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Functional performance and interlimb asymmetries of young football players during single-leg jump tests

Introduction

Injury epidemiology in football

Football is one of the most popular sports worldwide, both at professional and amateur level. In Germany, more than about five-hundred thousand young players between 15–18 years old are registered with clubs and regularly participate in training and matches (DFB, 2015). Sports participation leads to positive effects on children's and adolescents' health, education and behaviors (Felfe, Lechner, & Steinmayr, 2016), but it cannot be overlooked that football also owns the highest injury incidence (47.4%) among participants below 19 years of age (Kirkwood, Hughes, & Pollock, 2019). In particular, 10–37% are severe injuries (Faude, Rößler, & Junge, 2013). Football participation represents an extrinsic risk factor for long-term and growth-related knee injuries in young players, such as anterior cruciate ligament (ACL) injuries (de Loës, Dahlstedt, & Thomée, 2000). ACL rupture is one of the most unfavorable non-contact knee joint injuries that affects the development of sport athletes and their future careers in Europe (Niederer, Engeroff, Wilke, Vogt, & Banzer, 2018). Furthermore, ACL injuries are highly frequent in young ath-

letes ≤ 18 years (Seil, Chotel, & Robert, 2019). In professional football, 88% of all ACL injuries occur without direct knee contact (Della Villa, Buckthorpe, & Grassi, 2020) due to a combination of mechanisms such as femoral adduction, knee abduction and ankle eversion that contributes to dynamic knee valgus (Hewett et al., 2005). These mechanisms especially occur during common movements in football such as one-leg landing after a jump or during fast change of direction (Waldén et al., 2015), key actions repeated by the players a multitude of times during matches or training sessions (Nygaard Falch, Guldteig Rædergård, & Van den Tillaar, 2020), which require greater amount of unilateral strength and power production for optimal performance (Vaisman et al., 2017).

Interlimb asymmetries

The limb symmetry index (LSI) is usually defined as the ratio between the injured limb score and the uninjured limb score expressed as a percentage [$LSI = (\text{injured/uninjured}) \times 100$] and can support injury rehabilitation and the return to sports. Generally, an $LSI \geq 90\%$ cut-off criterion is used to determine whether an interlimb difference can be classified as normal (Gokeler et al., 2017a). However, the LSI can be also used as a screening tool in uninjured athletes (Bishop et al.,

2016), obtained by dividing the non-dominant by the dominant limb scores expressed as a percentage [$LSI = (\text{non-dominant/dominant}) \times 100$] (Lambert et al., 2020; Bishop, Read, Chavda, & Turner, 2016). Athletes who practice professional or amateur sports with a perpetual dominance of one leg during training or competition (i.e. football) could develop significant asymmetry between dominant and non-dominant legs in terms of muscular strength and power (Vaisman et al., 2017; Bahamonde, Weyer, Velotta, & Middleton, 2012). Leg asymmetry in strength and power is used to assess the risk of hamstring injury in elite sports (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008). The normalization of strength, power and flexibility imbalances may significantly reduce the incidence of hamstring injuries (Opar, Williams, & Shield, 2012). In addition, several studies already pointed out that young players may have higher interlimb asymmetries in single-leg jump tests and consequently higher risk of lower extremities injuries to the knee and ankle joints (Harrison, Yorgey, Csiernik, Vogler, & Games, 2017; Gokeler et al., 2017a; Munro & Herrington, 2011; Thomee et al., 2011).

Functional jump tests

Physical performance tests (PTTs) including components of sport-specific

Availability of data and material

Data is available upon reasonable request.

Table 1 Anthropometric data (mean $\pm$ SD)

Team	N	Mass (kg $\pm$ SD)	Height (m $\pm$ SD)	BMI (kg/m ² $\pm$ SD)	Limb length (cm $\pm$ SD)
U11	15	35.2 $\pm$ 4.9	1.5 $\pm$ 0.1	16.5 $\pm$ 1.4	82.5 $\pm$ 4.3 (Dom) – 82.5 $\pm$ 4.4 (N-Dom)
U12	18	38.0 $\pm$ 3.7	1.5 $\pm$ 0.0	17.8 $\pm$ 1.2	80.1 $\pm$ 3.3 (Dom) – 80.5 $\pm$ 3.2 (N-Dom)
U13	19	48.4 $\pm$ 8.5	1.6 $\pm$ 0.1	18.6 $\pm$ 2.1	88.2 $\pm$ 6.0 (Dom) – 88.1 $\pm$ 5.8 (N-Dom)
U14	19	56.5 $\pm$ 8.2	1.7 $\pm$ 0.1	20.1 $\pm$ 1.8	94.2 $\pm$ 4.7 (Dom) – 94.4 $\pm$ 5.1 (N-Dom)
U15	19	63.3 $\pm$ 9.7	1.7 $\pm$ 0.1	20.9 $\pm$ 1.9	96.3 $\pm$ 4.6 (Dom) – 96.4 $\pm$ 4.7 (N-Dom)
U16	21	67.8 $\pm$ 8.7	1.8 $\pm$ 0.1	21.7 $\pm$ 1.8	97.2 $\pm$ 6.3 (Dom) – 97.4 $\pm$ 6.3 (N-Dom)
U17	18	71.2 $\pm$ 7.2	1.8 $\pm$ 0.1	22.7 $\pm$ 1.5	98.4 $\pm$ 3.9 (Dom) – 98.4 $\pm$ 3.9 (N-Dom)
U19	17	72.8 $\pm$ 8.7	1.8 $\pm$ 0.1	22.1 $\pm$ 2.1	100.1 $\pm$ 5.2 (Dom) – 99.9 $\pm$ 5.4 (N-Dom)

