Asymmetries of Maximum Trunk, Hand, and Leg Strength in Comparison to Volleyball and Fitness Athletes

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Abstract

Mattes, K, Wollesen, B, and Manzer, S. Asymmetries of maximum trunk, hand, and leg strength in comparison to volleyball and fitness athletes. *J Strength Cond Res* 32(1): 57–65, 2018—Playing volleyball and corresponding training loads lead to specific strains and might result in asymmetric muscle pattern. The study aimed to identify volleyball-specific maximum bilateral strength asymmetries in comparison to fitness athletes. The cross-sectional study design compared an age-matched male volleyball group ($n = 23$; 27.9 ± 5 years) with a fitness group ($n = 30$; 26.3 ± 3 years). The participants performed an isometric maximum handgrip strength test followed by 2 isokinetic concentric maximum strength tests to determine the performance capacity of the axial trunk rotators (left-right) and bilateral leg extensors. Differences between groups and left-right side (within group) were proven by variance analysis with repeated measurements. There was a left-right difference with higher maximum forces for the rotation in the right direction in the volleyball group ($p = 0.0058$) but the group interaction effect was not significant after alpha error accumulation. The results of the leg press indicated a stronger left leg in the fitness group (nonsignificant) in comparison to the volleyball group. Overall, the volleyball group displayed symmetry in maximum handgrip and leg strength and asymmetry in trunk rotation with higher strength in right rotation. This asymmetry for the right trunk rotation showed a small effect size. The resulting asymmetry might be an adaptation to the volleyball techniques, but it remains unclear if this is a cause for or of injury. As a practical implication, the asymmetries should be examined to develop individualized strength training programs for both groups.

Key Words trunk rotation, isometric maximum handgrip strength, strength, asymmetry, sport-specific muscle patterns, leg press

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Introduction

Several sport activities require asymmetric movements (e.g., volleyball) to gain a high level of sport-specific performance. This is associated with specific muscular adaptations. Although required for optimum performance, these asymmetries in strength could also lead to pain (38) and subsequently to reduced performance (3,4). Left-right differences of 10% or above are considered as risk factors for injuries (6,17,45). Therefore the assessment of muscular asymmetries is becoming increasingly important in the clinical field as well as for strength and conditioning of practitioners (3).

Volleyball is a sport with a distinct profile. As shown in a review by Seminati and Minetti (37), 250–300 highly explosive actions take place over a period of 5 sets in high-level volleyball matches. These can be divided into jumps (50–60%), attacks (27–33%), and ground moves, such as diving for the ball (12–16%). According to Hadzic et al. (15), the specific movements of volleyball athletes result in an asymmetric dominant side. Serving and smashing techniques are characterized by a hyperlordosis of the lower back in combination with lateral flexion before hitting the ball and thoracic kyphosis and side bending as well as shoulder hitching during and after hitting the ball (31), resulting in strength asymmetries of the upper body, especially for the shoulder girdle and for trunk rotation.

The lower extremities are challenged due to jumps and attacks: Both techniques are performed with a sequenced step approach to alleviate the forward impulse of movement (horizontal speed) across the weight-bearing leg in a vertical direction related to jumping height (18,41). The take-off technique requires increased leg loading which determines the vertical height due to the foot position, which is situated closer to the vertical projection of the body's center of mass (5,44). Individuals who are right-hand dominant usually use their left leg to gain vertical height (44). Another example of unbalanced movements is the spike movement, which is linked to unilateral trunk rotation to facilitate higher speeds for hitting the ball. This movement comprises the back swing of the spiking arm in combination with rotation of the trunk (7), although the trunk muscles are first pre-stretched and then concentrically contracted.

A study by Miltner et al. (32) examined trunk strength of 12 professional volleyball athletes in comparison to nonvolleyball players to identify predisposing factors and create a corresponding prevention program to avoid overuse injuries. The volleyball players showed less muscle strength for the left trunk rotation compared with right trunk rotation. The individual analysis of each player revealed distinct muscle imbalances in 5 of the 12 players. Overall, these results cannot be generalized because of the small sample size.

In contrast to volleyball practice, fitness training is commonly associated with a symmetric movement pattern as the goal of the exercise is to train symmetric strength. In case of asymmetric movement patterns, the work load is controlled to avoid dysfunctional asymmetries. However, if asymmetries are identified, the training of weak muscles gains priority (26).

Previous research on muscular imbalance and dependent force data for left and right rotations focused on various isometric and isokinetic measurement protocols, used different athlete groups and measuring instruments, and therefore led to contradictory results. Some studies showed significant left-right-differences of trunk rotational strength (2,8,20,23,29), whereas other studies reported symmetric strength (14,21,29,34,39). Furthermore, axial movements of the trunk are related to spine and back pain (19,20,23,24,32) and the bilateral asymmetric strength to trunk rotation (13,19–21,23,27,28,37). However, these studies did not take the handedness and footedness into account and did not have an appropriate control condition.

