Explorative Study on Muscle Strength and Muscle Strength Ratios in Top National and International Badminton Players

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Abstract:

Introduction: Badminton is a type of sport that is characterized by unilateral and bilateral physical load. The extent to which muscular imbalances are reflected in competitive badminton has been analyzed only in the context of shoulder rotation. Despite the fact that the entire body is used, badminton-specific studies have not been published concerning the lower extremity, trunk, cervical spine, and arms. Therefore, this study's objective is to obtain an overview of the muscular strength ratios and the strength values of the key badminton-specific muscle groups.

Methods: For this study, 53 (male $n = 31$, female $n = 22$) top national and international badminton players were examined regarding isometric maximum strengths (MVC) of the knee, hip, trunk, shoulder, arm, and cervical spine. The measurements took place between June 2012 and December 2014 during the semi-annual sports medicine examinations at the Olympic Training Centre Rhineland-Palatinate/Saarland, Germany. The isometric maximum strength measurement was performed using the Diers Myoline Professional device for a defined angular position. The mean value calculations of dominant and non-dominant side and the agonist and antagonist were analyzed applying the T-test and Wilcoxon test; relationships between strengths and smash speed and maximum jump height were determined using the Pearson correlation coefficient.

Results: Comparing dominant and non-dominant side, significant strength differences were identified for flexing the knee joint ($P<0.001$) and the elbow joint ($P<0.033$). Comparing agonist and antagonist, significant differences were identified for the ratios between knee extension and flexion ($P<0.000$), as well as for arm extension and flexion (dominant and non-dominant side $P<0.001$ each). Also, the extension ratios of trunk and neck musculature were significantly greater than the flexion ratios ($P<0.000$). High degrees of correlation existed between various strength values and maximum smash speed and maximum jump height.

Discussion: A muscle's maximum strength depends on multiple factors. With the measuring device tested by us, measurements were taken in only one angular position, which has a decisive influence on strength. Strength values can also be influenced by lever arms. The measurements were all taken in a sitting initial position. First reference values exist, which will be used for further assessing strength values and help plan and control badminton-specific strength training.

Conclusion: In this study, muscular differences were shown between the two sides in the arm and leg musculature of competitive badminton players. Differences in knee and elbow flexion for the two sides were particularly obvious. The maximum strength ratios of agonist to antagonist of the athletes tested are mostly congruent with the results of other, related disciplines. Therefore, no essential sports type based differences seem to exist. However, the trunk musculature is of emphasized significance.

1 Introduction

Badminton is characterized by specific paths, jumps, swings, lunges, and constant changes of accelerated, decelerated, and re-accelerated movements, all of which require specific strengths to be generated by the muscles involved (Diehl & Kohl, 1999; Ooi et al. 2009). In contrast to popular sports, such as soccer, handball, tennis, or track and field and team sports, the scientific state of research in badminton is generally rather insufficient. Even though considerable increases have been recorded over the past few years, scientific aspects concerning strength behavior or strength ratios of badminton-specific muscle group analyses are dealt with only rudimentarily (see BWF: http://www.bwfbadminton.org/file_download.aspx?id=40759, access on May 1, 2015). Studies that cover only racket-specific strength ratios usually consider only the strength values of the arm and shoulder musculature (compare, e.g., Noffal, 2003; Stülcken et al., 2008; Ivey et al., 1985; Hurd et al., 2011; Forthomme et al., 2011).

Since in badminton the entire body (bilaterally and unilaterally) is integrated in the movement pattern, it is of major interest to examine how strength values and ratios are represented in competitive athletes in terms of sports-specific balances or imbalances. Therefore, this study is to investigate a) which maximum strength values and b) which muscular strength ratios exist in competitive athletes in badminton. The identification of the agonist and antagonist ratios, the general strength values, as well as possible imbalances of the major badminton-specific muscles is the focus of this study. The findings are to support the players, their trainers, and physical therapists in order to prevent disorders of the musculoskeletal system during performance development. Based on the results, performance factors are to be analyzed, and possible pathological risk factors are to be recognized early on (Hewett & Myer 2011).

Risk of injury in badminton

Badminton is a low-risk sport, but if injuries do occur, they are usually major (Hensley und Paup 1979). According to a study by Kroner et al. (1990), joint and ligament injuries take first place with 58.5%, followed by muscle injuries with 19.8%. It is noticeable that the joint and ligament injuries mostly occurred in players below age 30. 66.8% of these injuries affected the ankle joints, and 55.8% of the muscle injuries involved the lower extremities (Kroner et al. 1990).