U under, N number, BMI body mass index, SD standard deviation, Dom dominant leg, N-Dom non-dominant leg

function (e.g. power), can be useful to measure quantitative differences between dominant/non-dominant leg and to detect interlimb asymmetries (e. g. LSI), besides to determine readiness for return to sport especially after ACL injuries (Harrison et al., 2017). Single-leg jump tests seem to be appropriate for measuring muscle power of the lower extremities (Kockum & Heijne, 2015; Myers, Jenkins, Killian, & Rundquist, 2014). Currently, it is well known that LSI $\leq$ 90% in functional jump tests is categorized as a risk factor for lower extremities injuries among professional or amateur sports athletes (Harrison et al., 2017; Gokeler et al., 2017b; Munro & Herrington, 2011; Thomeé et al., 2011). Furthermore, a combination of multiple jump tests is recommendable to broadly assess the functionality of the knee joint and is a crucial part of most functional performance test batteries (Thompson, Cazier, Bressel, & Dolny, 2018). The one-leg jump for distance and vertical jump tests are valid and reliable tools for knee stability evaluation (Harrison et al., 2017; Kockum & Heijne, 2015; Fitzgerald, Lephart, Hwang, & Wainner, 2001). The side hop is also a valid and reliable test (Kockum & Heijne, 2015; Gustavsson et al., 2006) that assesses the strength of the lower extremities under fatigue state through controlled, fast and repetitive lateral jumps (Gustavsson et al., 2006). The one-leg speedy jump is shown to be a reliable and easy-to-perform test for detecting interlimb differences and knee functionality during jumps in the frontal, sagittal and transversal planes, representing also an important basis for

the clinical setting (Hildebrandt et al., 2015).

Prevention screening

The long-term negative consequences of ACL injuries are quite concerning: considerable time lost, increased risk of secondary injuries, knee osteoarthritis and financial burden on the health care system (Maffulli, Longo, Gougoulis, Lopini, & Denaro, 2010). All of this could be minimised through an injury prevention approach for the identification of possible injury risk factors at young age, with a precautionary medical screening, academic environment and professional supervision (Deehan, Bell, & McCaskie, 2007). Therefore, it is necessary to examine research evidence on the safety practices that best control injury risk in young football players (Olsen et al., 2004). For instance, the role of baseline data and mean values allows relevant comparisons on the basis of the sport-specific athletic prerequisites, gender, age, level of competition and individual athlete's LSI (Myers et al., 2014).

Aims of the study

The first aim of this study was to provide mean values of single-leg jump tests for young (pre-adolescents and adolescents) and uninjured male football players divided into age groups (U11–U19). Besides, it was expected to determine a benchmark for LSI in jump tests, assuming that normal range (LSI $\geq$ 90%) might be guaranteed for all age groups and in all tests. The second aim was to detect whether there was an age effect on

interlimb functional performance differences (dominant, non-dominant) within age groups as well as on LSI between age groups, assuming that a significant main age effect might be present. The third aim was to investigate the direction and magnitude of the association between age and single-leg functional performance (dominant, non-dominant) as well as LSI, assuming that a higher age might be correlated with a higher single-leg functional performance and a higher LSI.

Methods

Participants

A total of 146 young and uninjured male football players from a 3rd division professional German team have been included and tested in the study based on age groups (number of players per age groups: U11, 15; U12, 18; U13, 19; U14, 19; U15, 19; U16, 21; U17, 18; U19, 17). Teams from U11 to U17 competed at regional level while U19 at national level. Anthropometric data of the participants were collected (Table 1). A questionnaire was administered to each participant before performing the tests to request specific information on date of birth, category of team (U11 to U19), dominant leg and number/type of injuries/surgeries (if any) suffered in the last 12 months. Inclusion criteria were the active involvement in training practices/games without restriction and participants had to be between 10–19 years old. Exclusion criteria consisted of lower limbs major injury (with more of 7 days of absence) or surgery in the previous 12 months. Written informed consent

was obtained prior to test participation from full age players (≥ 18 years old) or from the parents of underage players (≤ 18 years old). In addition, the dominance of the lower limbs was determined by the leg with which the participants would kick the ball (van Melick, Meddeler, Hoogeboom, Nijhuis-van der Sanden, & van Cingel, 2017). The leg length was measured as the distance from the greater trochanter to the lateral malleolus (Hébert-Losier, 2017). The study was approved by the ethical committee of the German Sport University (GSU) of Cologne (reference number 056/2018).

Testing procedures

The tests have been conducted at the German Sport University (GSU) of Cologne and supervised by two research assistants from the Institute of Movement Therapy and Movement-Oriented Prevention and Rehabilitation, with scientific experience in the field. All tests were performed in the same indoor gym facility on the same therapeutic mat (Fuchsius multimedia GmbH, RehaMatte, München, Germany). Participants performed the tests barefoot, dressed only with athletic training shorts and t-shirts. Before the tests, all athletes performed 10 min warm-up on a cycle ergometer at moderate intensity followed by basic lower extremity dynamic stretching and joint mobility. All tests were performed unilaterally and the left leg was tested first. The same standardized test order was used for each participant (■ Fig. 1): countermovement jump test (CMJ), jump for distance test (JFD), side hop test (SH) and speedy jump test (SJ). To familiarise with the task, participants performed one practice trial before starting three valid attempts (only two for the SH and SJ) with the left leg (first) and the right leg (second), with regeneration time between each attempt of 30 s (for the CMJ and JFD) and 60 s (for the SH and SJ). All the tests were carried out with the hands fixed on the hip to avoid the influence of arm swing. Compensatory movements (see below in the sections Countermovement jump test (CMJ), Jump for distance test (JFD), Side hop test (SH) and Speedy-jump test (SJ) for

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Abstract

Background. Jumps are predominant components in football (soccer). Interlimb functional difference in single-leg jump performance is a risk factor for lower extremities injuries. Screening uninjured athletes is essential to design prevention strategies and implement individual training interventions. The aims of this cross-sectional study were (1) to provide age-specific mean values and limb symmetry index (LSI) in young football players, (2) to detect age effect on LSI and interlimb functional differences and (3) to investigate the association of age with single-leg functional performance and LSI.