In summary, it is important for the prevention of injuries and for the rehabilitation after injuries to recognize the optimal balance between asymmetric strength required by the sport-specific techniques and asymmetries that increase the risk of (re-)injury (16,31). Therefore, the awareness of this sport-specific asymmetry is important for the assessment of muscular imbalances and their detraining during rehabilitation. Especially after being injured, it is essential to regain strength, with an important criterion being the bilateral adjustment of strength imbalances in the lower limb. However, it should be considered that for volleyball athletes, the forces, which are required for take-off, have to be produced asymmetrically by the take-off leg.

Moreover, the handedness and footedness influence muscular strength symmetries (10), because the dominant side is usually stronger. To describe the handedness and footedness, there is a distinction between the preferred hand or leg during activities and the performance of the dominant hand or leg. The preferred limb will be used frequently in everyday movements such as using a tool or manipulating objects such as throwing a ball. In contrast, the dominant limb shows higher forces in strength tests (e.g., handgrip tests, unilateral strength, or jump tests).

The middle part of Europe is dominated by right-handed persons. The right hand is therefore used more frequently and has a higher grip strength. This handedness could be associated with 1 dominant take-off leg (left or right). For right-handed persons, the most frequent combination is the right hand with a left take-off leg (33).

Overall, it seems to be important to analyze sport-specific aspects of symmetry and asymmetry concerning the whole body movement. For the volleyball movements, there might be an association of handgrip forces, trunk rotation, and leg strength with resulting asymmetries, whereas these specific asymmetries might not occur for fitness athletes with no sport-specific movement patterns.

Therefore, the aim of this study is to compare the muscle strength profiles of maximum isometric handgrip strength, isokinetic concentric trunk rotation strength, and bilateral leg extension strength in the closed chain of volleyball players and fitness athletes, and furthermore to assess possible strength asymmetries between the left and right side. Our hypothesis is that volleyball athletes show a left/right asymmetry in trunk rotation and leg strength but not for handgrip strength. For the group of fitness athletes, no asymmetry is expected because of their training goal of muscular symmetry.

Methods

Experimental Approach to the Problem

This cross-sectional study design compared 2 groups of volunteers who participated in 2 different sports (volleyball and fitness group). The participants performed an isometric maximum handgrip strength test followed by 2 maximum isokinetic concentric strength tests to determine the performance capacity of the axial trunk rotators to the left and right side in addition to bilateral closed-chain leg extension (leg press).

Subjects

Participants (Table 1) were recruited by online advertisements targeting fitness groups. In addition, personal contact was made with 2 semi-professional male volleyball teams (third division German league). Participants in the volleyball group had trained for 13 ± 5 years (practicing 3 times a week in addition to in-season matches). The fitness group had trained for 10 ± 6 years with an average of 4 times per week (fitness, handball, martial arts, gymnastics, and other sports). The volleyball athletes were on an average 6.5 cm taller and 7.2 kg heavier than the fitness group. At the time of measurement, all participants were free of any orthopedic diagnostic finding and had no previous episodes of back pain. We did not include any person younger than 18 years. The range of age in the groups was from 19 to 45 years. All subjects were informed of the risks and benefits of the study and then gave written informed consent to participate. We did not account for nutritional intake, hydration status, and time of testing due to logistics and availability of participants to perform tests and their participation in our study. However, most, if not all, of the participants were acutely aware of their nutritional and hydration intake during testing and

Table 1. Age and anthropometric data ($N = 53$).*†

Group	N	Age (y)	B_M (kg)	B_H (cm)	Hand dominance	
					Right	Left
Fitness	30	26.3 ± 3	78.5 ± 8.9	180.1 ± 5.6	26	4
Volleyball	23	27.9 ± 5	85.7 ± 11.1	186.6 ± 6.2	21	2
Total	53	27.0 ± 4	81.6 ± 10.4	182.9 ± 6.7	47	6

*B_M = body mass; B_H = body height.
†Values are mean ± *SD*.

did not seem to deviate from their usual nutritional and hydration status. The institutional local ethics committee of the University of Hamburg approved this study.

Procedures

Participants were introduced and familiarized with the tests and asked about their dominant hand and leg. All athletes completed a 10-minute warm-up, running on the treadmill at a preferred speed.

Assessment of Handgrip Strength. The Jamar Hydraulic hand dynamometer (Model 5030J1; J. A. Preston Corporation, Clifton, NJ, USA) was used to measure the maximum handgrip strength. The instrument has previously shown excellent reliability (intraclass correlation coefficient [ICC] (1,3) = 0.98) and validity (ICC (2,K) = 0.99) (16). The hand dynamometer was adjusted to the individual's hand size. Maximum handgrip strength was measured to identify the stronger hand. The handgrip strength test was conducted in a randomized order (starting with the left or right hand). Each hand was tested twice with a 1-minute rest between trials. The test took place in a standing position with extended arms perpendicular to the body. If required, the participants could use magnesium carbonate (chalk) for the hands to ensure grip. The mean value of both tests served as the result.

