommended. With respect to the functional tests, no significant changes were observed. On the other hand, the composite score of the Y-Balance test demonstrated values below the suggested. Overall, the results showed that young female handball athletes had symmetry between the limbs in the muscular and functional performance; however, there was a tendency to muscle imbalance (hamstrings weaker than quadriceps), and dynamic balance deficits that might increase the risk of musculoskeletal injury.

Keywords: *young female athletes, team handball, muscle strength, functional evaluation*

Introduction

Handball is an Olympic sport and one of the most popular sports in the world. It is a sport in which two teams of seven players each (one goalkeeper and six outfield players) play on a court 20x40 meters (Ingebrigtsen, Jeffreys, & Rodahl, 2013). The game is characterized by intermittent periods of high-intensity actions such as sprints, jumps, throws, and body contacts, interspersed by less intensive activities such as standing, walking, and jogging (Ingebrigtsen, et al., 2013; Moss, McWhannell, Michalsik, & Twist, 2015). Thus, a high physical fitness and variability of movements such as accelerations, shots, changes of directions, stops, and jumps are required from the players (Ingebrigtsen, et al., 2013; Moss, et al., 2015). Players need to have various neuromuscular skills such as throwing accuracy, running speed, jumping ability, muscle power, endurance, strength, and the dynamic and static balance of joints of the lower limbs (Manchado, Tortosa-Martínez, Vila, Ferragut, & Platen, 2013). These high-intensity specific sport demands allied with low physical fitness and an incorrect technique of skill execution could result in the development of bilateral muscle strength imbalances and poor dynamic/static balance in athletes, which have been reported as risk factors for injuries and also of performance decline (Kramer, et al., 2019; Raya-González, Clemente, Beato, & Castillo, 2020).

The knee and the ankle are the most injured body areas in handball players (Bedo, Manechini, Nunomura, Menezes, & Da Silva, 2019), due to the role these joints have in specific movements, for example, jumps, decelerations, accelerations, and landings, controlled by quadriceps (knee extensors) and hamstrings (knee flexors) (Raya-González, et al., 2020; Xaverova, et al., 2015). In addition, handball players present incidence values between 1.7 to 7.8 injuries/1000 hours of exposure (Giroto, Hespanhol-Junior, Gomes, & Lopes, 2017). Furthermore, injuries occur more frequently in female than male athletes, mainly teenagers (Giroto, et al., 2017).

Isokinetic dynamometry provides an objective analysis of muscle function and muscular imbalances through the quantification of muscular strength (Xaverova, et al., 2015). This method evaluates and compares muscular strength between the dominant limb (DL) versus the non-dominant limb (NDL) and may provide quantification of a variety of muscle function indices (e. g. peak torque and conventional hamstrings/quadriceps ratio [H/Q ratio) (Paul & Nassis, 2015). The conventional H/Q ratio needs to be around 60% at low speeds (60°/s to 180°/s), and between 80% to 100% at higher speeds (240°/s) (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008; Risberg, et al., 2018). For bilateral comparisons, a difference higher than 15% in the asymmetry index suggests an increased risk of injury (Cheung, Smith, & Won del, 2012; Dauty, Menu, Foausson-Chailloux, Ferréol, & Dubois, 2016).

Functional tests are used to evaluate joint stability, balance, proprioception, agility, muscular coordination, and muscular strength (Kramer, et al., 2019). Main advantages of these tests are: low cost, easy application, and they are considered open field tests (Kramer, et al., 2019). Specifically, for assessing the lower limbs, the most used are the hop tests and Y-Balance Test (YBT) (Brumitt, Heiderscheit, Manske, Niemuth, & Rauh, 2013; Coughlan, Fullam, Delahunt, Gissane, & Caulfield, 2012). These two methods complement each other and provide valuable information about the neuromusculoskeletal system. However, few studies have investigated muscular imbalances in the lower limbs through the isokinetic test (Bonetti, et al., 2018; Haddad, et al., 2019; Xaverova, et al., 2015) and the functional performance through functional tests (Barendrecht, Lezeman, Duysens, & Smits-Engelsman, 2011; Briem, Ragnarsdóttir, Árnason, & Sveinsson, 2016; Sabido, Hernández-Davó, Botella, Navarro, & Tous-Fajardo, 2017) in young handball athletes. Hence, this study aimed to describe the knee's muscular performance and the lower limbs' functional performance in young female handball athletes.