The injuries analyzed were all caused by acute, traumatic events. Currently, there are no study results pertaining to the issue of "degenerative impairments". However, it is generally known that these can occur due to strain, incorrect load distribution, joint changes, and also muscular imbalances (de Marèes 2003). As badminton as a sport is partly of an asymmetric character it may be relevant to find out if physical asymmetries exist in the form of muscular imbalances.

Muscular imbalances in sports

Muscular imbalance is an imbalance between individual muscles or individual muscle groups building a functional unit (Vogt et al. 2011). In everyday life, these differences are not of any greater relevance. In competitive sports, however, with the body being subject to maximum loads, this issue is of major relevance. Imbalances are often caused by previous injuries that reduce both muscle strength and flexibility. Asymmetric strain, which also occurs in badminton, can also be a cause of such changes (Graf 2012). The consequences of these issues can promote injuries of the musculoskeletal system and the development of incorrect load distribution or strain (Cameron et al.2003; Knapik et al. 1991; O'Sullivan et al. 2008; Orchard et al. 1997).

Literature review

In order to obtain an overview of the literature available in the area of strength ratios (racket sports in general and badminton in particular), research was performed using the major medical databases (e.g., Medline, Elsevier). The ratio of M. quadriceps f. f. to hamstrings is highly important in literature (Croisier et al. 2002, 2008; Knapik et al. 1991, Yeung et al. 2009; Thompson et al. 2011). A major part of these studies was carried out considering possible risk of injury and existing injury issues, with injuries of the cruciate ligaments representing the focus of these studies. In the upper extremity area, studies covered mostly rotator cuff problems. When looking at badminton, it is noticeable that the number of scientific studies has increased slightly. Nevertheless, the studies focus on a large array of topics, covering nutrition, optimal training, pathological mechanisms, etc. In comparison with soccer, tennis, or track and field, the study situation is rather slim, and therefore, our search for suitable studies was performed independently of the type of sports. Preferred were sports with a high degree of similarity, such as tennis or squash, or featuring other overhead situations such as volleyball and basketball.

Badminton musculature

Badminton is a sport during which the entire body is subject to diverse types of strain. Depending on the qualitative and anthropometric characteristics of a player and the opponent's strength, the player's musculature is strained to various degrees.

Lower extremity

A study by Read and Bellam from 1990 compared tennis players, squash players, and track and field athletes. The results showed significant differences in the area of the ratio of the M. Quadriceps f. and the hamstring (compare also Coombs et al. 2002; Costa et al. 2009; Grygorowicz et al. 2010; Knapil et al. 1991). Highly significant differences were also recorded between dominant and non-dominant leg. In contrast, no differences were identified among the individual sports (Read &Bellamy 1990). A 2014 study by Dai Sugimoto et al. dealt with the analysis of gender differences in hip abduction and adduction. The result showed that men reach significantly higher strength levels in hip abduction than women, while hip adduction did not exhibit any major differences pertaining to gender (Sugimoto et al. 2014). Other badminton-specific studies have covered the distinctiveness and development of leg musculature and the forces occurring during the lunge (Whired, Johansson et al. 1983; Harrison, Lees et al. 1986; Kollath und Schwirtz 1991; Lee und Hurley 1995).

Upper extremity

Gabriel and Patrick (2002) have dealt with the isokinetic strength ratios of the left and right side of the body, as well as with the agonist-antagonist relationship of internal and external rotation in badminton. They identified significant differences between the dominant and non-dominant side (Gabriel & Patrick 2002; Chen et al. 2011; Yildiz et al. 2006, Tomin et al. 2013). In this study, differences of 1.9:1.0 for the ratio of eccentric internal rotation to concentric external rotation on the dominant side were determined, and 1.3:1 on the non-dominant side. These ratios were recorded only during the backswing. In contrast, a ratio of 1.1:1 on the dominant and 1.3:1 on the non-dominant side was analyzed during the serve phase. This shows that significant differences exist in the antagonist-agonist ratio between dominant and non-dominant side, a fact that has been comprehensively examined for the sport of tennis (Soccol et al 2010; Stenley et al. 2004; Ellenbecker & Roetert 1999). The effect that these ratios may have on the risk of injury or racket speed, or which conclusions should be drawn for strength training, have not been explained in any more detail, though. The authors and Niederbracht et al. ((2008) do recommend, however, that these imbalances preferably be eliminated if injuries occurred.