Assessment of Trunk and Leg Strength. The isokinetic tests for maximum strength of trunk rotation and bilateral leg extension were carried out with the IsoMed 2000 (D&R Ferstl/GmbH, Henau, Germany) using the adapters produced by the manufacturer. The torque and rotation angle were measured in each direction of axial trunk rotation. The footrest of the leg press was equipped with 2 strain gauges to measure the force of the left and right leg separately. This allowed the measurement of extension strength

Figure 1. Positioning of the participants on the IsoMed 2000-Dynamometer.

TABLE 2. Comparison between left and right side and between fitness and volleyball; analysis of variance, main effects (ME), interaction side × group (IA), and between-subject effect groups (BE) ($N = 53$).*†

		Fitness ($N = 30$)		Volleyball ($N = 23$)		ME		IA	BE
Test	Variables	Left	Right	Left	Right	p	η_p^2	p	η_p^2
Hand grip	Max force/body mass ($N \cdot kg^{-1}$)	0.53 ± 0.13	0.56 ± 0.13	0.44 ± 0.1	0.43 ± 0.09	0.1736	0.036	0.031	0.0006
	Max force (N)	41.4 ± 10.3	43.6 ± 9.7	37 ± 7.1	36.3 ± 6.4				
Trunk rotation	Mean torque/body mass ($Nm \cdot kg^{-1}$)	1.17 ± 0.35	1.17 ± 0.34	1.20 ± 0.31	1.33 ± 0.31	0.0053	0.142	0.0058	0.2878
	Mean torque (Nm)	105.1 ± 31.9	105.3 ± 31.1	108 ± 27.7	119.7 ± 28.1				
	Mean power (W)	220.1 ± 66.7	220.1 ± 64.9	225.9 ± 57.9	250.5 ± 58.9				
	Mean work (J)	102.5 ± 29.6	104.2 ± 31	104.9 ± 29.2	120 ± 28.2				
	Mean ROM (°)	55.8 ± 3.2	55.9 ± 3.9	55.3 ± 3.2	56.5 ± 2.2				
	Max torque/body mass ($Nm \cdot kg^{-1}$)	1.78 ± 0.46	1.77 ± 0.45	1.81 ± 0.42	1.98 ± 0.36				
	Max torque (Nm)	160.2 ± 41.2	158.9 ± 40.4	163.1 ± 37.5	178.5 ± 32.4				
	Max power (W)	335.1 ± 85.6	332.7 ± 84.3	341.3 ± 78.6	374 ± 67.7				
	Max work (J)	114.6 ± 33.6	113.3 ± 31.5	115 ± 29.5	128.9 ± 28.3				
Leg press	Mean force/body mass ($N \cdot kg^{-1}$)	14.9 ± 2.4	14.4 ± 2.5	14.7 ± 2.2	14.5 ± 1.8	0.0187	0.104	0.419	0.899
	Mean force (N)	1,170 ± 217	1,132 ± 227	1,250 ± 176	1,234 ± 173				
	Mean power (W)	211 ± 39	204 ± 41	225 ± 32	222 ± 31				
	Mean work (J)	333 ± 68	322 ± 69	368 ± 55	363 ± 55				
	ROM (mm)	282 ± 17	–	292 ± 13	–				
	Max force (N)	1,673 ± 331	1,654 ± 343	1,815 ± 291	1,806 ± 271				
	Max force/body mass ($N \cdot kg^{-1}$)	21.4 ± 3.8	21.1 ± 3.8	21.5 ± 4.0	21.3 ± 3.4				
	Max power (W)	302 ± 60	298 ± 62	327 ± 53	326 ± 49				
	Max work (J)	345 ± 69	334 ± 71	382 ± 56	376 ± 55				
	Max ROM (mm)	283 ± 17	–	293 ± 13	–				

*ROM = range of motion expressed in degrees and millimeters.
†Values are mean ± *SD*.

independently for each of the left and right side during the bilateral movement. The accuracy of the measurement for the torque of the trunk rotation was 0.25% and for the stretcher force 2% with a measuring frequency of 200 Hz. Test results were generated by the computer software IsoMed analyze 2008. For the isokinetic maximum strength tests, the average and maximum values were derived from the values of work and power.

The participants performed an isokinetic maximum strength test of the trunk muscles in a sitting position with a hip and knee angle of 90° during an angular velocity of $120° \cdot s^{-1}$. The test instructor fixated the test person with cushions alongside the pelvis, anteriorly and laterally on the tibia and frontally along the shoulders to keep knees, hip, and shoulders in position during testing. The hands were kept on gripped bars to the side at the height of the chin (Figure 1).

