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Handgrip Strength Asymmetry in Elite Young Czech Male Tennis Players: Implications for Injury Prevention

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ABSTRACT

The term laterality refers to the preference or dominance of the lateral asymmetry of the human body. The prevalence of left-handedness is reported to be 10–13%, but in some interactive sports (e.g., fencing, racquet sports), the proportion of left-handers is higher. The left-handedness is considered an advantage in tennis; however, the one-sided load can cause muscular dysbalances leading to injuries. The research aim was to assess bilateral differences in handgrip strength youth male tennis players under-14 as to injury prevention (n = 232). In the study 12.5% were left-handed players. Handgrip strength was tested using a digital hand dynamometer (TKK 5401). A significant difference in grip strength in favor of the dominant hand was found between all players and right-handed players, only a non-significant difference was found between left-handed players. Regarding injury prevention, a difference between dominant hand and non-dominant hand force of >15% was found in 5.6% of players (high risk of injury) and >20% in 1.3% of players (very high risk). This predicts an increased risk of injury, so it is desirable to pay attention to both sides of the training load and to include compensatory or strengthening exercises.

Keywords: bilateral asymmetry; dominance, dynamometer; handedness; laterality

INTRODUCTION

The research of human laterality has a rather long history, the notion of laterality is understood as a preferred use of one part of the body in comparison with the other one (left or right upper and lower extremity, eye, ear, etc.). From the general viewpoint, the notion of laterality relates to the preference or dominance as to the side asymmetry of the human body but also to the primary use of one brain hemisphere (e.g., Houle & Tremblay, 2020; Loffing et al., 2014). Laterality is considered one of the important factors for the development of talent, which is hereditary and develops from childhood. Assessment of bilateral asymmetries should be considered during the training process not only at the beginning but also as feedback on the training effect (Kubota & Demura, 2011; Loffing et al., 2016).

According to various authors, 10–13% left-handers can be found in the normal population (Loffing et al., 2014), e.g., Papadatou-Pastou et al. (2020) report in a meta-analysis of 144 studies that left-handedness prevalence lies between 9.3% and 18.1% (depending on criteria), with the best overall estimate being 10.4%, Wang et al. (2019) observed 8.6% left-handedness (US men and women aged 6 to 80 years). Among children and adolescents, Alqahtani et al. (2023) observed 8.4% left-handed boys and 7.0% girls (Saudi Arabia, aged 6 to 18 years), Amo-Setién et al. (2020) observed 14.4% left-handed boys and 9.6% girls (Spain, aged 12 to 18 years), Rostamzadeh et al. (2021) reported left hand dominance in 5% of participants (Iran, aged 7 to 18 years).

In team sports, Barrenetxea-Garcia et al. (2019) identified 9.6% left-handed males in world class the water polo; Gualdi-Russo et al. (2019) found 5.4% left-handers among male basketball players from Italian leagues. Among professional volleyball players, Hadzic et al. (2014) observed 5.7% male left-handers. Prevalence of left-handers among adult athletes in team sports is therefore similar to that of the normal population. A higher prevalence was found among German youth male handball players: 22.6% left-handers (Baker et al., 2013) and 15.5–22.7% left-handers (Schorer et al., 2016).

As to various interactive individual sports, e.g., Loffing and Schorer (2021) showed that a higher numbers of left-handed boys' junior athletes than in the general population were in foil (20.67%), épée (18.57%) and tennis (15.3%). In indirect interactive sports, Loffing and Hagemann (2016) presented the prevalence of left-handers among the top 100 male players in badminton being 12.6%, in table tennis 22.7%, and in tennis 13.4%. Malagoli Lanzoni et al. (2013) showed that among the top 100 male world players in racquet sports, 15% were left-handed in tennis, 29% in table tennis, 14% in squash and 16% in badminton. Among Czech youth male tennis players under-10, 7% were identified as left-handers (Kolínský et al., 2017) and 12.4% among male players under-12 (Kolínský & Zháněl, 2019). Very different from the above data are the results reported by Carrasco et al. (2010) who found 34.2% of left-handers among Spanish young elite table tennis players.