Methods. A total of 146 male football players (age 14.2 ± 2.3) performed the countermovement jump, jump for distance, side hop and speedy jump tests. Descriptive statistics, mean values (dominant/non-dominant) and LSI were provided according to age groups (U11–U19). Two-way mixed analysis of variance (ANOVA), one-way ANOVA and Pearson's correlation were used for the statistical analysis.

Results. Participants showed on average perfect LSI ($103.8 \pm 14.2\%$) amongst all

tests and age groups. Interlimb functional differences occurred in three out of four tests ($p < 0.05$), without age interaction ($p > 0.05$). Age effect was positively associated with single-leg functional performance ($p < 0.05$), but not with LSI ($p > 0.05$), in all tests and age groups.

Conclusion. An LSI $\geq 100\%$ in single-leg jump tests is proposed as a benchmark in young football players, but interlimb performance differences may occur without age interaction. Nevertheless, the growth process plays a crucial role in the development of functional capacities: older players may show a higher single-leg jump performance, but not a higher LSI, than younger players. In football practice, preventive intervention is advisable to counteract interlimb performance differences, for which unilateral strength, power and plyometric training is recommended.

Keywords

Anterior cruciate ligament injury risk · Hop test · Injury prevention · Symmetry index · Test battery

each test description) were not allowed, rated as invalid trials and consequently not included in the data analysis.

Countermovement jump test (CMJ)

The starting position was one-legged up-right standing with the hands fixed on the hips during the entire execution. After a starting electronic signal from the software (Optojump Next Kit Version 1.12.1.0, Microgate, Bolzano, Italy) the subject performed a countermovement flexion with the standing leg and then explosively jumped as high as possible trying to reach the maximum height, without swinging the contralateral leg or flexing the jumping leg. The landing had to be confident and safe, the final position kept for at least 2 s with no intermediate jumps allowed and legs or arms were not allowed to touch the ground (Moser & Bloch, 2015; Gonzalo-Skok,

Serna, Rhea, & Marín, 2015; Holsgaard-Larsen, Jensen, & Aagaard, 2014).

Jump for distance test (JFD)

The starting position was one-legged up-right standing, with hands fixed on the hips for the entire execution and with the toes at the marked line (0 cm) on the ground. After the starting oral signal from the examiner, the subject jumped as far as possible and landed on the same leg. The swing of the contralateral leg was not allowed. The landing had to be stable, under complete control and kept for 2 s, without loss of balance or other compensatory movements such as extra jumps, support of the contralateral leg or help with the arms. One measuring meter was already painted on the therapeutic mat used to carry out the tests and the jumped distance was measured in centimeters (cm) by the examiner from the toe at the push-off (starting

Fig. 1 ▲ **a** Countermovement jump (CMJ), **b** jump for distance (JFD), **c** side hop (SH) and **d** speedy jump (SJ) tests

marked line) to the heel where the subject landed (Moser & Bloch, 2015; Gonzalo-Skok et al., 2015; Gustavsson et al., 2006).

Side hop test (SH)

Two parallel strips were painted 40 cm apart on the therapeutic mat. Participants had to stay on the tested leg, with their hands on the hips, jumping from side to side over the two parallel strips. Participants were instructed to jump as many times as possible during a period of 30 s recorded using a stopwatch. The number of successful jumps (score = total jumps – error jumps) performed without touching the tape or committing any other errors (such as extra/double jumps, support of the contralateral leg or leave the arms from the hips) were recorded (Moser & Bloch, 2015; Kockum & Heijne, 2015; Gustavsson et al., 2006).

Speedy jump test (SJ)

Participants performed as fast as possible a total of 16 single-leg jumps with the

hands on the hips: three jumps through each of the four red hurdles (front–back–front) in the sagittal plane and one jump through each of the four blue hurdles (sideways) in the frontal plane (Speedy Jump Test Kit, TST GmbH, Grosshöflein, Austria). After the starting signal, time was measured by using the mean between two stopwatches. It started as soon as the tested foot left the ground and ended as soon as the tested foot landed on the ground after the last jump. The attempt was invalid if the hands were moved out from the hips, the free leg touched the ground or the testing leg touched the instrument. Double jumps at landing were allowed (Steidl-Müller, Hildebrandt, Müller, Fink, & Raschner, 2018; Hildebrandt et al., 2015).