For familiarization to the test conditions and to warm-up the analyzed muscles, 2 submaximal contractions were performed as trial-runs before the actual test. Data collection took place during maximum concentric contraction in 2 sets with 3 repetitions and a 3-minute rest between sets. The potential range of movement was 46° in both directions. The 2 test-sets started with left rotation (movement to the left). The medial torque, power, and work ICC (3.1)-values 0.94–0.98 of the left rotation and 0.97–0.98 of the right rotation have been calculated as measuring accuracy for the test protocol. The limits of agreement were located at 20.7 or 20.5 Nm for the average torque, 43.5 or 42.7 W for the power, and 27.9 or 27.2 years for the work to the left and right side of rotation (26).

After testing trunk rotation, the IsoMed was converted to the leg press test. The participant had 5 minutes to recover between the 2 exercises. The participant sat on the leg training machine with his feet on the footrest with a defined distance between the heel and buttock. The angle of the footrest was inclined forward to 15° (second hole as shown in Figure 1). The position of the footrest depended on the individual leg length. The angle of the backrest was on a 78° incline to the horizontal. Again, the participant completed 2 submaximal contractions to become accustomed to the testing conditions. After 3 minutes of rest, the bilateral isokinetic maximum strength test started with 2 sets, each with 3 repetitions at a speed of $180\ mm \cdot s^{-1}$ and a 3-minute break between the sets. A relative reproducibility could be determined for the average of strength, work, and power with ICC(3.1)-values ≥0.9 for the test protocol to determine the bilateral maximal strength being achieved with the leg training machine (25).

The entire testing procedure was supervised by an experienced test instructor. The test instructor verbally motivated the participant. During the test, the instructor provided visual feedback to support maximal strength development (28). The entire test took approximately 20 minutes. Out of each trunk rotation and leg press trial, the set with the highest performance was included in the analysis as the average of the 3 contractions performed.

Statistical Analyses

To process and to analyze the results of the isokinetic maximum strength tests, data were exported into a file format compatible with Excel using the manufacturer's software (IsoMed analyze, 2008). To determine the degree of symmetry between the left and right side of the body, the index of symmetry was calculated by the following formula (36):

$$SI = \frac{(X_R - X_L)}{0.5(X_R + X_L)} \times 100\%$$

For X_R and X_L, the corresponding data of trunk rotation to the left and right side or the left and right side of the extremity (hand or leg) were used to calculate the index of symmetry for the handgrip strength and isokinetic maximum strength of trunk rotation as well as for leg extensions.

The statistical analysis included the description of the arithmetic mean values and *SD*s. For the main outcomes (maximum handgrip force/body mass, average trunk rotation torque/body mass, and average leg press force/body mass), a variance analysis with repeated measures based on the general linear model and the inner subject factor "side" (left and right) as well as between-subject factor

Table 3. Comparison of the symmetry index (SI) between fitness and volleyball groups (*N* = 53).*†

Test	SI (%)	Fitness (*N* = 30)	Volleyball (*N* = 23)	*p* (sig.)
Hand grip	Max force	5.5 ± 13.4	−0.9 ± 6.6	0.0266
Trunk rotation	Mean torque	0.9 ± 14.2	10.6 ± 14.0	0.0083
	Mean power	0.9 ± 14.1	10.7 ± 14.2	0.0087
	Mean work	2.2 ± 16.8	14.0 ± 17.2	0.0105
	Mean ROM	0.2 ± 10.3	2.3 ± 7.7	0.5880
	Max torque	−0.3 ± 13.0	10.0 ± 12.5	0.0069
	Max power	−0.1 ± 12.9	10.0 ± 12.6	0.0063
	Max work	−0.2 ± 13.9	12.0 ± 15.7	0.0081
	Max ROM	−0.3 ± 2.1	−0.3 ± 1.3	0.8612
Leg press	Mean force	−3.6 ± 8.0	−1.3 ± 8.5	0.5780
	Max force	−1.3 ± 7.1	−0.3 ± 9.0	0.8928

*ROM = range of motion.
†Values are mean ± *SD*.

"group" (volleyball and fitness) was calculated. Normal distribution and variance homogeneity was verified by the Kolmogorov-Smirnov and the Levene's test. To test the paired mean differences, the least significant difference was used. The partial Eta-square (η_p^2) functioned as an indicator for the effect size (small effect $\eta_p^2 \geq 0.08$, moderate effect $\eta_p^2 \geq 0.20$, and $\eta_p^2 \geq 0.32$ high effect, (11,12)). The p-value was Bonferoni corrected ($p = 0.05$ divided by 9 tests resulted in an accepted p-value of 0.0056) considering the alpha error accumulation. The symmetry index was not normally distributed, therefore nonparametric tests were used (Mann-Whitney *U* Test). The statistical calculations were conducted using IBM SPSS 20.0 (Chicago, IL, USA).