In a number of studies, the issue of laterality is associated with handgrip strength (HGS) and the assessment of bilateral differences between the dominant hand (DH) and the non-dominant hand (NDH) in the context of injury in sport. Grip strength demonstrates good test-retest reliability, validity, and responsiveness (Wang et al., 2019). Bechtol (1954) formulated the rule that grip strength in the dominant hand is approximately 10% greater than in the non-dominant one. This fact (the "10% rule") has been verified in a number of other studies, but gradually, e.g., Petersen et

al. (1989), Armstrong and Oldham (1999), McGrath et al. (2021) concluded that the 10% rule is approximately correct for right-handed subjects, but left-handed subjects can be considered to have almost equal strength in dominant and non-dominant hands. Similar conclusions were also reached by De Smet and Vercammen (2001), Hepping et al. (2015) and McQuiddy et al. (2015) among children and college students. Published results involving both adult populations and children and college students lead to the conclusion that the general validity of the 10% rule has not been demonstrated. In the normal population, Wang et al. (2019) found greater grip strength in DH in comparison with NDH among male participants at the age of 13–14. Greater strength of right-handers was found in male schoolchildren at the age of 13–14 in the USA, Belgium, Chile, Hawaii, or Lithuania (e.g., Butterfield et al., 2009; De Smet & Vercammen, 2001; Gómez-Campos et al., 2018; Tutkuviene & Schiefenhövel, 2013). Greater strength of DH vs NDH has also been shown in male schoolchildren in Spain (Amo-Setién et al., 2020), Belgium (De Smet & Vercammen, 2001) and Netherlands (Ploegmakers et al., 2013).

In a review of HGS from many studies, Cronin et al. (2017) reported that elite and successful athletes in multiple team and individual sports have greater HGS compared to their sub-elite and less successful counterparts. Among young athletes e.g., in judo (Fukuda et al., 2018), padel (Pradas et al., 2022), soft tennis (Kenji & Demura, 2016), tennis (Pereira et al., 2011), significant differences between DH and NDH were demonstrated, while in ice hockey (Toong et al., 2018), only a non-significant difference was found. Kenji and Demura (2016) reported a non-significant difference in grip strength in other sports as well (track and field, football, judo, baseball, basketball, and swimming).

Among tennis players, coaches and researchers, the issue of connection of injuries in the context of bilateral differences is often discussed. In tennis, injuries to the wrist occur secondary to the repetitive nature of play and are seen at increasingly young ages. Isometric testing can be used to determine muscular strength levels, but dominant/non-dominant and agonist/antagonist relations are needed for meaningful interpretation of the results. Restoring greater dominant side wrist and forearm strength is indicated after an injury to the upper extremity in such players (Ellenbecker et al., 2022). Many studies point to the danger of injury as a result of lateral asymmetries in sports (Bishop et al., 2018; Clark & Clacher, 2020; Hepping et al., 2015; Roetert & Kovacs, 2018). Coren (1996) even talks about handedness as a predictor of increased risk of knee, elbow, or shoulder injury, fractures, and broken bones. A bilateral difference of 10–15% is considered significant muscle imbalance, which may result in a greater risk of injury (Ellenbecker & Davies, 2000). A minority opinion was published by Afonso et al. (2022) who state that although bilateral asymmetries are often seen in sport, there is no evidence that they increase the risk of injury. Some authors dealing with the health aspects of limb asymmetries (Bishop et al., 2018; Clark & Clacher, 2020; Hepping et al., 2015) state that a bilateral difference of up to 10% can be considered natural due to the preference of one of the limbs in everyday life (the "10% rule"). Clark and Clacher (2020) consider asymmetries >10% to be "clinically significant", associated with the risk of the first non-contact lower limb injury. Bishop et al. (2018) and Hepping et al. (2015) consider bilateral differences >15% a high risk and bilateral differences >20% a very high risk in terms of potential injury. In tennis, injuries to the upper limbs are usually caused by repeated excessive loading of the speed-force nature of the movement. Frequent impairment of the musculoskeletal system caused

by excessive load on the joints was found in junior tennis players by Fu et al. (2018), other authors (Colberg et al., 2015; Pluim et al., 2016) found health problems in 47% or even 67% of junior tennis players. Kovacs et al. (2014) found an injury rate in 28% of elite junior tennis players, Roetert and Kovacs (2018) therefore state the importance of maintaining an ideal level of grip strength and avoiding overload.

The purpose of the study was to evaluate handgrip strength and bilateral differences in tennis players under 14 years of age in the context of potential injury risk. The aim of the research was to identify (1) the level of somatic and strength characteristics, (2) the ratio of right-handed and left-handed players, (3) bilateral differences in grip strength between the dominant and non-dominant hands.

METHOD

Participants

The participants were elite young Czech male tennis players (n = 232) eligible to compete in tournaments for youth male tennis players under-14 age (U14) (https://www.tenniseurope.org/page/16456/Rules-and-Regulations). Young athletes were included in the Youth Training Centers of the Czech Tennis Association (CTA) - they were therefore selected as talented players. Ages of male athletes were between 13.0 and 14.9 years (age: 13.90 ± 0.58, body height: 170.15 ± 8.77 cm, body weight: 56.90 ± 9.21 kg). Players' handedness was determined by asking which hand they use when playing their forehands. This hand was designated as dominant and players as right-handed (RH; n = 203; 87.5%) or left-handed (LH; n = 29; 12.5%).