Ellenbecker and Roetert (2003) conducted a study with 38 young elite tennis players to examine elbow extension and flexion. They examined the isokinetic muscle profile of this joint. The results showed that the elbow extension of the male tennis players varied significantly from dominant to non-dominant side, but no differences existed regarding flexion. The female test persons did not exhibit any significant differences pertaining to the sides for neither extension nor flexion (Ellenbecker and Roetert 2003).

As regards the upper extremity, in addition to the shoulder musculature, the rotational force of the lower arm is of high significance during racket movement according to Brahms (2012) und Gowitzke & Waddell (1977). In current badminton, many shots are performed using the wrist. This leads to an internal-rotational flexion of the wrist. Especially for hard shots, this component becomes important (Brahms 2012). Overall, high stability of the entire arm, particularly of the shoulder musculature, is a prerequisite (Ny & Lam 2002).

Yang et al. (2014) examined 30 students (15 male/15 female) independently of their athletic activity regarding the maximum strength levels in different angular positions of the elbow. They found out that biceps and triceps develop different levels of strength depending on the angular position. However, the angular positions do differ. The test persons reached the maximum strength level with flexion at approx. 56°; with extension, the maximum strength was reached at 84° (Yang et al. 2014). Couppé et al. (2012) studied the shoulder musculature's strength profiles in badminton, and Simonet (1984), Warren (1983), as well as Fahlström (2006) and others examined these profiles considering medical points of view.

Trunk

From a functional-anatomic perspective, the trunk is a central component in badminton. It represents the connection between upper and lower extremities and requires coordinated ventral-dorsal muscle strength (Denner 1998). For directional changes, the trunk is the basis for the legs, and for racket swings it serves as the basis for the arms, thus being of major significance in sports like badminton, tennis, squash, etc. (Grosdent et al. 2014; Kort & Hendriks 1992). A basic precondition for hitting and running movement is a high degree of trunk stability in the player. The trunk is the punctum fixum (thrust bearing). Without pronounced stability in this area, it is difficult to carry out targeted and powerful hitting or running movements (Boyle 2012).

In a study, Mueller et al. (2014) analyzed the maximum strengths of the trunk in competitive athletes aged 11-15. 520 athletes from various types of sport underwent isokinetic strength measurements. The authors determined in their analysis that trunk extension outweighed trunk flexion. This dominance of extension seemed to be independent of age or gender (Mueller 2014).

Cervical spine

Strength measurements in the area of the cervical spine were performed with rugby players within the framework of another study. Flexion, extension, lateral flexion, and rotation were measured in 27 rugby players using a strength measurement device specially developed for this purpose. The result showed that these athletes generated the most strength when extending the cervical spine. The lowest degree of strength was achieved when flexing the neck. An additional objective of the study was to determine the differences between the individual playing positions. The result showed that the "forwards" can achieve significantly more strength when flexing the neck than the "backs". All other differences were insignificant. Therefore, it can be assumed that depending on the requirements profile, more or less high strength levels are achievable in the cervical spine. The extension-flexion ratio seems to be independent of this, though. As for trunk strength, the extension seems to be the strength that is larger by far (Hamilton und Gathere 2014; Miltner et al. 2010).

2 Methods

This study was conducted at the institute of biomechanics and training science at the Olympic Training Centre Rhineland-Palatinate/Saarland, Germany with data being collected between June 2012 and December 2014. All athletes tested were competitive badminton players of the top national and international performance category (world ranking < 40 and national ranking < 15) between 18 and 32 years of age. Both male and female singles and doubles players were tested and analyzed. The total number of test persons was 53 (22 female and 31 male).

Inclusion criteria

- Competitive badminton players of the top national and international category
- Age 18 to 32

Exclusion criteria

- Acute injuries of the structures to be tested
- Common cold or conditions that might have a performance-affecting influence

The diagnosis device used was the "DIERS myoline professional" which features the option to measure up to 28 muscle groups. During all measurements, the test persons received motivational biofeedback providing information on duration and strength of the ongoing measurement. Only isometric maximum strengths were recorded. All measurements were recorded using the DiCAM software version 2.4.9 (Diers International), visualized on the PC, and saved.

All measurement sessions started with a test run after a standardized warm-up protocol.

1. Start the bi-lateral use of strength of the musculature to be tested upon the command of the test conductor.
2. Increasing strength development up to the maximum with a holding period of 2-3 seconds.
3. Each muscle structure is tested only once if the exercise was performed correctly.
4. 30-60 seconds pause after each measurement.