Results

Table 2 reports the results of the relevant statistical analyses for the force data in relation to body mass. The fitness group showed higher grip forces in relation to body mass than the volleyball group. The handgrip forces were higher for the right hand in comparison to the left hand in the fitness group, whereas the handgrip forces for the volleyball group showed no differences between both hands. The main effect for the group interactions was significant ($p = 0.031$) after correction for multiple testing.

A significant main effect with a small effect size (0.142) was found for the trunk rotation strength in relation to body mass (Table 2). This left-right-difference with higher maximum forces for the rotation in the right direction was present in the volleyball athletes. The main effect for the group interaction failed to be significant after correction for alpha error accumulation ($p = 0.0058$).

Regarding the results of the leg press, the main effect for the differences between the left and the right leg failed to be significant after correcting for alpha error accumulation ($p = 0.0187$). Data indicate a stronger left leg in both groups (Table 2).

Table 3 shows the calculated symmetry index for handgrip strength, trunk rotation strength, and leg press when comparing the volleyball and the fitness group. The fitness group showed higher handgrip forces for the right hand (5.5 ± 13.4%) and reduced right leg power (−3.6 ± 8%) in comparison to the left leg. The volleyball athletes showed higher trunk rotation strength to the right side (10.6 ± 14%).

Discussion

The aim of this cross-sectional study was to compare body symmetry measured as maximum strength of handgrip, axial trunk rotation, and leg extension of 2 groups of athletes of the same age but participating in different sports (fitness vs. volleyball). This is important for prevention and rehabilitation of resulting injuries and to conduct sport-specific athletic training. The main expectation was that both groups do not differ in the maximum strength of handgrip. Moreover, we supposed an asymmetric strength for trunk rotation and leg extension for the volleyball group and no asymmetries for the fitness group.

Handgrip Strength

Results indicated that the fitness group had strength asymmetry of the hands and legs, but not for trunk rotation. The fitness group was characterized by a combination of a stronger right hand and a stronger left leg which is normal for right-handed persons. In contrast, the volleyball group displayed symmetry in handgrip strength.

There were more right-handed participants ($N = 47$) in the sample. This explains the greater maximum handgrip forces of the fitness group. The dominance of the right hand reflects the normal conditions of right-handed people being dominant in the German (European) population (30). Because of the 7.2 kg higher average of the body mass for the volleyball group, the difference between both groups increased with regard to the relative grip forces. One reason for these findings might be the fact that grip forces are not relevant for the spike movement in volleyball. It is more important to gain a good impulse transmission from the hand to the ball while hitting the ball. Moreover, the direction of the speed of the departing ball determines the impact on the ball. These aspects require a relaxed wrist and in this instance a grasping maneuver is not required.

Overall, the first hypothesis that both groups do not differ in handgrip strength has to be rejected. Moreover, it has to be reflected that for this examined group a general fitness training does not lead to symmetric handgrip strength. Because unilateral movements in daily or sporting activities might result in overuse or injuries as well, the individual symmetry profile needs to be integrated into the training routines for individualized prevention despite sport-specific recommendations.

Isokinetic Concentric Trunk Rotation Strength

For the volleyball athletes, the results showed an asymmetry in trunk rotation with higher strength toward right rotation, whereas the fitness group did not show a left/right asymmetry in trunk rotation strength. Thus, our results confirmed previous studies which did not find asymmetry in maximum trunk rotation strength for fitness athletes (14,21,29,34,39).

In contrast, the volleyball group had an expected asymmetry with stronger trunk rotation to the right side. This finding matches the results of Miltner et al. (32), who determined a stronger rotation to the right of volleyball players at national levels. The sports specific asymmetrical loads may explain parts of these findings. To gain the necessary speed for hitting the ball, the mechanisms of trunk, hip, and shoulder rotation are needed as explained by Brown et al. (7). To maintain trunk stability in the air while hitting the ball, the surrounding muscles for rotation to the right side are activated to a higher degree. Therefore, the strength training of the volleyball players involved more practice of jumping and trunk strength, as well as trunk stabilization without significant additional loads which exceed barbell or machine training with submaximal to maximum loads.

However, the observed asymmetries for the right direction had only a small effect size. In addition, it remains unclear whether the resulting asymmetry might be a cause of injury or whether it might be a necessary adaption to the requirements of the repetitive performance of volleyball techniques. Nevertheless, as left-right differences of 10% or above are considered as a risk factor for injuries (6,17,45), the volleyball group might be at a higher risk for back pain. In comparison to the fitness training group, they showed asymmetries of 10% and higher for the trunk rotation.