Measurement

Research data were obtained using the TENDIAG1 test battery (Zháněl et al., 2015), namely the results relevant to the purpose of this study: body height and weight and handgrip strength (HGS). Anthropometric measurements included body height and body mass. Athletes' body height was obtained with a fixed stadiometer (± 0.1 cm, Seca, Model 2131721009, Hamburg, Germany). Body mass to the nearest 0.1 kg was recorded with a digital balance (± 0.1 kg, Tanita BC-545N, Tanita Corporation, Tokyo, Japan). The HGS was tested using a digital hand dynamometer (TKK 5401 Grip-D, Takei Scientific Instruments Co. Ltd, Tokyo, Japan). The TKK dynamometer is a digital tool with an adjustable grip span, ranging from 3.5 to 7 cm, the precision of the dynamometer is 0.1 kg. The tests of HGS were performed with TKK dynamometer with the elbow in full extension. The players were standing during the entire test with the arm straight down at the side, with the shoulder slightly abducted, the elbow in full extension, the forearm in neutral position, and the wrist also extended. The players looked forward, with feet shoulder-width apart, and were instructed not to touch any part of the body with the dynamometer except the hand being measured. Each player performed the test twice with each hand (right and left alternatively). Participants were instructed to squeeze gradually and continuously for at least 2 seconds and were encouraged to do their best when performing the tests. If two trials for a given hand differed by more than 10%, a third trial was performed, with the two closest scores retained.

Statistical Analysis

The research data were analysed by descriptive methods (arithmetic mean, standard deviation, coefficient of variation, minimum and maximum value) and inferential statistics (t-test). The Shapiro Wilk test was used to test the normality of the frequency distribution of each variable.

The evaluation of the effect size (ES) index *d* for bilateral differences was interpreted as small (*d* = .20), medium (*d* = .30) or large (*d* = .50) based on Cohen (1988). The data were processed using the licensed software IBM SPSS Statistics (version 28.0, SPSS Inc., Chicago, IL USA) and Microsoft Excel.

RESULTS

Statistical analysis showed that the data came from a normal distribution (Shapiro-Wilk test). Among all players (*n* = 232), 87.5% (*n* = 203) were right-handed (RH) and 12.5% (*n* = 29) were left-handed (LH). Baseline statistical characteristics for anthropometric (body height and weight) and strength variables (handgrip strength of the dominant and non-dominant hands) are shown in Table 1. Grip strength (HGS) of the dominant hand (DH) was higher (difference 4.41 kg) than that of the non-dominant hand (NDH). High variability (CV) of handgrip strength values was found for both hands (difference between DH and NDH only 1.73%).

Table 1. Basic statistical characteristics of the sample

Sample	**U14 Czech male tennis players (n = 232)**				
Variables	**M**	**SD**	**CV (%)**	**min**	**max**
Age (y)	13.90	0.58	4.17	13.0	14.9
Height (cm)	170.15	8.77	5.15	148.0	192.0
Weight (kg)	56.90	9.21	16.19	33.2	83.9
DH (kg)	34.90	7.33	21.00	18.8	58.5
NDH (kg)	30.49	6.93	22.73	14.8	48.3

Note. *n* = sample size; DH = dominant hand; NDH = non-dominant hand; M = mean; SD = standard deviation; CV = coefficient of variation; min = minimum; max = maximum; y = years; cm = centimeter; kg = kilogram.

Table 2 shows the results of the assessment of bilateral differences between the dominant and non-dominant hands obtained by calculating bilateral asymmetry index (BAI-1). Out of 232 observed players, 13 (5.6%) had bilateral differences >15% (high risk in terms of potential injury). The strength difference >20% (very high risk) was found in 3 (1.3%) players.

Table 2. The assessment of bilateral differences between the dominant and non-dominant hands

Bilateral differences	***n*** = 232	%
RH vs LH	203 vs 29	87.5 vs 12.5
BAI-1 >15%	13 vs 0	5.60 *
BAI-1 >20%	2 vs 1	1.29 *

Note. *n* = sample size; RH = right-handers; LH = left-handers; BAI-1 = bilateral asymmetry index; * = from all players.

Table 3 presents the results of the HGS comparison of the dominant (DH) and non-dominant hands (NDH) of right-handed (RH), left-handed (LH) and all players (AP). To verify the significance of differences in handgrip strength between DH and NDH, we used the t-test for independent samples and the effect size index *d* (Cohen's *d*). Significant differences in handgrip strength between DH and NDH were demonstrated in right-handed players (RH) and all players (AP), only non-significant differences were found in left-handed players (LH). Assessment of differences in handgrip strength between the dominant and non-dominant hands using the bilateral asymmetry index (BAI-1) showed the highest value among RH players (7.13%), lower among all players (6.74%) and lowest among LH (3.98%). These summary results are therefore below the 15% threshold considered high risk in terms of potential injury. As Table 2 shows, only 6.89% of all players exceeded the 15% mark.

