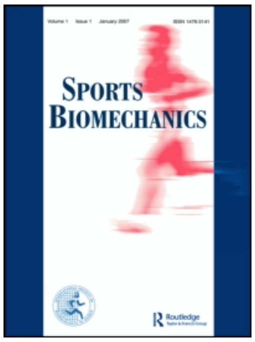

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Upper limb muscle strength and knee frontal plane projection angle asymmetries in female water-polo players

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ABSTRACT
Water-polo players frequently perform overhead throws that could result in shoulder imbalances. For overhead throws, execution of the 'eggbeater kick' (cyclical movement of the legs) is required to lift the body out of the water. Although a symmetrical action, inter-limb differences in task execution could lead to knee frontal plane projection (FPPA) differences. The present study examined imbalances shoulder and knee FPPA in female players. Eighteen competitive female field players (24.1 ± 5.5 years, 1.68 ± 0.06 m, 72.9 ± 13.3 kg) had their shoulder strength assessed in a shot-mimicking position with a portable dynamometer, standing and seated (isolating the shoulder contribution). Anterior: posterior and shooting: non-shooting shoulder comparison were made. Additionally, players performed a drop jump. Knee FPPA was recorded from digitising and comparing the frames just before landing and at stance phase. During standing, players exhibited higher shooting: non-shooting asymmetry ($p = 0.032$) in the anterior contraction direction, while during seated the shooting shoulder anterior: posterior asymmetry was higher ($p = 0.032$). Interlimb knee FPPA asymmetry was higher in the stance phase ($p = 0.02$). Despite the overhead throwing and eggbeater demands impacting differently on each limb, considerable asymmetries do not develop, suggesting the overall training requirements (e.g. swimming, resistance training) were sufficient to maintain the asymmetry within desirable limits.

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Bilateral imbalances; eggbeater; overhead shooting; conditioning exercises; injury risk

Introduction

The overhead shot in water-polo is the predominant shooting technique (Yaghoubi et al., 2015). This technique involves; a) preparation, where the ball is lifted out of the water, b) backswing, initiated by hip and shoulder rotation leading to rotation of the shooting arm with the elbow flexed 22°-27° and the ball above and behind the player's head, c) forwards swing, where the ball is moved forward with a proximal-to-distal chain to increase speed, and d) release, where the ball is released at highest possible speed and accuracy towards the goal (Elliott & Armour, 1988; Yaghoubi et al., 2015). During this technique, the contralateral arm is sculling underwater (Armour & Elliott, 1989) to provide stability and vertical thrust. Consequently, these different movement aims can result in intra- and

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inter-shoulder asymmetries. The lack of stability induced by the aquatic environment and the performance demands of the shot result in increased internal and decreased external rotation strength of the shooting shoulder (Hams et al., 2019), potentially inducing intra-shoulder strength imbalance, causing the same injury risk issues common to other overhead sports (e.g., 5). Indeed, isokinetic torque rotator cuff imbalances have been reported in male (McMaster et al., 1991) and female (Aginsky, 2016) water-polo players, with the prevalent intra-shoulder strength imbalances related to increased injury risk (Hams et al., 2019; Miller et al., 2018). In addition, inter-shoulder imbalances can affect swimming performance (2006), in turn affecting playing performance as swimming is a considerable part of the sport (31.5% of the game time or training, averaged across all positions, is considered as swimming (Tan et al., 2009)). With the shoulder being the main injury site for all water polo players and females ~2.4 times more likely to sustain a shoulder injury (Sallis et al., 2001), these asymmetries warrant further investigation.