Overall, as asymmetry is associated with low back pain (35,42) and long-term injuries of the spine are common in 8–15% of volleyball athletes (31), this study underlines the importance of developing training interventions for volleyball athletes to positively influence the illustrated effects of physical stress and overuse. These programs for prevention and rehabilitation may reduce unilateral overuse injuries. Seminati and Minetti (37) recommend better proprioception and control of trunk muscles as well as specific trunk strength training as common strategies among these types of interventions. Furthermore, they suggest optimization of stroke technique, eccentric training, and core stability practice to prevent injuries of the shoulder. An improvement of the reactive strength could be attained by plyometric training for volleyball players (22). In addition, various studies have shown positive effects of proprioceptive training on knee and ankle stability (1,43). However, it remains unclear, how to gain a symmetric trunk stability that allows the trunk rotation for the spikes speed as described above. This needs to be examined in future training studies.

Bilateral Leg Extension Strength

Both groups achieved higher forces for the left leg during the bilateral isokinetic contraction test. Thereby, the fitness group showed a greater difference than the volleyball group. However, a significant difference of the symmetry indices was not determined. The volleyball athletes had a higher absolute maximum strength in both legs which can be explained by the higher body mass compared with the fitness group or this might be explained by the nature of the sport (i.e., jumping). Relativized by body mass, no differences were found between both groups, neither for the mean strength nor for the maximum strength. Small leg differences were expected for both participating groups. Because volleyball players take-off with 1 leg carrying the whole body weight (44), it was presumed that the volleyball players being right handed would display a stronger left leg.

In summary, we did not confirm our hypothesis that there are differences for the bilateral maximum leg strength between both groups. The training routines of the volleyball athletes do not built up a stronger leg as expected. This might be a result of the additional strength training in semi-professional volleyball athletes. A second explanation could be the block technique which needs a symmetric bilateral strength.

In further studies, it should be examined whether or not there are differences in bilateral strength depending on either the athlete's position (e.g., middle blocker vs. outside hitter) or previous injuries of the athlete. In that way, athletic training routines could be optimized.

Limitations

This study examined a heterogeneous sample of young, sportive, and active male persons without acute back pain. Therefore, the results of the trunk asymmetries cannot be correlated with injuries or low back pain. Another limitation was the trunk test in a sitting position and only in 1 angular velocity ($120\ ^\circ \cdot s^{-1}$). This position does not mimic the positions used in real volleyball competitions.

However, trunk rotation strength depends on trunk position and angular velocity (24). The angular velocity was chosen to generate intense resistance during the test. The test condition was not explicitly considered as a typical rotation speed that appears in volleyball.

Because of a fixed order of left and right rotation, a sequence effect in favor of rotation to the right side cannot be excluded. The first left rotation took place without countermovement out of the starting position being prerotated to the right side. However, the following contractions were performed to the left and right side after reversal of the countermovement. The countermovement may have led to a preload of the muscles that may have affected the maximum strength development. Another limitation was the leg press test in only 1 movement speed ($180\ mm \cdot s^{-1}$) in a seating position bilaterally in the closed chain. Because of their complexity, exercises in the closed kinetic chain are described as more specific and functional (9).

Practical Applications

This study has additional information to previous findings of sports specific or movement-specific strength patterns which is important for professionals and coaches. These patterns might be asymmetric but they are necessary or might be functional to gain success for sport-specific action goals. Based on the results of our study, we offer the following recommendations to strength and conditioning professionals and coaches:

- Asymmetries should be captured and individually described because they might be reasons for overuse problems or injuries.
- The level of asymmetry which is adequate and tolerable for sportive performance (e.g., Volleyball) should be identified and, respectively, being combined with improved injury prevention (40). Therefore, an analysis of asymmetries for volleyball players should control if the sport-specific asymmetries are less than 10%.
- If the individual asymmetries are higher than 10%, an individualized training program with functional strength exercises should be added to the strength and conditioning training plans of volleyball athletes. This

program should account for the functional movement patterns of the asymmetries. However, it needs to be controlled for imbalanced strength output.

The specific identification of asymmetries and resulting recommendations of this study were designed for volleyball athletes; however, we suggest that the practical applications may also be very effective in an adapted form in other team sports, e.g., basketball, handball, American football, ice hockey, rugby, soccer, and others.