Table 3. Bilateral differences between the dominant (DH) and non-dominant hands (NDH)

HGS	M ± SD (kg)	diff. (*d*)	min (kg)	max (kg)	BAI-1 (%)
Right-handed players (RH, *n* = 203)					
DH	35.02 ± 7.34	4.66*(.66)	18.8	58.5	7.13
NDH	30.36 ± 6.75		15.1	48.3	
Left-handed players (LH, *n* = 29)					
DH	34.07 ± 7.34	2.61 (.34)	19.8	48.3	3.98
NDH	31.46 ± 8.18		14.8	44.8	
All players (AP, *n* = 232)					
DH	34.90 ± 7.33	4.41*(.62)	18.8	58.5	6.74
NDH	30.49 ± 6.93		14.8	48.3	

Note. HGS = handgrip strength; DH = dominant hand; NDH = non-dominant hand; M = mean; SD = standard deviation; diff. = difference between DH and NDH; *d* = effect size index (Cohen's *d*); BAI-1 = bilateral asymmetry index; kg = kilogram; *p < 0.05 for differences between DH and NDH.

DISCUSSION

Table 4 lists studies examining bilateral differences in handgrip strength in a population of school children (boys) aged 13–14 years (Amo-Setién et al., 2020; De Smet & Vercammen, 2001; Ploegmakers et al., 2013; Rostamzadeh et al., 2021; Wang et al., 2019).

The values of bilateral asymmetry index (BAI-1, %) in studies of male schoolchildren in the category 13–14 years range between 2.9–4.0% (*d* = 0.18–0.40, small) and are small, thus the validity of the often mentioned "10% rule" has not been proven.

Despite the different destinations (ESP, BEL, IRN, NLD, USA) and numbers of participants (*n* = 41–314), consistent levels of handgrip strength were found in both the dominant (28.1–32.3 kg, diff. = 4.2 kg) and non-dominant hands (26.4–30.5 kg, diff. = 4.1 kg). In studies that reported results by year (13 and 14 years), weighted arithmetic mean and standard deviation calculations were used for comparability with the U14 category used in sport.

The second part of the table shows the results of seven studies of under-14 male athletes in different sports. The representation of left-handers in our study (12.5%) corresponds to the

proportion of left-handers (10–13%) reported in the normal population (Loffing et al., 2014; Papadatou-Pastou et al., 2020).

Table 4. Handgrip strength (kg) and bilateral differences in different male participants (U14)

1st author (year of publish)	Participants	Age	*n*	DH (M ± SD)	NDH (M ± SD)	BAI-1 (%)	*d*
POPULATION							
Amo-Setién (2020)	Schoolchild., ESP	13–14	93	30.4 ± 6.7	28.3 ± 6.6	3.6	.32
De Smet (2001)	Schoolchild., BEL	13–14	81	31.4 ± 6.8	29.2 ± 6.5	3.6	.33
Ploegmakers (2013)	Schoolchild., NLD	13–14	112	31.4 ± 6.4	29.0 ± 6.4	4.0	.38
Rostamzadeh (2021)	Schoolchild., IRN	13–14	221	28.1 ± 4.4	26.4 ± 4.3	3.1	.40
Wang (2019)	Schoolchild., USA	13–14	314	32.3 ± 6.9	30.5 ± 5.5	2.9	.29
SPORT							
Chapelle (2022) *	Tennis, BEL	12.3 ± 1.6	41	28.7 ± 6.8	24.5 ± 5.7	7.9	.66
Kenji (2016)	Soft Tennis, JPN	13–14	38	38.3 ± 7.3	30.8 ± 6.3	10.9	1.11
Carrasco (2010)	Table tennis, ESP	12.0 ± 1.1	38	27.1 ± 5.1	22.1 ± 4.1	9.5	1.02
Pereira (2011)	Tennis, BRA	U14	42	29.6 ± 7.1	18.3 ± 3.7	23.6	.63
Pradas (2022)	Padel, ESP	13.8 ± 0.5	15	35.4 ± 7.3	30.5 ± 8.1	7.4	.64
Toong (2018)	Ice hockey, CAN	U14	123	30.7 ± 7.6	29.6 ± 7.5	1.8	.15
ZeDi Norm (unpub.)	Tennis, DEU	U14	202	34.0	29.2	7.6	-
This study	*Tennis, CZE*	*U14*	*232*	*34.9 ± 7.3*	*30.5 ± 6.9*	*6.7*	*.62*

Note. U14 = for studies reporting HGS values separately for ages 13 and 14, the values for U14 were calculated using a weighted arithmetic mean; *n* = sample size; Schoolchild. = schoolchildren; DH = dominant hand; NDH = non-dominant hand; BAI-1 = bilateral asymmetry index; M = mean; SD = standard deviation; BEL = Belgium; BRA = Brazil; CAN = Canada; CZE = Czechia; DEU = Germany; ESP = Spain; IRN = Iran; JPN = Japan; NLD = Netherlands; USA = United States of America; * = common values for the male and female participants; ZeDI Norm = Zentrum für Diagnostik und Intervention im Sport (Ruhr-Universität Bochum); unpub. = unpublished.