Materials and methods

Experimental approach to the problem

This research used a cross-sectional design to investigate the muscular and functional performance of thein DL and NDL lower extremities in young female handball athletes. This study was conducted in Centro Clinico at the University of Caxias do Sul, in Caxias do Sul, Rio Grande do Sul, Brazil. The research was approved (protocol number 3.361.817) by the Ethical Committee at the University of Caxias do Sul and conducted according to the Helsinki Declaration and 2012 Law N° 466 of the National Health Council, which approves the guidelines and rules for research involving humans.

Participants

Fifteen young female handball players, who participated in clubs competing at a national level, volunteered to participate in this research. Three players were excluded from the study because they did not appear on one of the two evaluation days. Overall, 12 participants (13.92±0.66 years of age) completed the research. Subjects were eligible for inclusion if they were regularly training on the team and signed the Written Informed Consent by themselves and their parents or legal guardians. The exclusion criteria were: an acute illness on one of the two evaluation days, an acute neuromusculoskeletal injury, a missing practice in the last three training sessions, an injury to the lower limb sustained 30 days prior to the assessment, not had participated in one of the two evaluation days, and cognitive impairment that may interfere with informed consent and assent or study instructions. Written Informed Consent was obtained from all participants and their parents.

Anthropometric characteristics

The anthropometric characteristics of the players are summarized in Table 1. The data show that the mean age of athletes was 13.92±0.66 years, while their body weight and height were 57.25±9.97 kg and 1.63±0.06 meters, respectively. Concerning the body mass index, it was 21.32±2.96 kg/m^2, and this value refers to normal body weight according to the World Health Organization (World Health Organization, 2020). The athletes practiced handball three times per week for 90 minutes each session, and their experience in the sport was 3.41±1.73 years. Ten athletes reported the right lower limb dominance, one athlete had left lower limb dominance, while one was ambidexter. The method used to determine lower limb dominance was the self-preferred kicking limb (Brown, Wang, Dickin, & Weiss, 2014).

Table 1. Means ± standard deviations of anthropometric characteristics of young female handball athletes

Variable	M±SD
Age (year)	13.92±0.66
Body weight (kg)	57.25±9.97
Body height (m)	1.63±0.06
Body mass index (kg/m^2)	21.32±2.96
Training experience (year)	3.41±1.73

Sample size

The sample size was established by convenience through research in the selected team, according to the number of athletes and their availability for participation in the research. Thus, the sample number was determined intentionally and not probabilistically.

Procedures

The assessments were performed in the preseason period on two days with a minimum interval of 48 hours between the tests. The order in which the test would be performed was randomly defined through a draw (e. g. if on the 1st day the athlete was drawn to perform the muscular performance tests, on the 2nd day the athlete performed the functional performance tests, and vice-versa). Tests were conducted from 2:00 to 5:00 p.m. The athletes received the following recommendations: do not consume stimulant substances (e. g. caffeine) 24 hours before testing, sleep at your usual time the day before testing, do not have any kind of analgesic and/or anti-inflammatory medicine within 48 hours before testing, and do not perform high-intensity physical activities 48 hours prior to the tests. In addition, the athletes answered a questionnaire about musculoskeletal injuries before the assessments. Briefly, the questionnaire contained the following questions: (1) personal data such as name, age, body weight, body height, and BMI; (2) if the athletes have been submitted to some surgery in the lower limbs; (3) if the athletes suffered from any injury; (4) type of the injury and anatomic region; (5) if the injury was contact or noncontact; (6) pain intensity after the injury; (7) if the athletes did physical therapy for the injury.

Muscular performance assessment

Bilateral isokinetic strength of the participants' knee flexors and extensors was measured using a Biodex Isokinetic Dynamometer 4® System (Biodex Systems, Shirley, New York, USA) with gravity correction. Before starting the assessment, the athletes received instructions about the procedures. Then, the athletes underwent warm-up exercises on a stationary bicycle (Biocycle Magnetic 2500, Movement, São Paulo, Brazil) for six minutes at moderate velocity (70 to 80 rotations per minute) without resistance. Each participant was led through isokinetic dynamometry. The participants were comfortably seated on an adjustable dynamometer chair with the hip joint at 85° with the motor axis aligned to the knee joint axis. They were stabilized through belts around the torso, pelvis, and thigh (1/3 distal) to avoid compensatory movements. The range of motion for testing was adjusted from 10° to 90° of knee flexions. Tests were first performed on the dominant limb (DL) and next on the non-dominant limb (NDL) (Bonetti, et al., 2018).