Players also frequently and repeatedly perform actions such as passing, blocking and scrimmaging which require execution of the 'eggbeater kick' (Oliveira et al., 2015; Sanders, 1999). The eggbeater is a rotational movement of the legs, which perform similar but alternative actions, allowing the player to stay afloat vertically or rise above the water to gain more freedom of movement to perform tasks where a more unrestricted range of motion is beneficial (Oliveira et al., 2015). It is separated in four phases based on knee extension (initial and final period of knee flexion and knee extension, respectively), each corresponding to 25% of the eggbeater cycle (Oliveira & Sanders, 2015). It is a skill performed (on average across all positions) at least 50% of the game time (Papadopoulos et al., 2015). Although studies have examined its kinetics and kinematics (Oliveira et al., 2015; Oliveira & Sanders, 2015; Sanders, 1999), almost no attention has been given to lower limb differences, perhaps based on the notion that eggbeater is a symmetrical cyclical movement. Nonetheless, inter-limb differences in eggbeater can exist (Oliveira & Sanders, 2015), as each leg is producing different force during eggbeating, suggesting each side controls different performance parameters (Oliveira & Sanders, 2015). It is likely to reflect players' shooting technique, with one limb working to create upwards thrust while the other to stabilise the body for an effective shot (Oliveira et al., 2016). Whichever the mechanistic reason, there may be a serious implication for female water polo players, in particular, if such asymmetries exist. Knee injuries and pain are more prevalent in female sport players (Ford et al., 2003; Herrington, 2010; Noyes et al., 2005) and poor conditioning and knee frontal plane projection angle (FPPA) can lead to an increased Q-angle, which is a risk factor for patellofemoral pain (Papadopoulos et al., 2015). As eggbeater places stress on the knee joint and water-polo players also train and play other sport on land (Sáez De Villarreal et al., 2015), it is importance to examine whether such lower limb imbalances exist.

Previous studies have mainly focused on physiological and time motion aspects (e.g., 10) or the kinematic and kinetics of the overarm shot and eggbeater (Armour & Elliott, 1989; Oliveira & Sanders, 2015; Yaghoubi et al., 2015) and have not considered any muscular asymmetries. Given the possibility of asymmetries increasing the injury risk of water-polo players (Aginsky, 2016; Drigny et al., 2020; Kennedy et al., 2009), it is important to further understand muscular asymmetries to inform relevant training guidelines (Kennedy et al., 2009). Therefore, the aim of the project was to examine the intra-shoulder (anterior: posterior) and inter-shoulder (shooting: non-shooting) muscle asymmetries of the upper limbs as well as the inter-limb knee FPPA asymmetries in elite female water-polo players. We hypothesised that a) the shooting shoulder would present higher anterior: posterior asymmetry than the non-shooting one, b) the anterior direction would present similar shooting: non-shoooting shoulder asymmetry to the posterior, and c) knee FPPA would present significant differences between lower limbs.

Methods

Subjects

Eighteen female, Division 1 water-polo field players (age 24.1 ± 5.5 years, height 1.68 ± 0.06 m, body mass 72.9 ± 13.3 kg), part of the team for a minimum of 3 years, with at least 5 years of playing water-polo competitively and at least two years of that in Division 1, agreed to participate in the study. Testing took place during a training weekend, mid-season of the British Water-Polo League. All players had no upper or lower limb injuries, fractures or other pathologies for one year prior. The study was approved by the Institutional Research Ethics Committee (ref: DC/SB 14/36) and the players provided written, informed consent to participate.

Procedures

All testing took place on a single occasion for all players in the same strength and conditioning gymnasium used for their normal training. Players' height was measured to the nearest 0.1 cm using a stadiometer (Harpenden, Holtain, Crymych, UK) and body mass was measured to the nearest 0.1 kg using a calibrated balance beam scale (Seca, Hamburg, Germany). All players familiarised themselves with the experimental procedures, performing between 3 and 5 trials for each exercise. During testing, a 2-minute resting interval was allowed between efforts and 5 minutes between tests.

Muscle strength asymmetry

Muscle strength asymmetry was evaluated through isometric contractions mimicking a water-polo shot position. A non-elastic sling with a handle at its end for the player to pull on was attached to a force gauge recording at 500 Hz (Myometer, MecMesin, West Sussex, UK), which was securely fixed on a rigid structure on the wall but allowing alteration of its vertical position to accommodate the different players' statures. Each player stood sideways to the wall and with their back to the strain gauge, and assumed a comfortable shooting position resembling the start of the shot (body upright, arm abducted along the frontal plane and in line with the body, upper arm at ~0° to the horizontal and forearm ~90° to the horizontal (Armour)) with the sling handle in their hand. Any slack was taken up at the beginning of the movement by repositioning the player further away from the gauge and the gauge was reset. The players were instructed to visualise they were about to shoot and asked to contract fast and maximally pulling the sling forwards (anterior), ensuring no countermovement to the opposite direction took place prior to the contraction. Verbal encouragement was provided throughout the trial. Trunk rotation (visually inspected) was not allowed to minimise shoulder injury risk through excessive external rotation (Miller). Great care was given during the contraction that the sling was pulled in a straight line and did not deviate in any direction; if it did deviate, the position of the gauge and player were adjusted and the trial repeated. The process was repeated with the player facing the gauge and pulling the sling backwards (posterior). Further, to enable 'isolation' of the upper body, the above process was also repeated with the players sat in a standard chair. The feet were kept flat on the ground, with the hip at 90° joint angle. The upper body and arm position were exactly the same as with standing, as were the positioning procedures followed and execution instructions. The chair was secured in place to prevent the chair leaning backwards or the legs moving.