References

1. Adamczyk, G. Natural course of the ankle Injury: Based on volleyball experience. *Sports Injuries: Prev Diagn Treat Rehabil* 1829–1841, 2015.
2. Bae, JH, Kim, DK, Seo, KM, Kang, SH, and Hwang, J. Asymmetry of the isokinetic trunk rotation strength of Korean male professional golf players. *Ann Rehabilitation Medicine* 36: 821–827, 2012.
3. Bailey, CA, Sato, K, Burnett, A, and Stone, MH. Carry-over of force production symmetry in athletes of differing strength levels. *J Strength Cond Res* 29: 3188–3196, 2015.
4. Bell, DR, Sanfilippo, JL, Binkley, N, and Heiderscheit, BC. Lean mass asymmetry influences force and power asymmetry during jumping in collegiate athletes. *J Strength Cond Res* 28: 884, 2014.
5. Bisseling, RW, Hof, AL, Bredeweg, SW, Zwerver, J, and Mulder, T. Are the take-off and landing phase dynamics of the volleyball spike jump related to patellar tendinopathy? *Br J Sports Med* 42: 483–489, 2008.
6. Bond, CW, Cook, SB, Swartz, EE, and LaRoche, DP. Asymmetry of lower-extremity force and muscle activation during knee extension and functional tasks. *Muscle Nerve* 56: 495–504, 2017.
7. Brown, JR, Alsarraf, BJ, Waller, M, Eisenman, P, and Hicks-Little, CA. Rotational angles and velocities during down the line and diagonal across court volleyball spikes. *Int J Kinesiol Sports Sci* 2: 1, 2014.
8. Byl, NN and Sadowsky, HS. Intersite reliability of repeated isokinetic measurements: Cybex back systems including trunk rotation, trunk extension-flexion, and liftask. *Isokinetics Exerc Sci* 3: 139–147, 1993.
9. Bynum, EB, Barrack, RL, and Alexander, AH. Open versus closed chain kinetic exercises after anterior cruciate ligament reconstruction: A prospective randomized study. *Am J Sports Med* 23: 401–406, 1995.
10. Clerke, A and Clerke, J. A literature review of the effect of handedness on isometric grip strength differences of the left and right hands. *Am J Occup Ther* 55: 206–211, 2001.
11. Cohen, J. *Statistical Power Analysis for Behavior Sciences.* Hillsdale, NJ: Lawrence Earlbaum Associates, 1988. pp. 20–26.
12. Cohen, J. Statistic a power primer. *Psychol Bull* 112: 155–159, 1992.
13. DeMichele, PL, Pollock, ML, Graves, JE, Foster, DN, Carpenter, D, Garzarella, L, and Fulton, M. Isometric torso rotation strength: Effect of training frequency on its development. *Arch Phys Med Rehabil* 78: 64–69, 1997.
14. Ellenbecker, TS and Roetert, EP. An isokinetic profile of trunk rotation strength in elite tennis players. *Med Sci Sports Exerc* 36: 1959–1963, 2004.
15. Hadzic, V, Sattler, T, Veselko, M, Markovic, G, and Dervisevic, E. Strength asymmetry of the shoulders in elite volleyball players. *J Athletic Train* 49: 338–344, 2014.
16. James, LP, Kelly, VG, and Beckman, EM. Injury risk management plan for volleyball athletes. *Sports Medicine* 44: 1185–1195, 2014.
17. Knapik, JJ, Cosio-Lima, LM, Reynolds, KL, and Shumway, RS. Efficacy of functional movement screening for predicting injuries in coast guard cadets. *J Strength Cond Res* 29: 1157–1162, 2015.
18. Kuhlman, JR, Iannotti, JP, Kelly, MJ, Riegler, FX, Gevaert, ML, and Ergin, TM. Isokinetic and isometric measurement of strength of external rotation and abduction of the shoulder. *J Bone Joint Surg Am* 74: 1320–1333, 1992.
19. Kumar, S, Dufresne, RM, and Van Schoort, T. Human trunk strength profile in lateral flexion and axial rotation. *Spine* 20: 169–177, 1995.
20. Kumar, S. Axial rotation strength in seated neutral and prerotated postures of young adults. *Spine* 22: 2213–2221, 1997.
21. Lee, JH, Hoshino, Y, Nakamura, K, Kariya, Y, Saita, K, and Ito, K. Trunk muscle weakness as a risk factor for low back pain: A 5-year prospective study. *Spine* 24: 54–57, 1999.
22. Lesinski, M, Prieske, O, and Granacher, U. Effects and dose–response relationships of resistance training on physical performance in youth athletes: A systematic review and meta-analysis. *Br J Sports Med* 50: 781–795, 2016.
23. Lindsay, DM and Horton, JF. Trunk rotation strength and endurance in healthy normals and elite male golfers with and without low back pain. North American journal of sports physical therapy. *NAJSPT* 1: 80–89, 2006.
24. Marras, WS and Granata, KP. A biomechanical assessment and model of axial twisting in the thoracolumbar spine. *Spine* 20: 1440–1451, 1995.
25. Mattes, K, Manzer, S, Kianmarz, Y, and Schaffert, N. Reproducibility of isokinetic maximum strength in the closed chain of the lower extremities, hand and leg bilateral asymmetry. *J Sport Hum Perform* 4: 2017.
26. Mattes, K, Manzer, S, Kianmarz, Y, and Paasch, J. Reproducibility and bilateral symmetry of maximal isocinetic trunk rotation strength of healthy and physically active male test subjects [in German]. *Sports Injuries Sports Damage.* 30: 211–217, 2016.
27. Mayer, TG, Smith, SS, Kondraske, G, Gatchel, RJ, Carmichael, TW, and Mooney, V. Quantification of lumbar function: Part 3: Preliminary data on isokinetic torso rotation testing with myoelectric spectral analysis in normal and low-back pain subjects. *Spine* 10: 912–920, 1985.
28. McGill, SM. Electromyographic activity of the abdominal and low back musculature during the generation of isometric and dynamic axial trunk torque: Implications for lumbar mechanics. *J Orthopaedic Res* 9: 91–103, 1991.
29. McIntire, K, Asher, M, Burton, D, Hongzeng, L, and Liu, W. Development of a protocol for isometric trunk rotational strength testing and strength asymmetry assessment. *Isokinet Exerc Sci* 15: 183–194, 2007.
30. McManus, IC. The history and geography of human handedness. In: *Language Lateralization and Psychosis.* IEC Sommer and RS Kahn, eds. Cambridge, United Kingdom: Cambridge University Press, 2009. pp. 37–57.
31. Miltner, O, Tschaepe, R, Weihe, W, Heinzinger, A, and Kieffer, O. Trunk strength profile in professional volleyball players [in German]. *Sport-orthopädie-sport-traumatologie-sports Orthopaedics Traumatol* 24: 243–248, 2008.
32. Miltner, O, Siebert, C, Tschaepe, R, Maus, U, and Kieffer, O. Volleyball specific trunk muscle strength in professional and non-professional volleyball players. *Z für Orthopädie Unfallchirurgie* 148: 204–209, 2010.
33. Oberbeck, H. Sideness-profiles: Methods of determination and consequences for teaching and education training [in German]. *Angew Sportwissenschaft, DVS-Protokolle* 333–339, 1986.
34. Pope, MH, Andersson, GBJ, Broman, H, Svensson, M, and Zetterberg, C. Electromyographic studies of the lumbar trunk musculature during the development of axial torques. *J Orthopaedic Res* 4: 288–297, 1986.
35. Renkawitz, T, Boluki, D, and Grifka, J. The association of low back pain, neuromuscular imbalance, and trunk extension strength in athletes. *Spine J* 6: 673–683, 2006.