1. **Knee flexion (figure 1)**

- Fixation with a hip strap
- Upright sitting position (back flat to the back pad)
- Lower legs fixated in the foot rest
- 45° knee flexion, 90° hip flexion
- Hands folded in front of the body

Figure 1: Knee ext/flex, hip abd

2. **Abduction/adduction (figure 1/figure 2)**

 (Horizontal abduction from 0° to 10°)

- Cushion on the inside (for adduction)
- Cushion on the outside (for abduction)

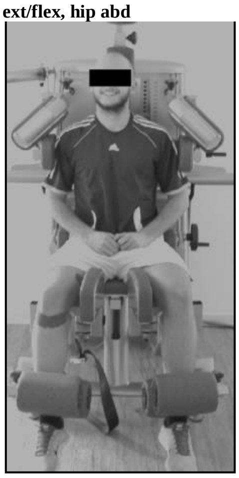

Figure 2: Hip add

3. **Internal/external rotation of the shoulder (figure 3)**

- Arms in 90° flexion in the shoulder joint
- Internal rotation = arms press inward
- External rotation = arms press outward

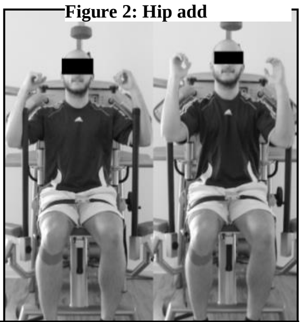

Figure 3: Shoulder IR/ER

4. **Arm flexion/extension (figure 4)**

- Back pad positioned at the 7th neck vertebra
- 45° flexion of the shoulder joint
- 90° flexion of the elbow joint
- Upper arms rest on the pads
- Pelvis and legs are fixated by means of straps
- Flexion = Hands outside
- Extension = Hands inside

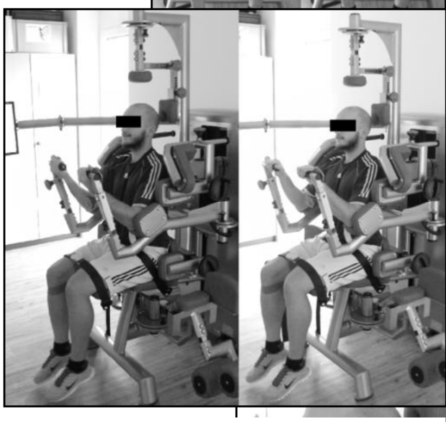

Figure 4: Arm FLEX/EXT

5. **Trunk extension/flexion/lateral flexion/rotation (figure 5)**

- Hands folded in front of the body
- Trunk fixated at the sides as well as in front by pads

6. **Cervical spine extension/flexion/lateral flexion (figure 6)**

- Flexion = Pad behind the head
- Extension = Pad in front of the head (nose is free)
- Lateral flexion = Pad to the side of the head

Figure 5: Trunk strength

Figure 6: Strength measurement of the cervical spine

The statistical evaluation procedure was performed using SPSS (vers. 16).

3 Results

3.1 Descriptive statistics

A total of 53 badminton players of the top national and international categories participated in this study. 22 (41.5%) were female and 31 (58.5%) were male. In the entire group, 44 players were dominant right-handers (83%) and 9 dominant left-handers (17%). The average age was 23.9 ± 5.2 years, the average body height was 176.5 ± 8.1cm, and the average body weight was 67.8 ± 11.2 kg. Table 1 lists the corresponding MVC values of the individual muscles or muscle groups from the dominant and non-dominant side.

Table 1: Results of the strength measurements in Newton (N)