Strength was recorded in kg from the strain gauge display. Players completed eight maximum voluntarily isometric contractions in total, one per shoulder (shooting and non-shooting), contraction direction (anterior and posterior), and position (standing and seated). A single trial was completed to conform to time restrictions imposed by the players' training schedule. The reliability of the strength assessment protocol was evaluated during a separate analysis with six different players with similar characteristics to the participating ones. They completed two trials of all four contractions 30 minutes apart. Pairwise t-tests showed no statistically significant differences for any contraction ($p < 0.05$) with acceptable intraclass correlation coefficients ($ICC_{2,1}$; range 0.89–0.93).

Muscle strength asymmetries were calculated for shooting: non-shooting shoulder and anterior: posterior contraction directions and compared between shoulders (i.e., the respective anterior: posterior asymmetries of the shooting and non-shooting shoulder) and between the anterior and posterior contraction directions (i.e., the respective shooting: non-shooting asymmetries of the anterior and posterior contraction directions), for both standing and seated positions. Asymmetries were calculated as (((anterior or shooting—posterior or non-shooting)/(sum of the two scores)*100) (Bishop et al., 2018).

Knee frontal plane projection angle (FPPA)

To assess knee FPPA, the drop jump test was utilised, which has previously been shown to reflect knee injury risk and an indicator of improved neuromuscular control (Noyes et al., 2005). Three markers were placed on the players' anterior superior iliac spine, middle of the knee patella and the middle of the ankle mortise (Herrington, 2010). The players stood on a 0.45 m-high rigid, stable bench at a comfortable position. They were then instructed to drop directly down from the bench, avoiding any upwards movement at the start of the movement, land on both feet and immediately jump. Arms were kept on their hips at all times and the players were aiming for minimum ground contact time.

Two-dimensional knee FPPA was obtained via a digital video camera recording at 100 Hz. Camera placement followed recommendations by Payton and Hudson (Payton & Hudson, 2017). Briefly, the camera was placed 3 m away from the anterior side of the box and aligned perpendicularly to the frontal plane, capturing the lower limbs throughout the movement (Figure 1).

Prelanding (just before ground contact) and stance phase (velocity was zero) frames were digitised using open-source video analysis software (Kinovea, Version 0.8.15). The angle formed by the line connecting the markers in proximal to distal order at prelanding and stance phase were recorded for each limb. This experimental set-up and measurement have been previously used in similar studies (Herrington, 2010). The difference between

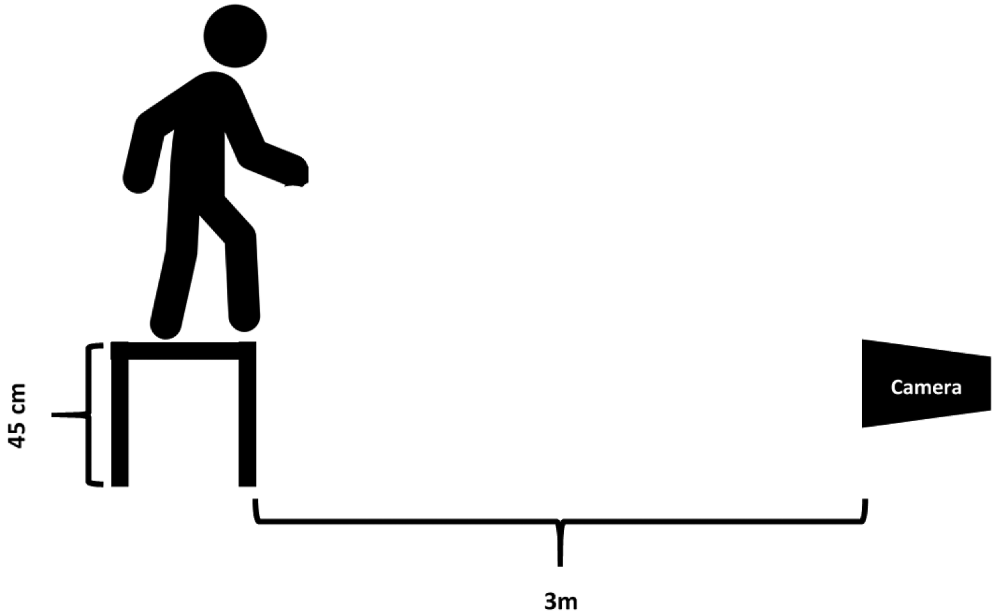

Figure 1. Schematic diagram of the experimental set-up for the drop jump. The players stood on the 45 cm bench and dropped directly down from it, while the camera positioned 3 m away was recording their lower limbs throughout the movement.