Statistical analysis

Descriptive statistics has been performed. Means and standard deviations according to tests and sorted per dominant/non-

dominant leg were calculated for each participant. For all tests, the best valid trial for each leg was used for the data analysis. To determine the limb symmetry index (LSI) between the dominant and non-dominant leg, the proposed formula for uninjured population [$LSI = (\text{non-dominant/dominant}) \times 100$] was used (Lambert et al., 2020; Bishop et al., 2016). In order to proceed with the data analysis, the tests were evaluated on the following variables: vertical jumped height (cm) for the CMJ, horizontal jumped distance (cm) for the JFD, number of total valid jumps (n) for the SH and execution time (s) for the SJ. Shapiro–Wilk ($p > 0.05$), Skewness (range ± 2), Kurtosis (range ± 7) and Levene tests were performed for the normality of distribution ($p > 0.05$) and homogeneity of variances ($p > 0.05$). Two-way mixed analysis of variance (ANOVA, $p < 0.05$) for repeated measures on leg (dominant, non-dominant) per jump test (CMJ, JFD, SH and SJ) was run to detect whether there was an age effect on inter-limb performance differences (dominant, non-dominant) within age groups (U11 to U19); a post hoc analysis (Tukey) with multiple comparisons was also provided ($p < 0.05$). One-way ANOVA ($p < 0.05$) was run per jump test (CMJ, JFD, SH and SJ) to detect whether there was an age effect on LSI between age groups (U11 to U19). Pearson's analysis was carried out to investigate the significance ($p < 0.05$) and magnitude (small: $0.1 < r < 0.3$; moderate: $0.3 < r < 0.5$; strong: $0.5 < r < 1.0$) of the association between age and single-leg functional performance (dominant, non-dominant) as well as LSI.

Results

Mean values

Data are presented according to tests and age groups, mean values (SD) are sorted per dominant/non-dominant leg and limb symmetry index (LSI) in **Table 2**. In general, the average performance (mean between dominant/non-dominant) and the average LSI were expressed by the following values for all age groups (U11–U19): countermovement jump test (CMJ):

Table 2 Mean values (SD)

		U11	U12	U13	U14	U15	U16	U17	U19
CMJ	Dom (cm)	13.9 ± 2.6	15.0 ± 2.7	16.2 ± 2.2	19.4 ± 3.2	19.3 ± 3.0	21.0 ± 3.5	21.6 ± 3.5	21.9 ± 3.1
	N-Dom (cm)	14.3 ± 3.2	15.7 ± 2.7	17.1 ± 2.8	19.2 ± 3.2	20.5 ± 3.0	20.9 ± 3.1	22.5 ± 4.9	23.5 ± 3.6
	LSI (%)	103.4 ± 19.9	105.9 ± 15.4	106.2 ± 13.2	99.9 ± 14.6	107.6 ± 14.3	100.4 ± 14.1	104.3 ± 13.5	107.9 ± 16.3
JFD	Dom (cm)	120.6 ± 10.3	120.8 ± 15.2	127.3 ± 15.4	146.1 ± 18.2	145.6 ± 16.0	154.0 ± 13.0	152.9 ± 11.3	154.7 ± 10.2
	N-Dom (cm)	117.1 ± 11.2	124.3 ± 11.5	127.4 ± 16.9	143.4 ± 17.8	153.6 ± 18.2	152.8 ± 19.5	161.1 ± 14.9	161.0 ± 15.7
	LSI (%)	97.5 ± 11.1	103.9 ± 12.4	100.6 ± 12.3	98.8 ± 12.3	106.1 ± 13.7	99.7 ± 9.2	104.6 ± 8.5	103.3 ± 10.6
SH	Dom (n)	31.1 ± 6.1	50.0 ± 7.8	49.9 ± 12.6	55.4 ± 10.9	60.3 ± 7.1	65.5 ± 7.6	64.2 ± 9.6	66.5 ± 6.9
	N-Dom (n)	33.6 ± 8.6	53.1 ± 7.4	52.6 ± 8.4	55.8 ± 7.6	61.3 ± 7.0	67.0 ± 6.1	66.6 ± 7.8	67.5 ± 8.8
	LSI (%)	109.8 ± 27.2	107.1 ± 11.2	111.2 ± 31.4	105.1 ± 30.6	102.3 ± 12.8	103.5 ± 8.8	105.2 ± 15.8	100.9 ± 8.9
SJ	Dom (s)	7.6 ± 0.9	7.2 ± 0.6	7.2 ± 0.8	6.8 ± 0.5	7.1 ± 0.6	6.7 ± 0.6	6.2 ± 1.0	6.7 ± 0.6
	N-Dom (s)	7.8 ± 1.1	7.2 ± 0.7	7.7 ± 0.7	7.2 ± 0.8	7.3 ± 0.5	6.7 ± 0.6	6.6 ± 0.9	6.8 ± 0.8
	LSI (%)	103.2 ± 15.8	101.1 ± 9.3	106.0 ± 10.2	105.2 ± 10.3	102.7 ± 7.2	100.3 ± 8.1	106.1 ± 9.1	102.6 ± 7.4

U under, Dom dominant leg, N-Dom non-dominant leg, LSI limb symmetry index, SD standard deviation, CMJ countermovement jump test, JFD jump for distance test, SH side hop test, SJ speedy jump test

Table 3 Two-way ANOVA for age-related effect on performance differences (Dom, N-Dom) within age groups

Test	Associations (ANOVA)			
	Df	F	Partial eta squared (η^2)	Sig.
CMJ				
Score	1	8.638	0.059	0.004*
Score × Age	7	0.985	0.048	0.445
Age	7	20.492	0.510	0.000*
JFD				
Score	1	2.289	0.018	0.133
Score × Age	7	1.306	0.068	0.253
Age	7	20.201	0.529	0.000*
SH				
Score	1	8.802	0.062	0.004*
Score × Age	7	0.343	0.018	0.933
Age	7	38.010	0.667	0.000*
SJ				
Score	1	11.142	0.081	0.001*
Score × Age	7	0.614	0.033	0.743
Age	7	6.902	0.276	0.000*

df degrees of freedom, F F ratio, Sig. significance, Score within subjects, Score*Age within subjects, Age between subjects, CMJ countermovement jump test, JFD jump for distance test, SH side hop test, SJ speedy jump test, Dom dominant leg, N-Dom non-dominant leg, ANOVA analysis of variance