D = Dominant - ND = Non-dominant	N	Min	Max	Mean	SD
Extension D knee in N	53	291.5	1004.0	549.5	162.8
Extension ND knee in N	53	230.0	944.0	529.9	160.3
Flexion D knee in N	53	101.0	456.0	231.6	86.0
Flexion ND knee in N	53	70.0	438.0	213.4	88.6
Abduction D hip in N	53	499.0	2330.0	1287.0	513.1
Abduction ND hip in N	53	481.8	2409.0	1274.7	525.9
Adduction D hip in N	53	430.2	2470.0	1353.6	540.7
Adduction ND hip in N	53	403.5	2467.0	1343.9	556.6
Internal rotation D shoulder in N	50	337.0	2282.0	1001.2	487.1
Internal rotation ND shoulder in N	50	379.2	2079.0	1005.4	478.6
External rotation D shoulder in N	50	333.8	1912.1	1021.6	480.6
External rotation ND shoulder in N	50	213.6	1960.0	1004.1	469.6
Flexion D Arm in N	49	110.0	468.0	275.9	81.0
Flexion ND Arm in N	49	110.0	421.0	265.9	77.7
Extension D Arm in N	49	86.0	429.4	226.6	69.7
Extension ND Arm in N	49	107.0	417.0	221.6	71.9
Flexion of the trunk in N	44	155.5	754.0	385.2	144.4
Extension of the trunk in N	46	348.0	1812.0	1069.3	355.4
Lateral inclination of the D side in N	45	172.0	1193.0	538.6	276.6
Lateral inclination of the ND side in N	45	119.0	1138.0	550.1	270.7
Rotation of the trunk to the D side in N	41	156.0	920.4	540.9	211.8
Rotation of the trunk to the ND side in N	42	112.0	921.1	541.7	228.1
Flexion of the cervical spine in N	50	93.0	282.5	167.8	41.3
Extension of the cervical spine in N	50	148.5	371.2	264.6	60.0
Lateral inclination of the CS to the D side in N	47	99.0	339.9	205.6	59.6
Lateral inclination of the CS to the ND side in N	48	106.0	310.0	200.7	52.3

After the descriptive output of the measurement results, they were checked for possible outliers. This was done using boxplot graphics by determining unusual cases and analyzing them in terms of their probability.

3.2 Inferential statistics evaluation

The following constitutes a list of inferential statistics evaluation results. The testing procedure applied was the T-test. In order to verify that the measurement data corresponded to a normal distribution, the Kolmogorov-Smirnov test (KS test) required for the T-test was selected. To minimize the risk of erroneously deciding for the null hypothesis, the significance level in the KS test was set to the 10% that are usual for this test. The result of the measurement was that the data corresponds to a normal distribution with the exception of the internal rotation of the non-dominant shoulder. Therefore, the Wilcoxon test was applied for this dependent variable.

In total, eleven T-tests were performed to compare dominant and non-dominant side for paired samples. Ten calculations were done for the agonist-antagonist ratio. As mentioned before, the data for the average maximum strength values of the athletes are represented, as well. Two groups (male/female) existed to take gender influence into account. If no statistical anomalies exist, the average value calculations differentiate between the average value of the dominant side and that of the non-dominant side.

3.2.1 Knee

When examining the leg musculature, the knee extensors and knee flexors were scrutinized in particular. The results show that highly significant data came to light for both the dominant and the non-dominant side. This is reflected in the ratios, as well: The preferred side had a ratio of 1:2.56, which means that the strength of the extensor musculature is double as strong as the flexion muscles. On the non-dominant side, this difference with a ratio result of 1:2.73 is even more considerable.

The comparison of sides pertaining to maximum flexion strength also turned out to be unusual. No significant result was reached in the comparison of sides pertaining to leg extension. The strength ratios for that were calculated at 1.13:1 for flexion and 1.06:1 for extension.

Table 2: T-test and ratio data of the knee joint musculature

	Extension D to ND	**Flexion D to ND**	**Extension to flexion**	
			Dominant	**Non-dominant**
Significance	.055	.001	.000	.000
Ratio	1.06:1	1.13:1	2.52:1	2.73:1

3.2.2 Hip

For the hip musculature measurement, both abduction and adduction of the hip joint was considered. The analysis shows that no significant deviations are recognizable in the side comparisons. For the

abduction, the results show a P value of .512 and a ratio of 1.02:1 between dominant and non-dominant side. For the adduction, the P-value is .631 with the side ratio of 1.02:1 being identical.
In the agonist-antagonist comparison, the results are not significant, either. However, the P-values lie slightly above the significance level with .065 on the dominant side and .069 on the non-dominant side. In contrast, the abduction-adduction ratio on both sides is 1:0.97, which can be viewed as slightly different.

Table 3: T-test and ratio data of the hip joint musculature

	Abduction D to ND	**Adduction D to ND**	**Abduction to adduction**	
			Dominant	**Non-dominant**
Significance	.512	.631	.065	.069
Ratio	1.02:1	1.02:1	1:0.97	1:0.97

3.2.3 Shoulder

The shoulder rotation calculations were performed applying two different test procedures. Since normal distribution did not apply to the internal shoulder rotation on the non-dominant side, the statistical procedure selected in this case was the Wilcoxon test. The results of the comparison between dominant and non-dominant side indicated significant differences in external rotation (P=.033). When considering the internal rotation results, a value of .379 was calculated based on the Wilcoxon test. Therefore, it is assumed that there are no differences when comparing sides for internal rotation.
The agonist-to-antagonist ratios show an almost congruent match of muscle ratios. For the non-dominant side, an significance level of .977 was reached. Therefore, it is assumed that hardly any differences exist between internal and external rotation on the non-dominant side. On the dominant side, a value of .669 was reached.
The calculation of ratios for internal rotation (0.99:1) does not exhibit any major differences in the agonist-antagonist comparison (D 1.03:1/ ND 1.09:1). Only the comparison of dominant and non-dominant side for external rotation showed an increase with 1.14:1.