prelanding and stance-phase angles was calculated for each limb and used to compare between them. Three players exhibited knee varus (prelanding angle < stance-phase angle), and the rest knee valgus (prelanding angle > stance-phase angle) for both limbs. Asymmetry was calculated as the absolute value of (((higher score—lower score)/(sum of the two scores)*100) and compared between limbs for the prelanding and stance phases.

Statistical analysis

Normality of data for all variables (measured and calculated) was examined using the Shapiro–Wilks test. Normality was confirmed for the measured knee angle variables but not for the strength or the calculated measurements.

To assess intra-rater reliability of angle measurements, all videos were analysed twice, one week apart. Differences between analyses were examined with a paired-samples t-test, while agreement was assessed with a two-way mixed, absolute agreement, single measures intraclass correlation coefficient (ICC) model.

For non-parametric data, paired sample comparisons using the Wilcoxon test were conducted for the strength scores between standing and seated and for the strength asymmetry between shoulders, and contraction directions (for seated and standing separately). For parametric data, comparisons with paired t-test were made for the knee FPPA between left and right limbs at the prelanding and stance phase, while Wilcoxon test was used to compare the asymmetries between the two phases. The Holm-Bonferroni correction for multiple comparisons was applied in all comparisons and the corrected p values are reported. Non-parametric and parametric effect sizes (ES), as appropriate, were calculated and the magnitude of the effect interpreted as large, medium and small for values of 0.5, 0.3 and 0.1, respectively, for non-parametric ES and 0.8, 0.5 and 0.2, respectively, for parametric ES (Fritz et al., 2012).

All statistical analysis was conducted using IBM SPSS Statistics v25 (SPSS Inc., Chicago, IL, USA). Significance was set at $p < 0.05$. Data is presented as mean ± SD, unless otherwise stated.

Results

Intra-rater reliability analysis revealed a significant difference between the two analyses for the right leg prior to landing ($p = 0.005$) and a lower ICC value (0.634). No differences were found for the other three comparisons (right leg after landing, left leg prior to and after landing) with higher ICC values (0.944, 0.911 and 0.980, respectively). Therefore, the average of the two measurements was calculated for all four variables and used for further analysis.

When the strength scores were compared between standing and seated, anterior contraction direction of the shooting shoulder when standing was significantly lower than when seated ($p = 0.029$, ES = 0.40). No other differences were revealed. Further, paired-samples analysis of the strength asymmetries between standing and seated showed no differences except for the non-shooting anterior: posterior asymmetry ($p = 0.44$, ES = 0.47), with standing having a higher strength asymmetry than seated.

When standing, anterior: posterior asymmetry was not different between shoulders, but the anterior contraction direction shooting: non-shooting asymmetry was statistically significantly higher ($p = 0.032$, ES = 0.57) than the respective posterior one. When seated, however, the opposite was true; the shooting: non-shooting asymmetry for anterior and posterior contraction directions was not different, while the shooting shoulder anterior: posterior asymmetry was statistically significantly higher ($p = 0.032$, ES = 0.55) than the respective non-shooting one.

There was no statistically significant difference in knee FPPA between limbs for either the prelanding or stance phases. There was, however, a statistically significant difference for interlimb knee FPPA asymmetry between prelanding and stance phase ($p = 0.02$, ES = 0.51). There was also no difference between lower limbs for the knee FPPA difference. Descriptive statistics for all the results can be seen in Table 1.

Discussion and implication

The aim of the present study was to examine shoulder unilateral and bilateral muscle strength asymmetries of the upper limbs as well as the bilateral knee FPPA asymmetries in elite female water-polo players. Our results showed that there are both unilateral and bilateral asymmetry differences in the shoulder, raising a methodological issue, while there are also asymmetry differences in the knee FPPA, confirming our hypothesis.

With muscular asymmetry being possibly the strongest intrinsic injury factor in overhead throwing athletes (Wang, 2001) and strongly related to rotator cuff injuries and destabilisation of the humeral head (Berckmans et al., 2017), muscle strength asymmetry of the shoulder is frequently evaluated in overhead throw (e.g., handball (De Castro et al., 2019)) or repetitive movement (e.g., swimming (Drigny et al., 2020))

Table 1. Descriptive statistics for all measured and calculated variables.