The protocol described was according to Bonetti et al. (2018). The athletes performed three submaximal repetitions. The previous maximal for each test on all four velocities was a specific warm-up and familiarized themselves with the test procedures. Then, the subjects were instructed to extend/flex the knee with maximal intensity throughout the entire range of motion in each of the subsequent testing repetitions. Protocol during the test demanded 5, 10, 15, and 20 maximal repetitions of knee extension, and flexions in concentric-concentric mode on an angular velocity at 60°/s, 120°/s, 180°/s, and 240°/s, respectively. A one-minute rest period was set between evaluations of different velocities and a three-minute rest period between the DL and NDL evaluations. The same examiner tested athletes using verbal incentives to stimulate and encourage them to use their maximum strength potential throughout the process. The parameters monitored were peak torque (PT, N/m) to know the muscular function and conventional H (flexor)/Q (extensor) ratio (%) to detect possible deficits of strength and muscular imbalances (Bonetti, et al., 2018).

Functional performance assessment

Firstly, the athletes received instructions about the test and next performed warm-up on a stationary bicycle (Biocycle Magnetic 2500, Movement, São Paulo, Brazil) for eight minutes at moderate velocity (70 to 80 rotations per minute) without resistance. Then, each participant was led to perform the Y-Balance test and hop tests.

Y-Balance Test. The test was performed according to Plisky et al. (2009). Three metric tapes were placed on the floor and separated by an angle of 135°. One metric tape was placed in the anterior (ANT) direction, and the two other metrics tapes, one in the posterolateral (PL) direction and the other in the posteromedial (PM) direction, divided by an angle at 90° (Plisky, et al., 2009).

The subjects were positioned centrally to the three metric tapes with single leg support on the lower limb to be tested with the hands on the waist. Three practice trials were performed in each reach direction before the formal testing. From the fourth to the sixth trial, the examiner recorded the distance (centimeters). First, tests were performed on the NDL, and next on the DL (Plisky, et al., 2009).

Three measures were calculated to quantify the functional performance: normalized reach distance, total performance given by composite score, and limb symmetry index. For each limb, the reach distance was normalized by the NDL, and expressed as percent (%); e. g. Normalized distance = distance reached (centimeters) X 100/lower limb length. The total performance was determined by calculating the composite score, given by the formula: Composite score = sum of three (ANT, PL, and PM) directions/three X lower limb length) X 100. The values used in the formulas were the means of each limb in each of the three directions (Plisky, et al., 2009).

Hop tests. Hop tests are unilateral functional performance tests used to assess lower limb strength and neuromuscular control in preseason or pre-participation in competition, to monitor progress in rehabilitation, and identify the dynamic knee stability (Brumitt, et al., 2013; Fitzgerald, Lephart, Hwang, & Wainner, 2001). Hop tests are typically scored by computing a ratio of limb symmetry known as LSI that expresses the distance or time recorded from the test as a percentage (Fitzgerald, et al., 2001; Myers, Jenkins, Killian, & Rundquist, 2014). Five hop tests were chosen to assess the athletes: single hop for distance, triple hop for distance, crossover hop, timed hop, and vertical jump. The single-, triple-, crossover-, timed hop tests and vertical jump tests have been previously described in detail and were performed according to the protocol described by Noyes, Barber and Mangine (1991), and Östenberg, Roos, Ekdahl and Ross (1998).

The athletes performed the tests with the NDL and next with the DL. The upper limbs were free. Three warm-up hops followed by three trials of each hop test were performed by each lower limb. The participants performed practice trials with 30 seconds of resting period between the tests to reduce the error associated with learning and fatigue. The distance (single hop, triple hop, and crossover hop), time (timed hop), and height (vertical jump) were measured in each one of the three test trials. The average of the three values was used for the comparison between the NDL and DL, and to calculate the hop symmetry index:

For the single hop, triple hop, and crossover hop: Hop symmetry index = (NDL hop mean distance / DL hop mean distance) X 100. For the timed leg hop: Hop symmetry index = (NDL hop mean time / DL hop mean time) X 100. Finally, for the vertical jump: Hop symmetry index = (NDL hop mean height / DL hop mean height) X 100 (Noyes, et al., 1991; Östenberg, et al., 1998).