The values of the bilateral asymmetry index in elite young Czech male tennis players under-14 are similar to those observed by Chapelle et al. (2022) and ZeDI Norms among tennis players, Carrasco et al. (2010) among table tennis players, Kenji and Demura (2016) in soft tennis, and Pradas et al. (2022) among padel players. The BAI-1 values found by these authors range between 6.7–10.9% (d = 0.62–1.11, medium–large) with only one case exceeding the 10% threshold (the majority validity of the "10% rule" has therefore not been proven). Significantly higher BAI-1 value was published by Pereira et al. (2011) for tennis (23.6%, d = 0.63) and significantly lower one by Toong et al. (2018) for ice hockey (d = 0.15), which is not a unilateral sport though. In contrast to the consistent results of individual studies among schoolchildren, the findings of sports research in various destinations (BEL, BRA, CAN, CZE, DEU, ESP, JPN, NLD) and with different numbers of participants (n = 15–232) for both DH (M = 27.1–38.3 kg, diff. = 11.2 kg) and NDH (M = 18.3–30.8 kg, diff. = 12.5 kg) show significant differences among mean values, significantly larger than for schoolchildren. Carrasco et al. (2010) found significantly lower levels of handgrip strength in table tennis players, which is likely due to the much lower weight of the table tennis racket and balls compared to padel, soft tennis and tennis.

CONCLUSION

The aim of the study was to assess bilateral differences in the grip strength of Czech youth male tennis players under-14 in the context of injury prevention. A significant difference in handgrip strength in favor of the dominant hand was found both among all players and among right-handed players, only a non-significant difference was found among left-handed players. However, the assessment of bilateral differences using the bilateral asymmetry index (BAI-1) showed relatively low values among left-handed (3.98%), right-handed players (7.13%), and all players (6.74%). When analyzing the individual levels of bilateral asymmetries, only a small number of players (6.9%) exceeded values >15%. This indicates an optimal level of bilateral hand strength differences of the monitored players and a low risk of injury. The level of bilateral asymmetry should be checked regularly, values >15% should be considered as a predictor of possible injuries in tennis.

RECOMMENDATIONS FOR PRACTICE

Bilateral asymmetry could be a cause of an injury or muscle imbalances. Players and coaches should take this into account, recovery and compensatory exercises should be an important part of training. An exercise for eccentric external rotators strength may help with balancing the antagonist group strength. This crucial exercise should be incorporated into the training process in tennis mainly due to repetitively performed explosive concentric and eccentric contractions. Tennis strokes are usually characterized by the so-called stretch-shortening cycle so training sessions should consist of exercises of concentric and eccentric character. A larger amount of muscle mass in the dominant upper limb, according to Elliott (2006), also influences the overall posture of tennis players. The most common compensation is the elevation of the shoulder joint with overloading and shortening of the upper portion of the trapezius muscle. As a consequence, there is a reconstruction of movement patterns with premature and overly intense involvement of the upper scapular fixators, leading to scapular decentering. Therefore, compensatory exercises should be complemented with rehabilitation interventions that address these more complex pathokinesiological relationships.

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REFERENCES

Afonso, J., Peña, J., Sá, M., Virgile, A., García-de-Alcaraz, A., & Bishop, C. (2022). Why Sports Should Embrace Bilateral Asymmetry: A Narrative Review. *Symmetry*, *14*, 1993. https://doi.org/10.3390/sym14101993

Alqahtani, B. A., Alenazi, A. M., Elnaggar, R. K., Alshehri, M. M., Alhowimel, A., Najmi, A. A., Alasraj, M., & Alghadeir, M. (2023). Normative values for hand grip and pinch strength for 6 to 18 year-olds in Saudi Arabia. *BMC Musculoskeletal Disorders*, *24*(96). https://doi.org/10.1186/s12891-023-06197-0

Amo-Setién, F. J., Leal-Costa, C., Abajas-Bustillo, R., González-Lamuño, D., & Redondo-Figuero, C. (2020). Factors associated with grip strength among adolescents: An observational study. *Journal of Hand Therapy*, *33*(1), 96–102. https://doi.org/10.1016/j.jht.2018.10.005

Armstrong, C. A., & Oldham, J. A. (1999). A comparison of dominant and non-dominant hand strengths. *The Journal of Hand Surgery: British & European Volume*, *24*(4), 421–425. https://doi.org/10.1054/jhsb.1999.0236