Shoulder Strength	Shooting, anterior direction	Shooting, posterior direction	Non-shooting, anterior direction	Non-shooting, posterior direction
Standing (kg)	71.1(19.3)*	61.4 (20.6)	59.6 (16.5)	60.8 (17.3)
Seated (kg)	82.8 (31.1)	61.0 (11.7)	70.6 (17.5)	65.3 (13.5
Asymmetries	Shooting anterior: posterior	Non-shooting anterior: posterior	Anterior Shooting:Non-Shooting	Posterior Shooting:Non-Shooting
Standing	7.8 (6.4)	7.2 (9.2)*	8.9 (9.7)	3.2 (6.6)†
Seated	9.2 (12.7)	6.3 (5.2) †	9.8 (8.8)	4.7 (9.8)
Knees				
FPPA (°)	Right, prelanding 165.6 ± 2.8	Left, prelanding 166.1 ± 5.9	Right, stance 156.2 ± 10.0	Left, stance 160.9 ± 12.3
Asymmetry	Prelanding, higher:lower 0.8 (0.8)	Stance, higher:lower 4.2 (5.0) †	Difference, higher:lower 50 (27.2)	

Data is presented as mean ± SD or median (interquartile range). FPPA, frontal plane projection angle. * denotes statistically significant difference between seated and standing positions for the shoulder strength measurements. † denotes statistically significant difference between respective asymmetries.

sports. Isokinetic assessment is commonly used (Aginsky, 2016; Hams et al., 2019; McMaster et al., 1991) for that purpose, and a recommendation of external to internal rotation ratio between 0.66 and 0.75 (Ellenbecker & Davies, 2000) has been suggested for a 'healthy' shoulder, while water-polo-specific suggestions report a much wider range of 1.0.50 (Miller et al., 2018). Nonetheless, the measurement mode (e.g., concentric: concentric or concentric: eccentric) and the isokinetic speed (e.g., 60°/s or 300°/s) and their combination, will impact on the result and the test's sensitivity to detect imbalances (De Castro et al., 2019). Therefore, comparisons to such thresholds should be made with caution. With that caveat in mind, previous reports of overhead throwing athletes point towards a difference of 15% as the threshold above which muscle asymmetry becomes an injury risk factor (Wang, 2001). Our findings indicate that neither position (standing or seated) yielded 'high' intra-limb asymmetries, as all median values were below 10%, suggesting low injury risk (Miller et al., 2018).

The additional issue with any isokinetic assessment is the need for an isokinetic dynamometer, which can be a multi-faceted limitation; access, time, expertise, cost (Hams et al., 2019). In the present study, we opted for isometric testing as a measure widely used to assess muscle strength (Hams et al., 2019) and to allow field measurements through the portable strain gauge. The nature of the sport being played in the water, makes 'field' measurement logistically challenging and, ultimately, ending in loss of specificity due to the testing requirements (e.g., fixation requirements of the players). Aginsky et al. (Aginsky, 2016) examined the concentric: concentric and eccentric: eccentric ratios for dominant and non-dominant arms, and reported concentric: concentric ratio values for both sides lower than the 0.66–0.75 ratio reported earlier, while the eccentric: eccentric ratio was within that range for both sides (Aginsky, 2016). The difference in results could be attributed to the difference in testing mode (isokinetic v isometric) and speed (60°/s v static). If that is the case, it reinforces exercising caution in comparing studies, as it seems the three different modes (concentric, eccentric and isometric) provide different asymmetry values. Further, it prompts future research questions in identifying whether a single mode (or a combination; (De Castro et al., 2019)) is best in predicting injury or a battery of tests is required.

Similarly, the different pattern of results between the standing and seated positions could pose questions with regards to isometric assessment positioning. The seated position, which 'excluded' the use of the lower limbs, resulted in inter-limb asymmetries, while the standing one in intra-limb asymmetries, when the experimental protocol was requiring the same players to perform the same movement (activating the same shoulder relating muscles; (Yaghoubi et al., 2015)). The change may be attributed to a number of factors. As less core activation takes place during seating in comparison to standing (Saeterbakken & Fimland, 2012), one position could have offered better stabilisation for force generation than the other (Bampouras et al., 2017). Performance during the seated position was less familiar and consequently could have augmented the inter-limb difference (Palmer et al., 2018), even if it is unlikely that the sequential muscle activity would have been affected (Hirashima et al., 2002). Whichever the reason, our results support the development of sport-specific assessments that can account for the complex nature of the sport (Bampouras & Marrin, 2009).