Statistical analysis

The Shapiro-Wilk test was applied to evaluate the normality of the data. All data followed a normal distribution. The comparison between DL and NDL was analyzed by two-tailed Student's t-tests for paired observations. For the analysis of the limb symmetry index (LSI) of hop tests, a one-way analysis of variance (ANOVA) was used followed by Tukey's post-hoc test. Data are expressed as mean ± standard deviation (SD). For all comparisons, a significance level of $p < 0.05$ was considered. GraphPad Prism 8 (La Jolla, CA, USA) software was used for statistical analysis.

Results

Musculoskeletal injury questionnaire

Five (41.6%) out of the 12 athletes reported some injury to the lower limb in the last three months, while seven (58,3%) athletes reported not having any injury.

Muscular performance assessment

The knee flexors and extensors' peak torque (PT) was analyzed at 60°/s, 120°/s, 180°/s, and 240°/s angular velocity. PT values of the knee's extensor and flexor muscles demonstrated no differences between the DL and NDL at 60°/s, 120°/s, and 240°/s. However, there was a decrease in the knee flexors' PT at 180°/s in the NDL compared to the DL ($t=2.872$; $p<.05$; Figure 1a). No significant difference was found in the conventional H/Q ratio between the DL and NDL (Figure 1b).

Functional performance assessment

YBT. There were no differences between the limbs in all performance scores evaluated by YBT (Table 2), although the composite score values were decreased comparing to the normative values (<94%) in both (DL, and NDL) limbs. There was no significant difference between the DL and NDL (Table 2).

Hop tests. In hop tests, the comparison between the DL and NDL did not present statistically significant differences in the single hop, triple hop, vertical jump, and timed hop tests (Table 3). Nevertheless, a significant decrease was found in the NDL compared to the DL in the crossover hop test ($t=3.351$; $p<.01$; Table 3). Moreover, in LSI there was no difference in all tests (Table 4).

Discussion and conclusions

This study showed that there were no significant differences in knee flexors and extensors PT in the most analyzed parameters and conventional H/Q ratio between the DL and NDL in the most angular velocities evaluated. When athletes performed the functional tests, a significant decrease was found only between the NDL and DL in the crossover test.

On the PT analysis, the only significant difference between the limbs was in the knee flexors, where the NDL showed a mean value significantly lower than the DL at 180°/s. Nonetheless, because it was the only asymmetry between the limbs in the PT analysis, we believe this result does not have functional relevance. Similar to the present results, a couple of studies also found symmetries between the limbs at 60°/s (Bonetti, et al., 2018; Oliano,