Table 4: T-test/Wilcoxon test and ratio data of the shoulder musculature

	Internal rotation D to ND	**External rotation D to ND**	**Internal to external rotation**	
			Dominant	**Non-dominant**
Significance	.358/W .379	.033	.669	.977/W .977

Ratio	0.99:1	1.14:1	1.03:1	1.09:1

3.2.4 Arm

The arm measurements include both arm flexion and extension. In particular, the strength moving the elbow joint is measured. The result of our study shows no significant difference (P=.356) between dominant and non-dominant side when extending the arm. However, when observing the arm flexors, significant differences occur. A level of significance was calculated with .33 and is thus significant. When comparing arm extension and flexion, the differences must be deemed highly significant on both the dominant (.000) and non-dominant (.001) side.

Table 5: T-test and ratio data of the elbow musculature

	Extension D to ND	**Flexion D to ND**	**Extension to Flexion**	
			Dominant	**Non-dominant**
Significance	.358	.033	.000	.001
Ratio	1.05:1	1.05:1	0.89:1	0.90:1

The ratio data for arm extension is 1.05:1 and therefore rather low, similarly to the flexion ratio at 1.05:1. In contrast, the difference between flexion and extension on the dominant side is slightly higher with 1:0.88, similarly to the non-dominant arm with 1:0.90.

3.2.5 Trunk

The measurement results indicated highly significant differences for the flexion-extension ratio (P=.000). However, for lateral inclination (P=.614) and rotation of the trunk (P=.562), no differences were found.

It is therefore assumed that the trunk does not show any differences in terms of rotation and lateral inclination, but does indeed when it comes to flexion and extension. The ratios for the latter were calculated at 0.38:1. Thus, the maximum strength development of trunk extension is more than 2.5 times higher than that of trunk flexion. The ratios of lateral inclination (1:1.02) and rotation (1:1.02) of the trunk can be viewed as marginal.

Table 6: T-test and ratio data of the trunk musculature

	Flexion to extension	**Lateral flexion D to ND**	**Rotation D to ND**

Significance	.000	.614	.562
Ratio	0.38:1	1.02:1	1.02:1

3.2.6 Cervical spine

The test results support the current study situation. Highly significant results (P=.000) were analyzed for the flexion-extension ratio. As suspected, the lateral inclination was calculated as not significant with a value of .326. It is therefore assumed that the differences in lateral inclination are almost identical, whereas the flexion-extension ratios differ considerably.

The ratio calculations indicated a ratio of 1:1.55 between flexion and extension. The ratios are lower compared to those of the trunk, but they are still very different. The lateral inclination ratios are almost identical. With a ratio of 1:1.02 the differences are rather slight. But, here as well, the dominant side is slightly prevalent.

Table 7: T-Test und ratio data of the musculature of the cervical spine

	Flexion to extension	**Lateral flexion D to ND**
Significance	.000	.326
Ratio	0.65:1	1.02:1

3.3 Summary of the orientation values

To achieve a better overview, all orientation values have been summarized in one table. This table is to serve as a basis for subsequent measurements, as well as for providing coaches and athletes with a rough overview of the maximum strength values for their orientation.