36. Robinson, RO, Herzog, W, and Nigg, BM. Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. *J Manipulative Physiol Ther* 10: 172–176, 1987.

37. Seminati, E and Minetti, AE. Overuse in volleyball training/practice: A review on shoulder and spine-related injuries. *Eur J Sport Sci* 13: 732–743, 2013.

38. Sheikhhoseini, R, O'Sullivan, K, Alizadeh, MH, and Sadeghisani, M. Altered motor control in athletes with low back pain: A literature review. *Ann Appl Sport Sci* 4: 43–50, 2016.

39. Smith, SS, Mayer, TG, Gatchel, RJ, and Becker, TJ. Quantification of lumbar function: Part 1: Isometric and multispeed isokinetic trunk strength measures in sagittal and axial planes in normal subjects. *Spine* 10: 757–764, 1985.

40. Teixeira, J, Carvalho, P, Moreira, C, and Santos, R. Isokinetic assessment of muscle imbalances and bilateral differences between knee extensores and flexores' strength in basketball, footbal, handball and volleyball athletes. *Int J Sports Sci* 4: 1–6, 2014.

41. Tilp, M, Wagner, H, Sust, M, Thaller, S, and Blickhan, R. Modelling vertical jumps on the basis of individually measured qualities of muscles in order to prognosticate training effects. In: *Welfare & Michel (Hrsg), writings of the German Association for Sports Science Contributions to the Special Training Science Athletics.* (Vol. 153). Hamburg, Germany: Czwalina, 2006. pp. 86–94.

42. Van Dillen, LR, Sahrmann, SA, Caldwell, CA, McDonnell, MK, Bloom, NJ, and Norton, BJ. Trunk rotation-related impairments in people with low back pain who participated in 2 different types of leisure activities: A secondary analysis. *J Orthop Sports Phys Ther* 36: 58–71, 2006.

43. Vriend, I, Gouttebarge, V, van Mechelen, W, and Verhagen, EALM. Neuromuscular training is effective to prevent ankle sprains in a sporting population: A meta-analysis translating evidence into optimal prevention strategies. *Joint Disord Orthop Sports Med* 1: 202–213, 2016.

44. Wagner, H, Pfusterschmied, J, Tilp, M, Landlinger, J, Von Duvillard, SP, and Müller, E. Upper-body kinematics in team-handball throw, tennis serve, and volleyball spike. *Scand J Med Sci Sports* 24: 345–354, 2014.

45. Xergia, SA, Pappas, E, and Georgoulis, AD. Association of the single-limb hop test with isokinetic, kinematic, and kinetic asymmetries in patients after anterior cruciate ligament reconstruction. *Sports Health* 7: 217–223, 2015.