The drop jump test has been widely used to assess, in particular, female athletes' neuromuscular control (Herrington, 2010; Noyes et al., 2005). Typical knee valgus values for females is 17° (Ford et al., 2003). Our results (when converted; 180°—measured knee

FPPA) were somewhat lower than this typical value, suggesting that the players in the present study have a smaller knee FPPA than the norm. Our results compare favourably with the (average between limbs) values reported by Herrington (Herrington, 2010) but are worse than the ones reported by Howe et al. (Howe et al., 2020). It is unclear whether the discrepancy could be attributed to the population studied, as the cited studies used recreational athletes and not well-trained athletes as in the present study. Although the limbs had similar performance in knee FPPA, the inter-limb asymmetry at prelanding and stance phases was different, suggesting the two limbs 'worked' differently to deal with the required task. This moderate change may reflect the somewhat different work the lower limbs do in the water (vertical thrust vs stabilisation), supporting suggestions made by Oliveira and Sanders (Oliveira & Sanders, 2015) regarding differences in lower limbs during eggbeater. This change was not large enough to result in a difference when the inter-limb knee FPPA was compared at stance phase. Interestingly, fatigue has shown to affect eggbeater (Oliveira et al., 2016), increasing the risk of injury. Future research should examine whether this translates into a higher injury risk during subsequent land training, as it would help coaches to plan better training session sequencing and therapists to focus on these asymmetries.

The use of a more sport-specific position, meant that the movement performed was less restricted than on an isokinetic dynamometer. Zemková et al. (Zemková et al., 2019) showed that trunk rotation power was different between rotation directions. Although in the present study, trunk rotation was not permitted, the trunk would still have been activated (Saeterbakken & Fimland, 2012). If this activation was different between positions, offering e.g., better stabilisation for force generation (Bampouras et al., 2017), the muscle strength and asymmetry scores are not reflecting purely the shoulder rotation from the shoulder and surrounding activated muscles (Yaghoubi et al., 2015), but rather the overall 'movement strength' and 'movement asymmetry' score.

The present study investigated asymmetries in female water polo players. It is, however, unclear whether the injury risk is gender-specific (Miller et al., 2018). Asymmetry differences were previously found between genders in Judokas (Malá et al., 2017). Given the somewhat different results between male (McMaster et al., 1991) and female (Aginsky, 2016) water-polo players' asymmetries and the issues identified with testing, future studies should explore gender differences and relevant injury risk. Further, it has been shown that asymmetries can change throughout the season, as a result of accumulated fatigue (Hams et al., 2019; Wang, 2001). The results of the present study represent the asymmetries seen mid-season and they may not be representative of the asymmetries across the season. Finally, although the sample size of 18 players is similar to previous relevant studies [Hams et al. (2019) (six female and nine male state-level players), Aginsky (2016) (15 female club-level players)], it is unclear whether it sufficiently represents the training loads of all competitive water polo players. Along with a dose-response existing for shoulder injuries (Wheeler et al., 2013), these results should be interpreted with caution.

Conclusion

The current study explored shoulder intra- and inter-limb muscle asymmetries and the inter-limb knee FPPA asymmetries in competitive female water-polo players. Our results show that, despite the sport-specific demands placed on the shoulder (overload of shooting shoulder v non-shooting shoulder, anterior v posterior), neither bilateral or anterior: posterior asymmetry should give cause for concern to the coaches, in terms of asymmetry being an injury risk. Similarly, the asymmetry in knee FPPA, although suggesting each limb negotiates the landing differently, revealed a low injury risk. Taken together, these findings support the notion that despite the overhead throwing and egg-beater demands impacting differently on each limb, they do not result in considerable asymmetries. We posit that the overall training requirements (e.g., swimming, resistance training) were sufficient to maintain the asymmetry within desirable limits. Thus, coaches and relevant professional may wish to focus on other areas such as muscle activity, strength, endurance, muscle control, range of motion, glenohumeral laxity, glenohumeral instability, shoulder posture and scapular dyskinesis (Struyf et al., 2017) as priorities for avoiding shoulder injuries. Finally, the study also highlighted some discrepancies in methodology and their impact and proposed considerations for future testing towards a more standardised, relevant and robust assessment of water polo players.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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