Table 8: Orientation values of the maximum strength in badminton players

	Group categorization (age and gender)							
	male >20		female >20		male <=20		female <=20	
	Mean	N	Mean	N	Mean	N	Mean	N
Ext D knee in N	622.24	14	411.88	9	620.34	17	473.98	13
Ext ND knee in N	624.54	14	374.11	9	596.85	17	448.33	13
Flex D knee in N	268.91	14	182.55	9	266.32	17	179.77	13
Flex ND knee in N	259.57	14	159.22	9	246.69	17	157.56	13
Abd D hip in N	1668.85	14	1170.77	9	1142.27	17	1145.57	13
Abd ND hip in N	1652.74	14	1118.88	9	1106.17	17	1195.70	13
Add D hip in N	1690.13	14	1112.11	9	1242.80	17	1303.39	13
Add ND hip in N	1714.94	14	1076.66	9	1247.951	17	1254.96	13
IR D shoulder in N	1356.50	14	1020.120	8	858.14	16	764.90	12
IR ND shoulder in N	1409.34	14	940.00	8	871.54	16	756.13	12
ER D shoulder in N	1309.23	14	903.75	8	985.95	16	812.08	12
ER ND shoulder in N	1342.72	14	879.37	8	908.60	16	819.65	12
Ext D arm in N	249.66	13	179.75	8	225.15	16	234.85	12
Ext ND arm in N	246.46	13	156.87	8	220.74	16	238.916	12
Flex D arm in N	278.06	13	235.750	8	333.21	16	224.05	12
Flex ND arm in N	268.63	13	222.00	8	323.45	16	215.32	12
Flex of the trunk in N	462.97	10	327.25	8	378.24	15	366.09	11
Ext of the trunk in N	1057.60	12	956.87	8	1244.98	15	924.28	11
LatFlex trunk D in N	578.48	12	322.62	8	672.17	13	498.14	12
LatFlex trunk ND in N	585.78	12	308.37	8	767.36	13	440.15	12
Rot trunk D in N	743.29	10	377.87	8	573.37	14	410.32	9
Rot trunk ND in N	719.25	10	369.75	8	632.00	14	375.45	10
Flex of the CS in N	186.40	14	174.62	8	169.30	15	141.98	13
Ext of the CS in N	285.26	14	242.62	8	296.77	15	218.63	13
LatFlex of the CS D in N	226.06	13	149.87	8	253.25	14	164.85	12
LatFlex of the CS ND in N	219.73	13	160.12	8	233.42	14	171.30	13

3.4. Correlations pertaining to badminton-specific techniques

In table 9, the strength values measured are correlated with the maximum smash speed (quantified by racket speed of the shuttle; for more information on the method to quantify the maximum racket speed please refer to Kollath et al. (1986) as well as Tsai and Chang (1998).

Table 9: Correlation between strength values and maximum smash velocity (n = 23; * p < 0.01)

body part / movements	r
leg strength (extension/flexion)	.21
hip strength (adduction/abduction)	.18
shoulder strength (internal/external rotation)	.78 *
arm strength (flexion/extension)	.68 *
trunk strength (flexion/extension)	.67 *
trunk strength (rotation)	.69 *
trunk strength (lateral flexion ri le)	.69 *
cervical strength (flexion/extension)	.41
cervical strength (lateral flexion ri le)	.38

Table 10 shows the correlations between the maximum strength values collected and the maximum jump height (for more information on the method to determine the maximum jump height please refer to Fröhlich et al. 2014).

Table 10: Correlation between strength values and maximum jump height (n = 19; * p < 0.01)

Body part / movements	r
leg strength (extension/flexion)	.82 *
hip strength (adduction/abduction)	.78 *
shoulder strength (internal/external rotation)	.28
arm strength (flexion/extension)	.18
trunk strength (flexion/extension)	.69 *
trunk strength (rotation)	.65*
trunk strength (lateral flexion ri le)	.51
cervical strength (flexion/extension)	.31
cervical strength (lateral flexion ri le)	.36

3.4 Assessment of results

The analysis of assessments shows that badminton players exhibit only limited muscular differences in the sides. Only the flexion ratio of the dominant and non-dominant knee and the flexion ratio of the left and right elbow displayed statistically remarkable values. In addition to the knee flexor difference, the extension ratios of the knee joints are also noticeable because with a value of .055 they are only slightly above the significance level. A possible explanation could be that the athletes may have a preferred takeoff/supporting leg. Literature says that a technically correct takeoff in both the clear and the jump requires the players to select the same side for the takeoff leg in which they also hold their racket. The same applies to drop and drive. During a lunge, the players shift their body weight to the dominant leg and use the same leg to take off from the ground to reach the central playing position (Brahms 2012). Therefore, the leg of the dominant side is subject to higher strain during a technically proper execution. This suggests the origin of imbalances in the side ratio.

The reason for the high flexion ratios of the elbow could be that according to Brahms (Brahms 2012), the major part of the hitting strength is generated from the force of the forearm rotation. The key pronators of the forearm include the pronator teres, which rotates the arm inside and can simultaneously flex the arm (Altenburger et al. 2013). Since this muscle is always exercised during hitting practice, the arm flexion strength is improved, as well. Therefore, it can be assumed that this important muscle brings about the difference in arm flexion.