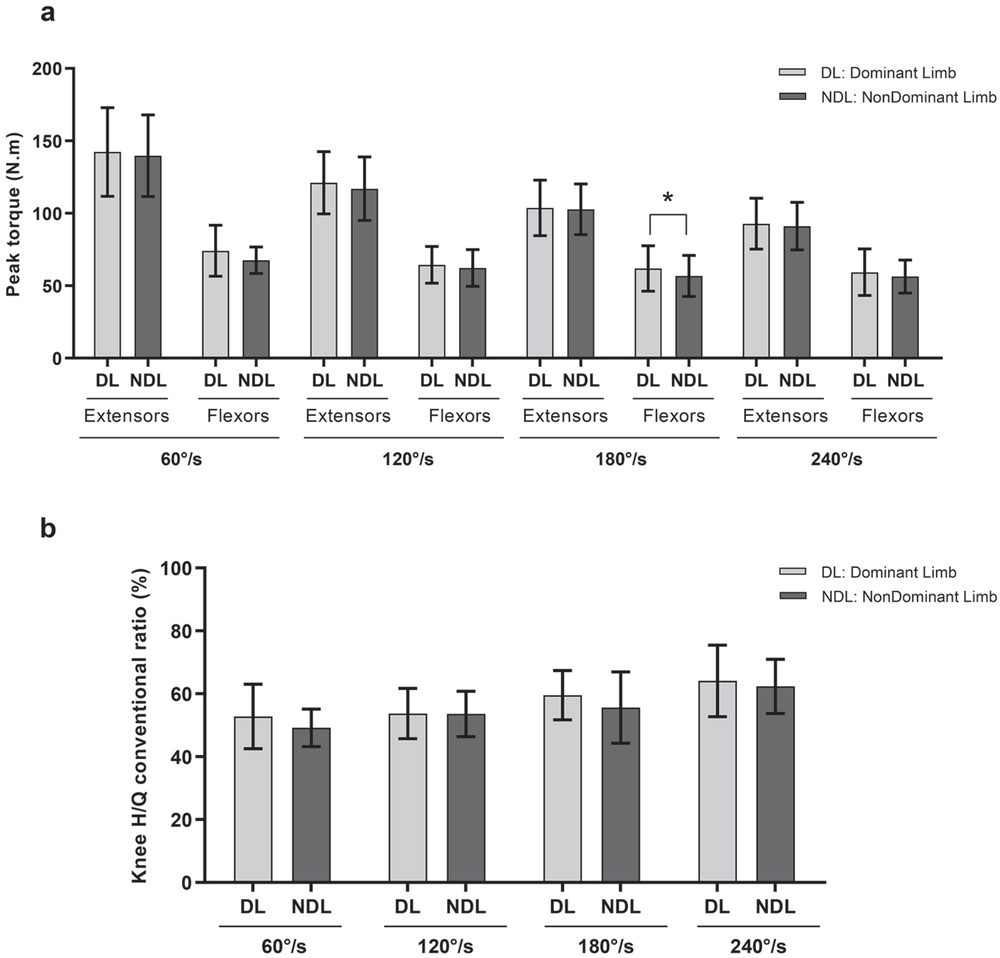

*Figure 1. Knee extensors and flexors' peak torque (a), and flexors (H)/extensors (Q) conventional ratio (b) for both lower limbs on the isokinetic test performed by young female handball athletes. Data are expressed as mean±SD (n = 12) and were analyzed with two-tailed Student's t-tests. * p<.05.*

Table 2. Y-balance test scores of reached distances in Y-balance test in dominant limb and non-dominant limb of young female handball players

Variable	Dominant Limb (M±SD)	Non-dominant Limb (M±SD)	t-value	DF	p-value
Lower limb length (cm)	84.5 ± 4.29	84.4 ± 4.20	0.3640	11	0.72
Anterior (cm)	69.5 ± 8.05	64.7 ± 6.32	0.5588	11	0.58
Posteromedial (cm)	93.8 ± 12.7	92.0 ± 12.6	0.5357	11	0.60
Posterolateral (cm)	81.5 ± 11.3	80.0 ± 11.3	0.4394	11	0.66
Composite score (% cm)	80.3 ± 9.02	78.9 ± 8.36	0.6900	11	0.50

Note. DL – dominant limb; NDL – non-dominant limb.

Table 3. Hop-tests scores in dominant limb and non-dominant limb of young female handball players.

Variable	Dominant limb (M±SD)	Non-dominant limb (M±SD)	t-value	DF	p-value
Single hop (cm)	143.4 ± 27.0	141.3 ± 20.1	0.7744	11	0.45
Triple hop (cm)	418.2 ± 68.2	408.4 ± 60.3	1.673	11	0.12
Crossover hop (cm)	397.1 ± 67.0	374.0 ± 56.4	3.351	11	**0.006**
Timed hop (s)	2.29 ± 0.54	2.35 ± 0.47	1.408	11	0.18
Vertical jump (cm)	21.3 ± 9.11	19.2 ± 6.42	1.180	11	0.26

Note. DL – dominant limb; NDL – non-dominant limb. Significant effects (*p*<.05) are presented in bold font. ** *p*<.01.

Table 4. Hop tests: limb symmetry index in dominant limb and non-dominant limb of young female handball players

Variable	Limb symmetry index (%) (M±SD)	*F*-value	DF	p-value
Single hop	99.4 ± 9.11	2.404	11	0.06
Triple hop	98.1 ± 5.93	2.404	11	0.06
Crossover hop	94.8 ± 6.6	2.404	11	0.06
Timed hop	104.9 ± 12.7	2.404	11	0.06
Vertical jump	99.3 ± 2.29	2.404	11	0.06

Note. DL, dominant limb; NDL, non-dominant limb.