*Age-related effect is significant at the 0.05 level

18.9 ± 4.0 cm/104.5 ± 15.2%), jump for distance test (JFD: 143.4 ± 19.6 cm/101.8 ± 11.3%), side hop test (SH: 56.8 ± 12.6 jumps/105.6 ± 18.3%) and speedy jump test (SJ: 7.1 ± 0.76 s/103.4 ± 9.7%).

Analysis of variance

Two-way mixed analysis of variance (ANOVA) for repeated measures was

run to detect the impact of age on interlimb functional performance differences (dominant, non-dominant) within age groups (Table 3). A significant interaction effect of age on interlimb functional performance differences (dominant, non-dominant) was not found in any of the tests performed: CMJ ($F = 0.985$; $p = 0.445$; $\eta^2 = 0.048$), JFD ($F = 1.306$; $p = 0.253$; $\eta^2 = 0.068$), SH ($F = 0.343$; $p = 0.933$; $\eta^2 = 0.018$)

and SJ ($F = 0.614$; $p = 0.743$; $\eta^2 = 0.033$). However, age showed a significant main effect on single-leg functional performance scores (dominant, non-dominant) in all tests (CMJ: $F = 20.492$; $p = 0.000$; $\eta^2 = 0.510$; JFD: $F = 20.210$; $p = 0.000$; $\eta^2 = 0.529$; SH: $F = 38.010$; $p = 0.000$; $\eta^2 = 0.667$; SJ: $F = 6.902$; $p = 0.000$; $\eta^2 = 0.276$). Additionally, leg dominance showed a significant main effect on interlimb functional performance differences (dominant, non-dominant) in three out of four tests: CMJ ($F = 8.638$; $p = 0.004$; $\eta^2 = 0.059$), SH ($F = 8.802$; $p = 0.004$; $\eta^2 = 0.062$) and SJ ($F = 11.142$; $p = 0.001$; $\eta^2 = 0.081$), except for the JFD ($F = 2.289$; $p = 0.133$; $\eta^2 = 0.018$). Finally, one-way ANOVA was used to detect the impact of age on LSI between age groups (Table 4). Age showed no significant main effect ($p > 0.05$) on LSI in any of the tests performed.

Normal distribution, homogeneity of variances and correlation between age and performance

Table 5 contains the results of the analysis for normal distribution and homogeneity of variances. The homogeneity of variances was confirmed in all tests for all variables (dominant, non-dominant and LSI). Thus, the veracity of ANOVA can be assumed. The only exception was observed for LSI of SH test ($p = 0.027$), which was the only het-

Table 4 One-way ANOVA for age-related effect on LSI between age groups

Test	Associations (ANOVA)			
	Df	F	Mean Square	Sig.
CMJ	7	0.769	175.379	0.614
JFD	7	1.119	146.765	0.355
SH	7	0.507	215.869	0.828
SJ	7	0.869	84.290	0.533

df degrees of freedom, F F-ratio, Sig. significance, LSI limb symmetry index, CMJ countermovement jump test, JFD jump for distance test, SH side hop test, SJ speedy jump test, ANOVA analysis of variance

erogeneous variable. Shapiro–Wilk test ($p < 0.05$) revealed that variables (dominant, non-dominant and LSI) were not normally distributed in all tests, except for LSI of CMJ test ($p = 0.115$). However, Skewness maintained the assumption of symmetric distribution (within the range ± 2) in two out of four tests (CMJ and SH). In addition, Kurtosis maintained the assumption of symmetric distribution (within the range ± 7) in all tests, except for single variables of the SH (LSI) and SJ (dominant and non-dominant) tests. ■ **Table 5** contains the results of the Pearson's correlation analysis. Age and single-leg functional performance (dominant, non-dominant) showed a significant linear correlation ($p < 0.05$), with a positive direction and strong ($0.5 < r < 1.0$) magnitude of the association for the CMJ, JFD and SH tests; the only exception was found in a single variable of the JFD (dominant: $r = 0.381$), which revealed a moderate ($0.3 < r < 0.5$) magnitude effect. A negative and weak ($0.1 < r < 0.3$) correlation was found for the SJ test (dominant: $r = -0.271$; non-dominant $r = -0.211$). Finally, no correlation was found ($p > 0.05$) between age and LSI in any of the jump tests performed. A post hoc analysis (Tukey) with multiple comparisons between age groups was also provided (■ **Table 6**).

Discussion

To date, there is little evidence data that supports the use of sport-specific standards for jump tests in football players with the same test executions; therefore further studies are required. Specifically, studies need to examine dominant/non-dominant performances and limb symmetry indices (LSI) as mean values (SD)

in jump tests within large populations grouped by sport, age and gender (Myers et al., 2014).

