#IndEsPrev: A Prospective, International, Injury Prevention Study in Badminton

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Abstract

Introduction

Force, velocity, and power generation are important factors that could impact sporting success. In the case of badminton, players must have the potential to generate these variables at both the upper and lower limbs, to face the demands of competition. In a sport where male and female players often train and compete together, the knowledge of differences between the sexes in the development of force, velocity, and power can help coaches fine-tune strength and conditioning sessions for each set of players. Therefore, this study aimed (1) to analyze the influence of a 15-min game on the physical performance in men and women badminton players on measures of jump, agility, and flexibility performance variation after the match; and (2) to compare differences between young, elite male and female badminton players in the discrete and continuous variables registered using Linear Position Transducers during the squat and bench press.

Methods

Twenty-two elite, junior badminton players (age: 16.3 ± 1.3 years; 13 male and 9 female players; height: females = 160.7 ± 6.48 cm, males = 170.3 ± 3.18 cm; weight: females =55.1 ± 3.87 kg, males = 60.6 ± 5.00 kg) were recruited for the study. All players had experience in playing in international tournaments. Participants performed the tests over two days.

On the first day, the joint flexibilities of both the lower limbs were measured. The players then performed three bilateral counter-movement jumps (CMJ) and three unilateral CMJs with each limb. The players then proceeded to perform a badminton-specific BADCAMP test where they performed two repetitions of the same. The jump and BADCAMP tests were performed in pairs alternatively to prevent a player from getting fatigued. These players then played a fifteen-minute match between themselves, and the flexibility, jump, and BADCAMP tests were repeated after the match.

On the second day, they performed basic strengthening exercises such as the squat and the bench press on a Smith machine where their force, velocity, and power profiles were recorded using a Linear Position Transducer.

Results

Significant differences were only found in the hip flexion for the non-dominant limb in male participants (difference: -3.08°; $p=0.046$) and the single leg CMJ for the right limb in female players (difference: +1.31 cm; $p=0.038$). No other significant differences were found for the flexibility and agility variables. In terms of the strength tests, differences between male and female players were seen in the bench press for peak velocity ($p< .001$), peak normalized power ($p< .001$), and normalized RM for the bench press ($p< .001$), and the displacement pattern was also different between the sexes. No differences were seen in the squat except for the normalized squat RM ($p=0.025$).

Discussion and Conclusion

The results indicate that a 15-min game has no real effect on the physical performance of men and women badminton players on measures of jump, agility, and flexibility performance. Moreover, when the strength variables were normalized for the body mass, no differences were observed between male and female badminton players. Nevertheless, differences between male and female players were seen in the displacement patterns for the bench press exercise, which could provide an indication where training in young female badminton players can be focused to improve their smash velocities.

Introduction

Performance in sport depends on physiological, biomechanical, and psychological factors. Performance improvement not only depends on the study of these factors, but injury prevention also plays a key role in ensuring that the players are available to perform to the best of their abilities as the presence of an injury can affect on-field performance. Measurement of these factors could be fundamental in the evaluation and prediction of injuries, and as a consequence, determine the functional capacity of the player. Although such studies have been carried out extensively different sports such as soccer (Ekstrand, Hägglund, & Waldén, 2011; Schuermans, Van Tiggelen, Danneels, & Witvrouw, 2016), rugby (Hulin, Gabbett, Caputi, Lawson, & Sampson, 2016), tennis (Abrams, Renstrom, & Safran, 2012), field hockey (Barboza, Joseph, Nauta, van Mechelen, & Verhagen, 2018) and cricket (Das, Usman, Choudhury, & Osman, 2014) among others (Dalton, Kerr, & Dompier, 2015) the number of studies in badminton is limited.

Performance in badminton

Badminton is a discipline that involves high coordination and technical complexity (Tomaszewski et al., 2017) and is characterized by high intensities, intermittent changes of direction, and movements such as jumping, landing, twisting, lunging, stretching, smashing, and stopping in response to an opponent's shot (Campos et al., 2009; Chin et al., 1995; Maloney, 2018; Phomsoupha & Laffaye, 2015). In physiological terms, badminton belongs to endurance- and speed-based disciplines with changing modes of effort and intensity (Cabello et al., 2004). In this sense, badminton at the elite level requires a combination of the aerobic and anaerobic systems and the involvement of these systems depends on the nature of the rally (short or long) and the duration of the game (short set or long match) (Chin et al., 1995). Currently, rally time and resting time were estimated at 7 s and 15 s respectively with an effective playing time of 31% of the match (Phomsoupha & Laffaye, 2015). Thereby, such traits as velocity, endurance, motor coordination, decision-making efficiency, the anticipation of the opponent's movements, and spatiotemporal orientation play an important role in a player's preparation (Tomaszewski et al., 2017). Thus, players require a very high level of eye-hand coordination (Alam et al., 2009). In addition, a specific race preparation to anticipate the shuttlecock's atypical and surprising flight trajectory (Hong et al., 2014). In this way, players may adapt their movements using biomechanical factors to respond to the set of visual information. This requires quick changes of direction, jumps, and quick arm movements from different postures (Hong et al., 2014; Shariff et al., 2009).

Thereby, it is very important to carry out specific tests in an ecological environment to simulate the competing demands in order to evaluate the performance of the players (Chin et al., 1995). Within these assessments, specific agility tests are essential to be able to evaluate the demands of competition in a controlled environment (Ooi et al., 2009). Therefore, it is important an adequate battery of specific badminton tests, which simulates match situations (Zhang et al., 2013). It will generate different results depending on gender and level of competition, thus being able to evaluate how physical demands are affected by fatigue in competition (Cabello et al., 2004).