Teixeira, Lara, Balk, & Fagundes, 2017), 120°/s, 180°/s, and 240°/s (Bonetti, et al., 2018) in young female handball athletes (a mean age of 13 years and ages from 16 to 18 years). In addition, symmetries between the limbs in the analysis of knees extensors and flexors' PT were found in adult female handball athletes at 60°/s, 180°/s, and 240°/s (Lund-Hanssen, Gannon, Engebretsen, Holen, & Hammer, 1996; Xaverova, et al., 2015). Unlike handball, sports that require unilateral kicking action of the lower limbs, like soccer, may develop asymmetries that increase with age and experience in the sport. Studies in young female soccer players and senior soccer players showed an increase in knee extensors and flexors' PT and an increase of muscular strength in the DL compared to the NDL (Andrade, et al., 2020; Eustace, Page, & Greig, 2019).

Regarding the conventional H/Q ratio, it was observed no significant differences between the limbs at all the four angular velocities tested. At low velocities the conventional H/Q ratio was below 53% in the DL, and 50% in the NDL; while at high velocities the conventional H/Q ratio was in the DL lower than 65%, and in the NDL below 63%. Concerning the values of the conventional H/Q ratio between the DL and NDL in female handball players, the data shows an age-dependent variance. Bonetti et al. (2018) analyzed isokinetic parameters including conventional H/Q ratio in young handball athletes; significant differences were not found either; at the same four velocities evaluated as in our test, the conventional H/Q ratio found at low velocities was around 55% in the DL, and 50% in the NDL; while at high velocities it was around 65% in the DL, and 60% in the NDL. In athletes aged between 12 and 13 years values in the DL were below 50%, while in the NDL they were around 50% conflicting with our results regarding the muscular imbalance in the DL (Oliano, et al., 2017). Xaverova et al. (2015) observed that female senior handball athletes, at a median age of 26 years, at the angular velocity of 60°/s, had a similar conventional H/Q ratio in both limbs (around 55%) as female athletes aged 20 years, whereas at the angular velocity of 240°/s the young athletes had conventional H/Q ratio values in both limbs (70%) higher than the senior athletes (65%). Furthermore, previous research found significant differences between the DL and NDL in the analysis of conventional H/Q ratio at 60°/s in female athletes aged 21 to 23 years (Gonosova, Linduska, Bizovska, & Svoboda, 2018; Risberg, et al., 2018).

Furthermore, it has been reported in the literature that the conventional H/Q ratio has a range of 50% to 80%, depending on angular velocities (Holm & Vollestad, 2008). Values lower than 60% are associated with injuries to the lower limb (Kim & Hong, 2011), and values below 50% indicate severe muscular imbalance (Andrews, Harrelson, & Wilk, 2012). Thereby, our results are following the literature, and even though there were no significant differences between the DL and NDL, we can observe that values at 60°/s are below 60% in both limbs and lower than 70% at high angular velocities (180°/s; 240°/s), suggesting a muscle imbalance that could increase the risk of lower limb musculoskeletal injuries.

Related to YBT, the results demonstrated no differences between the limbs in the three distances reached. This result is consistent with previous research with handball athletes (Hammami, Gaamouri, Aloui, Shephard, & Chelly, 2019a; Hammamni, et al., 2019b, 2020). Although there was no difference regarding the composite score, we observed that the value in the DL of athletes was 80.3%, while in the NDL it was 78.9%, the values below the normative values (94%) suggested (Plisky, et al., 2009). These results are agreeing with previous studies performed with handball players, as well as in other sports. Male handball athletes (average age of 16.6 years) demonstrated a composite score of 85.98 cm (Chang, Chou, Chang, & Chen, 2020); while athletes with either a contact or noncontact injury had a composite score of 86.5 cm and 92.8 cm, respectively (Scheller, Keller, & Kurz, 2018). Likewise, Bittencourt et al. (2017) analyzed 37 female athletes aged 14 years participating in different sports and found a composite score in the DL of 87.5% and in the NDL of 87.8%. Interestingly, high school athletes with a composite score below 94% were 6.5 times more likely to sustain a musculoskeletal injury to the lower limbs (Plisky, Rauh, Kaminski, & Underwood, 2006). The data found in the present study may be due to the participants' age and, consequently, the incomplete development of their neuromusculoskeletal system.