Baker, J., Kungl, A. M., Pabst, J., Strauß, B., Büsch, D., & Schorer, J. (2013). Your fate is in your hands? Handedness, digit ratio (2D: 4D), and selection to a national talent development system. *Laterality: Asymmetries of Body, Brain and Cognition*, *18*(6), 710–718. https://doi.org/10.1080/1357650X.2012.755992

Barrenetxea-Garcia, J., Torres-Unda, J., Esain, I., & Gil, S. M. (2019). Relative age effect and left-handedness in world class water polo male and female players. *Laterality: Asymmetries of Body, Brain and Cognition*, *24*(3), 259–273. https://doi.org/10.1080/1357650X.2018.1482906

Bechtol, C. O. (1954). Grip test; the use of a dynamometer with adjustable handle spacings. *Journal of Bone and Joint Surgery America*, *36*(4), 820–832. https://doi.org/10.2106/00004623-195436040-00013

Butterfield, S. A., Lehnhard, R. A., Loovis, E. M., Coladarci, T., & Saucier, D. (2009). Grip Strength Performances by 5- to 19-year-olds. *Perceptual and Motor Skills*, *109*(2), 362–370. https://doi.org/10.2466/pms.109.2.362-370

Bishop, C., Read, P., Lake, J., Chavda, S., & Turner, A. (2018). Interlimb Asymmetries: Understanding How to Calculate Differences from Bilateral and Unilateral Tests. *Strength & Conditioning Journal*, *40*(4), 1–6. https://doi.org/10.1519/SSC.0000000000000371

Carrasco, L., Pradas, F., Floría, P., Martínez, A., Herrero, R., & Jurado, J. (2010). Grip strength in young top-level table tennis players. *International Journal of Table Tennis Sciences*, *6*(6), 64–66.

Clark, N. C., & Clacher, L. H. (2020). Lower-limb motor-performance asymmetries in English community-level female field hockey players: Implications for knee and ankle injury prevention. *Physical Therapy in Sport*, *43*(1), 43–51. https://doi.org/10.1016/j.ptsp.2020.02.001

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Science* (2nd ed.). Hillsdale, NJ: Erlbaum. ISBN 0-8058-0283-5

Colberg, R. E., Aune, K. T., Choi, A. J., & Fleisig, G. S. (2015). Incidence and Prevalence of Musculoskeletal Conditions in Collegiate Tennis Athletes. *Journal of Medicine and Science in Tennis*, *20*(3), 137–144.

Coren, S. (1996). Handedness as a predictor of increased risk of knee, elbow, or shoulder injury, fractures and broken bones. *Laterality: Asymmetries of Body, Brain and Cognition*, *1*(2), 139–152. https://doi.org/10.1080/713754232

Cronin, J., Lawton, T., Harris, N., Kilding, A., & McMaster, D. T. (2017). A brief review of handgrip strength and sport performance. *Journal of Strength and Conditioning Research*, *31*(11), 3187–3217. https://doi.org/10.1519/jsc.0000000000002149

De Smet, L., & Vercammen, A. (2001). Grip Strength in Children. *Journal of Pediatric Orthopaedics B*, *10*(4), 352–354.

Ellenbecker, T. S., & Davies, G. J. (2000). The Application of Isokinetics in Testing and Rehabilitation of the Shoulder Complex. *Journal of Athletic Training*, *35*(3), 338–350.

Ellenbecker, T. S., Roetert, E. P., Petracek, K., Kovacs, M., Barajas, N., & Bailie, D. (2022). Bilateral Comparison of Anterior Shoulder Position in Elite Tennis Players. *International Journal of Sports Physical Therapy*, *17*(5), 863–869. https://doi.org/10.26603/001c.36629

Elliott B. (2006). Biomechanics and tennis. *British Journal of sports Medicine*, *40*(5), 392–396. https://doi.org/10.1136/bjsm.2005.023150

Fu, M. C., Ellenbecker, T. S., Renstrom, P. A., Windler, G. S., & Dines, D. M. (2018). Epidemiology of injuries in tennis players. *Current Reviews in Musculoskeletal Medicine*, *11*(1), 1–5. https://doi.org/10.1007/s12178-018-9452-9

Fukuda, D. H., Beyer, K. S., Boone, C. H., Wang, R., La Monica, M. B., Wells, A. J., Hoffman, J. R., & Stout, J. R. (2018). Developmental associations with muscle morphology, physical performance, and asymmetry in youth judo athletes. *Sport Sciences for Health*, *14*(1), 555–562. https://doi.org/10.1007/s11332-018-0460-3