Mean values (SD)

Single-leg jump tests in different plane directions should be included in football-specific muscular power assessment as well as talent identification protocols at elite and non-elite level (Murtagh et al., 2017). Unfortunately, different test executions and standard procedures have been used hitherto amongst young football players and therefore any comparison of results is difficult. The participants of this study performed the CMJ test with an average jumped height of 18.5 ± 2.9 cm (dom) / 19.2 ± 3.3 cm (N-dom) and the JFD test with an average jumped distance of 1.40 ± 13.7 m (dom) / 1.42 ± 15.7 m (N-dom). According to the “VBG—Return to competition manual”, the interlimb difference for the JFD test should not exceed 20 cm to be categorised as normal (Moser & Bloch, 2015). The outcomes of this study support this assumption, as on average the interlimb difference in the JFD test was 4.2 cm among all age groups, with the minimum peak presented by the U15 (mean interlimb difference of 8 cm) but still considered in the normal range. Nonetheless, adult male football players from the third Spanish division showed greater jumped height (CMJ) of 22.81 ± 3.45 cm (dom) / 23.34 ± 2.73 cm (N-dom) and greater jumped distance (JFD) of 1.80 ± 0.13 m (dom) / 1.81 ± 0.12 m (N-dom) (Yanci, Arcos, Mendiguchía, & Brughelli, 2014). These performance differences can be explained by the age and performance level gaps of the two cohorts of participants, as in the present study only the U19 age group

was competing at professional youth level (1st German U19 division). Interestingly, the U12 (dom 50.0 ± 7.8 jumps/N-dom 53.1 ± 7.4 jumps), U13 (dom 49.9 ± 12.6 jumps/N-dom 52.6 ± 8.4 jumps) and U14 (dom 55.4 ± 10.9 jumps/N-dom 55.8 ± 7.6 jumps) have performed the SH test with almost similar results compared to healthy male adults (55 ± 6.0 jumps) (Gustavsson et al., 2006). This can be interpreted as a consequence of the higher levels of performance for the above-mentioned age groups (U12–13–14), despite the great age difference with the compared adult population. It is worth noting that the age groups mostly involved in competitive-oriented levels such as the U15 (dom 60.3 ± 7.1 jumps/N-dom 61.3 ± 7.0 jumps), U16 (dom 65.5 ± 7.6 jumps/N-dom 67.0 ± 6.1 jumps), U17 (dom 64.2 ± 9.6 jumps/N-dom 66.6 ± 7.8 jumps) and U19 (dom 66.5 ± 6.9 jumps/N-dom 67.5 ± 8.8 jumps) also showed greater results in the SH test when compared to mixed adult population (right leg 49.6 ± 13.5 jumps/left leg 47.4 ± 13.0 jumps) involved at recreational and competitive sports level (Kockum & Heijne, 2015). In addition, to the authors' best knowledge, no investigation has been carried out yet on young football players with regard to the speedy jump test (SJ). The participants involved in this study (dom 7.0 ± 0.8 s/N-dom 7.2 ± 0.9 s) have performed not much lower than healthy subjects aged 10–50 years (dom 6.3 ± 0.8 s/N-dom 6.4 ± 0.9 s) (Hildebrandt et al., 2015) and this slight performance variation could be explained by the non-conformity of the age groups and the specific practiced sports.

Age effect on dominant/non-dominant performance differences and LSI

Firstly, it was assumed an age-related effect on interlimb functional performance differences (dominant, non-dominant) within age groups (U11–U19). The results of this study rejected this assumption. Two-way mixed ANOVA ($p < 0.05$) revealed that significant interlimb functional performance differences (dominant, non-dominant) can be as-

Table 5 Pearson's correlation of age with performance (Dom, N-Dom, LSI), normal distribution of data and homogeneity of variances

Test	Correlation		Shapiro–Wilk test		Normal distribution		Homogeneity of variances (Levene)	
	Pearson	Sig. (2-tailed)	Statistic	Sig. (2-tailed)	Skewness	Kurtosis	Statistic	Sig. (2-tailed)
<i>CMJ</i>								
Dom	0.654	0.000*	0.981	0.038**	0.344	−0.133	0.892	0.515
N-Dom	0.654	0.000*	0.982	0.047**	0.381	−0.005	20.063	0.052
LSI	0.042	0.616	0.985	0.115	0.303	−0.046	0.972	0.454
<i>JFD</i>								
Dom	0.381	0.000*	0.715	0.000**	−2.211	4.679	1.184	0.317
N-Dom	0.549	0.000*	0.768	0.000**	−2.164	5.586	1.302	0.255
LSI	0.096	0.276	0.659	0.000**	−2.325	5.137	0.494	0.837
<i>SH</i>								
Dom	0.553	0.000*	0.908	0.000**	−1.244	1.853	1.174	0.322
N-Dom	0.510	0.000*	0.902	0.000**	−1.407	2.917	0.494	0.838
LSI	−0.119	0.162	0.741	0.000**	−0.311	9.422	2.355	0.027***
<i>SJ</i>								
Dom	−0.271	0.001*	0.669	0.000**	−2.696	8.064	1.870	0.080
N-Dom	−0.211	0.011*	0.697	0.000**	−2.798	9.983	1.719	0.110
LSI	0.021	0.807	0.605	0.000**	−2.651	6.432	1.756	0.102

LSI limb symmetry index, Dom dominant leg, N-Dom non-dominant leg, Sig. significance, CMJ countermovement jump test, JFD jump for distance test, SH side hop test, SJ speedy jump test