As previously stated in the literature section, the agonist-antagonist ratios of badminton players are similar to those of other athletes. Statistically noticeable were the extension-flexion ratios of the knee and elbow joint, of the trunk, and of the cervical spine. Nevertheless, they do not seem to be unusual when looking at the literature, because such differences occur in other sports and even in persons without an athletic background. In this context, it therefore seems to be more important to minimize poor static posture and, at the same time, to improve mobility of individual spinal joints in order to prevent strain syndromes, particularly in the area of the spine.

The calculations of the average maximum strength values of the individual muscle groups were divided into four groups as shown in table 8. They are to serve as an orientation for coaches and athletes during further measurements. However, these measurement values are only valid in combination with the "Diers Myoline Professional". They cannot be compared with values obtained with other measuring devices due to the fixed angular positions and the lever ratios.

4 Discussion

As our literature research has shown, there is an optimal angle for each joint of the body, in which a muscle can develop its maximum strength. Our study did not take into account the degree of these sometimes very individual angles. Therefore, our statements only apply to the angular positions we tested (compare Krishnan & Williams 2014). We also need to point out that the measurement results apply only to the measurement unit and measurement device ("Diers Myoline Professional") we used. In addition to the angle settings, the lever ratios have an impact, as well. Depending on arm/leg length, greater strengths can be achieved with an increased lever. Anthropometric data, such as height or weight, also influence the measurement results, but the extent to which they do still needs to be determined. In our study, only muscle groups are considered without targeting individual muscles.

Other factors that may influence the measurements include each athlete's daily fitness form. The athletes were interviewed on their physical fitness before tests, but psychological components could, of course, impact the maximum strength. The inhibiting effect of the antagonists is another factor. Despite the antagonistic inhibitions, this effect can never be completely eliminated (de Marèes 2003).

Regarding the measuring procedure, it needs to be taken into account that the test persons did not perform any warm-up phase and that the measurement was conducted only once. This raises the question whether an increased blood circulation results in an increase of muscle strength. Also, multiple executions can lead to a learning effect, which might enable the athletes to boost their performance.

Even though badminton is a sport that is performed in an upright position, all measurements were executed in a sitting position, which is due to the nature of the measurement device. The angular position of the musculature again plays a decisive role, which in turn may have an impact on the test results.

Due to the low number of test persons, gender and age consideration could not be calculated in statistical terms.

Measurements of the movement considered most important by Brahms, the forearm rotation, were not carried out (Brahms 2003). However, the key forearm pronator (M. pronator teres) was included in the arm flexion measurement. Its influence on the maximum strength calculation for elbow flexion can only be presumed, though.

5 Conclusion

Between June 2012 and December 2014, we examined a total of 53 badminton players by performing maximum strength measurements for the muscles that are important for this sport. Up to 26 maximum strength measurements were conducted with each athlete during the semi-annual performance diagnostic. Only two muscle groups (knee flexion and arm flexion) exhibited significant ratio differences of 1.14:1 (knee flexion) and 1.05:1 (arm flexion) in side comparisons. When looking at the agonist-antagonist ratios, the flexion and extension ratios of trunk (0.38:1), cervical spine (0.65:1), dominant arm (0.88:1), and both knee joints (D: 0.39:1 ND: 0.37:1) were very remarkable.

These results are important orientation values to adjust their training programs.

- Because of the present study, general strength values are now available for all badminton-relevant muscles/muscle groups and serve as strength training orientation values.
- Ratio values (dominant versus non-dominant side/agonist versus antagonist) are available for all badminton-relevant muscles/muscle groups.
- A percentage distribution pattern of all relevant muscle strengths exists with regard to the entire body.

- It has been shown that the trunk musculature plays a key role. This applies not only to preventive considerations, but also to badminton-specific motion sequences. The high degree of correlation between trunk strengths and maximum jump height points at the great necessity to exercise these muscle groups explicitly.

It remains to be seen to what extent and intensity the muscle groups examined need to be exercised. In order to improve overall sports performance, this component is important because an optimal balance of strength, flexibility, and coordination leads to economized movement patterns and thus has performance-boosting effects.

Based on these findings, the study conducted represents a foundation for the strength component, and they enable coaches and athletes to more effectively develop and control strength capabilities. By means of the diagnostics introduced, training history can be documented in a more specific way to recognize and minimize possible imbalances. Subsequent studies should decidedly be dedicated to strength training in badminton.

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