Normal LSI values have been reported in the literature as greater than or equal to 90% (Beischer, Senorski, Thomeé, & Thomeé, 2019). An LSI of less than 90% indicates a functional deficit in the lower limb (Fitzgerald, et al., 2001). Interestingly, the present study results showed that in five hop tests, the LSI was around 98%, which is in accordance with the literature. Studies involving young athletes showed an LSI with the value mean of around 100% (Hoog, Warren, Smith, & Chimera, 2016; Myer, et al., 2011). Moreover, in 201 subjects of multisport, with an average age of 15 years, the LSI in crossover hop was 93% for boys, while the girls had an LSI of 91% (Barber-Westin, Noyes, & Galloway, 2006). More recently, Brumitt, Mattocks, Engilis, Isaak, and Loew (2019) reported that LSI <69% in the single hop test was associated with a greater risk of lower quadrant injury in female collegiate athletes with a prior history of anterior cruciate ligament reconstruction. The presented results demonstrated a decrease in the distance of the crossover hop test in the NDL compared to the DL. However, there was no significant difference between the limbs in the single hop, triple hop, timed hop, and vertical jump tests. Contrary to our result about the crossover hop test, previous researchers in handball players aged between 21 and 26 years and 16 years found no differences between the limbs (Briem, et al., 2016; Myer, et al., 2011; Setuain, Bikandi, Amú-Ruiz, Urtasun, & Izquierdo, 2019). Later, normative values were proposed for female high school players (age of 15 years). The values suggested were a distance of 1.29 cm for the single hop test, 4.28 cm for the triple hop test, 3.75 cm for the crossover hop test, and a time of 2.25 s for the timed hop test (Myers, et al., 2014). These data are in accordance with the values found in the present study. Notably, female handball players showed mean values for hop tests similar to those in previous studies (Bolgla & Keskula, 1997; Setuain, et al., 2019), while male handball players, aged around 23.9 years, presented higher distances in both limbs (DL and NDL). An interesting study was conducted with handball players of both sexes divided into two groups per age (neuromuscular training group 1: age between 16 and 19 years versus regular training group 2: age 13 to 16 years) on functional parameters that included the single hop test. The results demonstrated that in the neuromuscular training group (group 1), the reached distance was 1.84 cm in both limbs, whereas in the regular training group (group 2) the distance reached was 1.82 cm in the DL and 1.85 cm in the NDL (Barendrecht, et al., 2011).

In general, the present study suggests that young female handball athletes did not present asymmetry between the lower limbs. However, a significant difference was found in the crossover hop test. This difference in the crossover-hop test may be important because it may cause a muscular strength imbalance between the limbs leading to injuries in the long term. Moreover, to our knowledge, no studies have been conducted on female handball players of this age that evaluated the YBT and hop tests. Thus, all differences found in the present study might be considered of functional relevance for understanding the normative values in functional performance.

Related to the strength test, the major aim of this study was the evaluation of the isokinetic test at low, intermediate, and high angular velocities, not only at low and high angular velocities. Furthermore, another important point was the analysis of five hop tests. Limitations of this study were the few studies reporting isokinetic dynamometry and functional tests in young female handball athletes at the same age evaluated in the present study and a small number of participants.

In summary, these findings provide two key take-home messages. First, there is a trend of the muscle imbalance in young female handball athletes, where their hamstrings are weaker than their quadriceps, and dynamic balance deficits that might increase musculoskeletal injury risk. Therefore, we suggest that physiotherapists, coaches, or the staff in the handball team should implement neuromuscular training programs at an earlier age to enhance neuromusculoskeletal control and, consequently, prevent injuries. Second, this study is the first to report values for isokinetic strength regarding the knee extensors and flexors at four angular velocities, YBT, and five hop tests in female handball players at an earlier age, consequently, athletes with incomplete neuromusculoskeletal maturation. Future studies could use these values as referent values. These results shed light on the referent values of muscular and functional performance for the multidisciplinary handball teams to monitor and prevent the risk of injuries in the athletes.

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