*Pearson correlation is assumed at the 0.05 level (2-tailed), **Normal distribution of the data is not assumed at the 0.05 level (2-tailed), ***Homogeneity of variances is not assumed at the 0.05 level (2-tailed)

sumed within age groups in three out of four tests (CMJ, SH and SJ), except for the JFD. However, although age demonstrated to have a significant effect ($p < 0.05$) on single-leg performance scores (dominant, non-dominant), a significant age interaction ($p > 0.05$) with interlimb functional performance differences (dominant, non-dominant) within age groups was not found. Nevertheless, the age groups (U11–U19) involved in this study might need specific training interventions on plyometrics and power reinforcement in unilateral and multidirectional jumps, in order to counteract the detected interlimb functional performance differences (dominant, non-dominant). Quite differently, previous studies showed no evidence for significant interlimb differences (dominant, non-dominant) in young and professional football players in terms of knee flexor/extensor muscles (García-García, Serrano-Gómez, Hernández-Mendo, & Morales-Sánchez, 2017), H/Q ratio (Zakas, 2006) and strength/power capacities (Capranica, Cama, Fanton, Tessitore, & Figura, 1992). However, in case of significant interlimb functional differences (dominant, non-dominant), the

performance of football players could be negatively affected during training sessions and games (Bishop, Turner & Read 2018). Thus, jump tests are strongly recommended for providing pre-injury data. Not only are these helpful as an index criterion for reducing re-injury risk, but they also serve as a measure to help athletes to reach the previous performance capacity (Davies, Myer, & Read, 2020). Secondly, it was assumed a normal LSI ($\geq 90\%$) for all age groups in all tests. The results of this study confirmed this assumption, showing an LSI of $103.8 \pm 14.2\%$ (as the average between all tests and age groups). Previous studies pointed out an LSI $\geq 90\%$ for healthy recreational athletes to be considered as normal range (Harrison et al., 2017; Munro & Herrington, 2011), while healthy male collegiate football players revealed a statistical impressive symmetry (De Lang, Kondrateg, DiPace, & Hew-Butler, 2017). The findings of the current study completely agree with the above-mentioned studies, as an LSI $\geq 90\%$ was showed in each single test and in all age groups. Furthermore, based on the results obtained in the present study, an LSI $\geq 100\%$ in the jump tests performed

can be suggested as a benchmark for young and uninjured football players. Conversely, Fousekis et al. describes interlimb isokinetic strength asymmetry in knee flexor/extensor muscles as adaptations which mainly occur in football players with short (5–7 years) and intermediate (8–10 years) professional training age, while players with a longer (> 11 years) professional training age are more balanced and with less musculoskeletal asymmetries (Fousekis, Tsepis, & Vagenas, 2010). However, this must be interpreted cautiously due to the different measuring systems between isokinetic tests and functional jump tests. Thirdly, it was assumed an age-related effect on LSI between age groups (U11–U19). The results of this study rejected this assumption. In fact, one-way ANOVA revealed no significant age-related effect ($p > 0.05$) on LSI between age groups. Therefore, LSI does not differ significantly between age groups and it could be deduced that their variations are not related to the age of the participants. However, several authors already pointed out that youngest categories (age groups) may have a higher risk of lower extremities muscle and joint injury due to their

Table 6 Post hoc (Tukey) with multiple comparison

	U19	U17	U16	U15	U14	U13	U12
U11							
CMJ	0.000*	0.000*	0.000*	0.000*	0.000*	0.190	0.916
JFD	0.000*	0.000*	0.000*	0.000*	0.000*	0.808	0.998
SH	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
SJ	0.006*	0.000*	0.000*	0.362	0.025*	0.945	0.312
U12							
CMJ	0.000*	0.000*	0.000*	0.000*	0.001*	0.883	—
JFD	0.000*	0.000*	0.000*	0.000*	0.000*	0.959	
SH	0.000*	0.000*	0.000*	0.010*	0.768	0.999	
SJ	0.759	0.019*	0.404	0.999	0.965	0.934	
U13							
CMJ	0.000*	0.000*	0.000*	0.015*	0.089	—	—
JFD	0.000*	0.000*	0.000*	0.000*	0.003*		
SH	0.000*	0.000*	0.000*	0.004*	0.644		
SJ	0.117	0.000*	0.018*	0.965	0.324		
U14							
CMJ	0.014*	0.091	0.647	0.999	—	—	—
JFD	0.206	0.180	0.429	0.953			
SH	0.000*	0.003*	0.000*	0.407			
SJ	0.999	0.284	0.973	0.904			
U15							
CMJ	0.078	0.333	0.949	—	—	—	—
JFD	0.820	0.815	0.979				
SH	0.215	0.576	0.289				
SJ	0.607	0.007*	0.239				
U16							
CMJ	0.564	0.935	—	—	—	—	—
JFD	0.999	0.999					
SH	0.999	0.999					
SJ	0.999	0.821					
U17							
CMJ	0.997	—	—	—	—	—	—
JFD	0.999						
SH	0.997						
SJ	0.700						

U under, CMJ countermovement jump test, JFD jump for distance test, SH side hop test, SJ speedy jump test

*Post hoc test is significant at the 0.05 level (2-tailed)

higher limb asymmetries; thus further research is needed to better investigate this aspect (Gokeler et al., 2017b; Harrison et al., 2017; Munro & Herrington, 2011; Thomeé et al., 2011). In fact, knee extensor muscles may exert significant interlimb differences (dominant, non-dominant) in subelite football players, with the dominant leg being the weakest one, according to Rahnama et al. This could be explained by the differential use of these muscles during the kicking

action, which in turn may lead to muscular imbalance, commonly associated to injury risk factor (Rahnama, Lees, & Bambaecichi, 2005). Contrarily, another research showed the dominant side performed significantly greater than the non-dominant side during jump tests in uninjured adult population (Bahamonde et al., 2012). Nevertheless, in the present study it was not statistically evaluated which was the most performant leg (dominant or non-dominant)

during single-leg jump tests. Therefore, a suggestion for future research is to investigate if the dominant leg is also the best performing leg or vice versa during single-leg jump tests in young and uninjured football players.