Gómez-Campos, R., Andruske, C. L., de Arruda, M., Sulla-Torres, J., Pacheco-Carrillo, J., Urra-Albornoz, C., & Cossio-Bolaños, M. (2018). Normative data for handgrip strength in children and adolescents in the Maule Region, Chile: Evaluation based on chronological and biological age. *PLOS ONE*, *13*(8): e0201033. https://doi.org/10.1371/journal.pone.0201033

Gualdi-Russo, E., Rinaldo, N., Pasini, A., & Zaccagni, L. (2019). Hand Preference and Performance in Basketball Tasks. *International Journal of Environmental Research and Public Health*, *16*, 4336. https://doi.org/10.3390/ijerph16224336

Hadzic, V., Sattler, T., Veselko, M., Markovic, G., & Dervisevic, E. (2014). Strength Asymmetry of the Shoulders in Elite Volleyball Players. *Journal of Athletic Training*, *49*(3), 338–344. https://doi.org/10.4085/1062-6050-49.2.05

Hepping, A. M., Ploegmakers, J. J., Geertzen, J. H., Bulstra, S. K., & Stevens, M. (2015). The influence of hand preference on grip strength in children and adolescents; a cross-sectional study of 2284 children and adolescents. *PLOS ONE*, *10*(11), e0143476. https://doi.org/10.1371/journal.pone.0143476

Houle, J., & Tremblay, F. (2020). Neurophysiological basis of manual force asymmetries in young and senior adults. *Laterality: Asymmetries of Body, Brain, and Cognition*, *25*(4), 469–489. https://doi.org/10.1080/1357650X.2020.1722149

Chapelle, L., Bishop, C., D'Hondt, J., D'Hondt, E., & Clarys, P. (2022). Morphological and functional asymmetry in elite youth tennis players compared to sex- and age-matched controls. *Journal of Sports Sciences*, *40*(14), 1618–1628. https://doi.org/10.1080/02640414.2022.2096769

Kenji, T., & Demura, S. (2016). Age-related Differences in Grip Strength Laterality in Male Elite Soft-tennis Players. *American Journal of Sports Science and Medicine*, *4*(4), 109–114. https://doi.org/10.12691/ajssm-4-4-5

Kolínský, R., Strašilová, K., Vodička, T., & Zháněl, J. (2017). Lateral Differences in Maximal Grip Strength in Czech Male Tennis Players Aged 9–10 in The Context of Injury Prevention. *Proceedings of the 11th International Conference on Kinanthropology, „Sport and Quality of Life",* 837–847.

Kolínský, R., & Zháněl, J. (2019). Lateral differences in maximal grip strength in Czech male tennis players aged 11–12 in the context of injury prevention. *Studia sportiva*, *13*(1), 55–62. https://doi.org/10.5817/StS2019-1-6

Kovacs, M. S., Ellenbecker, T. S., Kibler, W. B., Roetert, E. P., & Lubbers, P. (2014). Injury trends in American competitive junior tennis players. *Journal of Medicine and Science in Tennis*, *19*(1), 19–24.

Kubota, H., & Demura, S. (2011). Gender differences and laterality in maximal handgrip strength and controlled force exertion in young adults. *Health*, *3*(11), 684–688. https://doi.org/10.4236/health.2011.311115

Loffing, F., & Hagemann, N. (2016). Performance differences between left-and right-sided athletes in one-on-one interactive sports. In *Laterality in sports* (249–277). Academic Press. https://doi.org/10.1016/B978-0-12-801426-4.00012-2

Loffing, F., Hagemann, N., Strauß, B., & MacMahon, C. (Eds.). (2016). *Laterality in Sports: Theories and Applications*. Cambridge: Academic Press. ISBN 978-0-12-801426-4

Loffing, F., & Schorer, J. (2021). Handedness and Relative Age in International Elite Interactive Individual Sports Revisited. *Frontiers in Sports and Active Living*, 3:662203. https://doi.org/10.3389/fspor.2021.662203

Loffing, F., Sölter, F., & Hagemann, N. (2014). Left preference for sport tasks does not necessarily indicate left-handedness: sport-specific lateral preferences, relationship with handedness and implications for laterality research in behavioural sciences. *PLOS ONE*, *9*(8), e105800. https://doi.org/10.1371/journal.pone.0105800

Malagoli Lanzoni, I., Semprini, G., Di Michele, R., & Merni, F. (2013). Top athletes handedness in the major racket sports. *International Journal of Table Tennis Sciences*, *8*, 160–163.