Associations of age with functional performance and LSI

It was assumed that a higher age was positively associated with a higher single-leg functional performance (dominant, non-dominant) and a higher LSI. The results of the present study partially confirmed this assumption. Pearson's correlation was used to investigate the direction and magnitude effect of age on single-leg performance scores (dominant, non-dominant) and LSI. The analysis demonstrated age (years) and single-leg functional performance (dominant, non-dominant) to have a significant linear correlation ($p < 0.05$), with a positive direction and strong magnitude of the association for the CMJ (dominant: $r = 0.654$; non-dominant: $r = 0.654$), JFD (non-dominant: $r = 0.549$) and SH (dominant: $r = 0.553$; non-dominant: $r = 0.510$) tests, a moderate magnitude effect for the JFD (dominant: $r = 0.381$) test while a negative and weak correlation for the SJ (dominant: $r = -0.271$; non-dominant $r = -0.211$) test. Time reductions (s), however, are considered to be an improvement in the SJ test results, where the less the better. Hence, it can be assumed that in the four jump tests performed in the present study, a higher single-leg functional performance (dominant, non-dominant) was significantly associated with a higher age and these variables increased together. Nevertheless, age was not associated ($p > 0.05$) with LSI in none of the tests performed. This would mean that football players may or may not show a high LSI value, regardless of the age group. According to a recent study, older players are presumably stronger and faster than younger players and in particular they can perform better in physical condition tests (Michailidis, Zelenitsas, Mikikis, Christoulas, & Metaxas, 2020). Several studies have already shown correlations between age and physical performance in football

players, but the applicability in one-leg jump tests has not been fully addressed yet. For example, in male and female young athletes (9–17 years), increases in quadriceps and hamstrings strength performance are significantly correlated with age (Barber-Westin, Noyes, & Galloway, 2006). Furthermore, in male amateur adolescent football players the physical performance improves markedly in age groups between U15 to U19 (Karahan, 2016). Besides, linear improvements of the cognitive–motor performance are also positively correlated with age in young elite football players (Hicheur, Chauvin, Chassot, Chenevière, & Taube, 2017). Generally speaking, age and level of competition may play a key role in performance analysis concerning single-leg jump tests. Thus, special attention must necessarily be paid by future research regarding these two aspects in young and uninjured football players.

Finally, this cross-sectional study concerns three fundamental strengths. Firstly, the evaluation of a large number of young football players divided into age groups provides a practical insight into sport-specific functional performance. Secondly, the uninjured group of participants is a good starting point for creating general guidelines and for the observation of their performance trends. Thirdly, the standardised tests execution could also improve the transferability of the study to other samples. In a preventive approach, this study can be helpful in order to allow useful comparisons in youth football academies, as well as to promote decision-making processes and performance-oriented observations.

With regard to the practical applications of this study, the tests conducted on young and uninjured football players allow functional performance to be assessed in a clear and effective manner: for example, the better results achieved by the older age groups seem to be normal, due to the significant association demonstrated between age and single-leg functional performance (dominant, non-dominant). Conversely, age showed no effect on LSI between age groups and no interaction with interlimb functional performance differences (dominant, non-dominant) within age groups. Thus, the

planning of specific and individualised training programs may be needed for all the age groups involved in this study, so as to reduce the detected interlimb functional performance differences (dominant, non-dominant). Furthermore, in the event of a future injury, the available pre-injury data might be useful for a better rehabilitation protocol based on the individual level of the athletes.

There are several key directions for future research on jump tests in young football players. Further studies should assess a larger number of football players and ought to consider the female population. Moreover, more research studies should implement the so-called pre-injury screenings, suggested at least twice a season (at the beginning and in the middle of the season), to optimise both injury prevention and performance-oriented decisions. Studies are called to provide jump performance data according to activity level and field position, to better categorise the individual results. Finally, future studies need to observe correlations of single-leg functional performance (dominant, non-dominant) in jump tests and LSI with future injuries, to find out whether they could be prevented more frequently or to identify those players most at risk and intervene accordingly.

Limitations

The present study has a few limitations. First, the results cannot be extended to a football population older than 19 years, neither to females nor to other sports. Data were also not examined according to field position and activity level. Moreover, the results include mean values but not reference data, which does not allow a clear distinction between positive and negative performance.

Conclusion

The combination of four single-leg jump tests, performed in different plane directions, seems to be appropriate for the detection of interlimb functional performance differences and limb symmetry indices (LSI). This study showed that significant interlimb functional performance differences (dominant, non-

dominant) can be expected in young and uninjured football players. However, these differences have no interaction with age. In spite of this, age and growth process play a decisive role in the development of functional capacities and are positively associated with single-leg functional performance (dominant, non-dominant), but not with LSI. Thus, a higher single-leg functional performance, but not a higher LSI, could be considered normal in older age groups compared to younger age groups in the four jump tests performed. Furthermore, an LSI $\geq 100\%$ can be proposed as a benchmark for this specific population. To conclude, football players included in this study might need a preventive intervention to counteract the detected interlimb functional performance differences, for which unilateral strength, power and plyometric training is recommended in football practice.

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Declarations

Conflict of interest. G. Scinicarelli, C. Offerhaus, B. Feodoroff, I. Froboese and C. Wilke declare that they have no competing interests.

All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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