McGrath, R., Vincent, B. M., Jurivich, D. A., Hackney, K. J., Tomkinson, G. R., Dahl, L. J., & Clark, B. C. (2021). Handgrip Strength Asymmetry and Weakness Together Are Associated with Functional Disability in Aging Americans. *Journal of Gerontology: Medical Sciences*, *76*(2), 291–296. https://doi.org/10.1093/gerona/glaa100

McQuiddy, V. A., Scheerer, C. R., Lavalley, R., McGrath, T., & Lin., L. (2015). Normative Values for Grip and Pinch Strength for 6- to 19-Year-Olds. *Archives of Physical Medicine and Rehabilitation*, *96*(9), 1627–1633. https://doi.org/10.1016/j.apmr.2015.03.018

Papadatou-Pastou, M., Ntolka, E., Schmitz, J., Martin, M., Munafò, M. R., Ocklenburg, S., & Paracchini, S. (2020). Human handedness: A meta-analysis. *Psychological Bulletin*, *146*(6), 481–524. https://doi.org/10.1037/bul0000229

Pereira, H. M., Menacho, M., Takahashi, R. H., & Rosa Cardoso, J. (2011). Handgrip Strength Evaluation on Tennis Players Using Different Recommendations. *Revista Brasileira de Medicina do Esporte*, *17*(3), 184–188. https://doi.org/10.1590/S1517-86922011000300007

Petersen, P., Petrick, M., Connor, H., & Conklin, D. (1989). Grip strength and hand dominance: challenging the 10% rule. *The American journal of occupational therapy*, *43*(7), 444–447. https://doi.org/10.5014/ajot.43.7.444

Ploegmakers, J. J., Hepping, A. M., Geertzen, J. H., Bulstra, S. K., & Stevens, M. (2013). Grip strength is strongly associated with height, weight and gender in childhood: a cross sectional study of 2241 children and adolescents providing reference values. *Journal of Physiotherapy*, *59*(4), 255–261. https://doi.org/10.1016/S1836-9553(13)70202-9

Pluim, B. M., Loeffen, F. G. J., Clarsen, B., Bahr, R., & Verhagen, E. A. L. M. (2016). A one-season prospective study of injuries and illness in elite junior tennis. *Scandinavian Journal of Medicine & Science in Sports*, *26*(5), 564–571. https://doi.org/10.1111/sms.12471

Pradas, F., Toro-Román, V., Ortega-Zayas, M. Á., Montoya-Suárez, D. M., Sánchez-Alcaraz, B. J., & Muñoz, D. (2022). Physical Fitness and Upper Limb Asymmetry in Young Padel Players: Differences between Genders and Categories. *International Journal of Environmental Research and Public Health*, *19*, 6461. https://doi.org/10.3390/ijerph19116461

Roetert, E. P., & Kovacs, M. (2018). *Tennis anatomy*. Champaign, IL USA: Human Kinetics.

Rostamzadeh, S., Saremi, M., Abouhossein, A., Vosoughi, S., & Molenbroek, J. F. (2021). Normative data for handgrip strength in Iranian healthy children and adolescents aged 7–18 years: comparison with international norms. *Italian Journal of Pediatrics*, *47*(1), 1–9. https://doi.org/10.1186/s13052-021-01113-5

Schorer, J., Tirp, J., Steingröver. C., & Baker, J. (2016). Chapter 5 - Laterality and Its Role in Talent Identification and Athlete Development. In Loffing, F., Hagemann, N., Strauß, B., & MacMahon, C. (Eds.), *Laterality in Sports: Theories and Applications* (87–105). Cambridge: Academic Press. ISBN 978-0-12-801426-4. https://doi.org/10.1016/B978-0-12-801426-4.00005-5

Toong, T., Wilson, K. E., Urban, K., Paniccia, M., Hunt, A. W., Keightley, M., & Reed, N. (2018). Grip Strength in Youth Ice Hockey Players: Normative Values and Predictors of Performance. *The Journal of Strength & Conditioning Research*, *32*(12), 3494–3502. https://doi.org/10.1519/JSC.0000000000002815

Tutkuviene, J., & Schiefenhövel, W. (2013). Laterality of handgrip strength: age- and physical training-related changes in Lithuanian schoolchildren and conscripts. *Annals of the New York Academy of Sciences*, *1288*(1), 124–134. https://doi.org/10.1111/nyas.12126

Wang, Y., Bohannon, R. W., Kapellusch, J., Washburn, D., Li, X., Yen, S., & Rahman, M. H. (2019). Between-side differences in hand-grip strength across the age span: Findings from 2011–2014 NHANES and 2011 NIH Toolbox studies. *Laterality: Asymmetries of Body, Brain and Cognition*, *24*(6), 697–706. https://doi.org/10.1080/1357650X.2019.1604727

Zháněl, J., Černošek, M., Zvonař, M., Nykodým, J., Vespalec, T., & López Sánchez, G. F. (2015). Comparison of the level of top tennis players' performance preconditions (case study). *Apunts. Educació Física i Esports*, *122*(4), 52–60. https://doi.org/10.5672/apunts.2014-0983.es.(2015/4).122.06

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