Resistance training

In order to prepare for the high demands, players train frequently, often during multiple sessions during the same day, and regularly include resistance training as a part of their training regime. Resistance training is an effective method to enhance muscle strength and jump performance in youth athletes, influenced by sex and resistance training type (Lesinski et al., 2016). This improvement of the muscular strength of the upper and lower body is also considered an important factor to enhance performance, given the demands of speed, explosiveness, and agility required by the sport (Sturgess & Newton, 2008) Specifically in youth, resistance training needs to be incorporated prior to power training to acquire a great strength base for power training methodologies (Behm et al., 2017) that could help improve performance based on explosive actions.

It is well-known that sports performance requires high-speed movements (above 200°/s in some cases) (Mann & Herman, 1985), making it essential to develop resistance training at these velocities (Pereira & Gomes, 2003) and also assess the training load in the same way. In resistance training, training load is usually assessed through One-Repetition Maximum (1RM) Test (Grgic et al., 2020) and could be considered as the "gold standard" in non-laboratory conditions (Kraemer et al., 2006). However, its association with injuries and the significant time spent performing the test (Brzycki, 1993; Mayhew et al., 1992) has led to the emergence of new methods of evaluation training load, such as the movement velocity assessment (González-Badillo & Sánchez-Medina, 2010). Research has shown that the velocity registered in each repetition of a movement velocity assessment could be the best way to know the real effort developed by the athlete (González-Badillo & Sánchez-Medina, 2010).

Linear Position Transducers (LPTs) are one of the most used kinematic devices that allow assessing movement velocity in some resistance exercises (Orange et al., 2020). LPTs register the vertical displacement of a cable that is located on the barbell (Harris et al., 2010), and based on the resistance load added, different variables such as velocity, acceleration, force, and power are derived (Dorrell et al., 2019). These variables could give information related to both testing and training situations (Dorrell et al., 2019). So far, these tests have been used in soccer (González-Badillo et al., 2015; López-Segovia et al., 2010), cycling (Gil-Cabrera et al., 2021; Valenzuela et al., 2021), and rugby (Orange et al., 2019), but to our knowledge, not with badminton players. In this case, the bench press and the squat are commonly used exercises to enhance muscular strength of the upper and lower limbs respectively (Ooi et al., 2009; Sun & Yan, 2019). Thus, an evaluation of badminton players executing these tests using LPTs can serve as a tool for an evaluation of upper and lower body strength.

Gender differences

Being a sport played by both males and females, with players of either sex training regularly and even competing together in mixed doubles competitions, there are significant differences in the gameplay between male and female players (Fernandez-Fernandez et al., 2013).

In previous research, it has been observed that male players show greater smash velocities, had higher jump heights and engaged in longer rallies by executing more strokes per rally when compared to female players (Fernandez-Fernandez et al., 2013; Ferreira et al., 2020). In comparison to male players, females compensate by not jumping and continuing the intensity of the game for a slightly longer period (Gomez et al., 2020). These differences have been attributed to differences in the upper (Ferreira et al., 2020) and lower limb muscle strength (Fernandez-Fernandez et al., 2013). Specifically, it was observed that in youth badminton players males were stronger than females in all planes of shoulder isometric strength except in shoulder internal rotation (Couppe et al., 2014). Such a difference in force has been observed also in other racquet sports like tennis, where a greater rotational torque in males (Ida et al., 2005; Lees, 2003) has correlated with higher serve speeds (Fernandez-Fernandez et al., 2019). Although previous research has found differences in strength using isometric testing (Couppe et al., 2014), none have studied the specific strength of the upper limb and lower limb muscles in badminton players.

Aims

Keeping the aforementioned factors in mind, this study presented two specific aims. First, this study aimed to analyze the influence of a 15-min game on the physical performance in men and women badminton players on measures of jump, agility, and flexibility performance variation after the match. Secondly, this study aimed to compare differences between young, elite male and female badminton players in the discrete and continuous variables registered using LPTs during the squat and bench press.

Methods

Participants

Twenty-two elite, junior badminton players (age: 16.3 ± 1.3 years; 13 male and 9 female players; height: females = 160.7 ± 6.48 cm, males = 170.3 ± 3.18 cm; weight: females =55.1 ± 3.87 kg, males = 60.6 ± 5.00 kg) were recruited for the study. More than 50% had played at least a tournament at a professional level, with an average competitive experience of 5.33 ± 2.53 years, with most of them being right dominant (82.6%). The participants belonged to elite badminton academies in India and had badminton-specific training over two-hour sessions six times a week. The participants undertook additional strength training three times a week in gyms located in the same training facilities. Before the testing procedure, the entire experimental process was explained to the players. The participants had prior experience performing squats and bench presses on a Smith machine. Since all participants were under the age of eighteen, the participants and their parents/legal guardians signed an informed consent regarding their participation in the study. The entire study procedure was approved by the ethics committee of the European University of Madrid, Spain with the approval document number CIPI/21/013. All experimental procedures were performed following the ethical standards of the Helsinki Declaration.

Procedures

Participants performed the tests over two days: one day for the agility and flexibility tests and another for the strength tests.

Agility and flexibility tests

First, the joint flexibility of the players was recorded, with tests measuring the passive flexibility of the ankle dorsiflexion, knee flexion, and hip flexion (both with the knee flexed, and the knee extended). The tests were performed by an experienced sports scientist using a goniometer and a video camera (Söderman, Alfredson, Pietilä, & Werner, 2001).

The players then proceeded to perform three bilateral counter-movement jumps (CMJ) and three unilateral CMJs with each limb, separated by 45 s of passive recovery. The jump height from the jump tests was recorded with the Optojump Next system (Microgate ®, Italy). The players then proceeded to perform a badminton-specific BADCAMP test (Loureiro Jr et al., 2017) where they performed two repetitions of the same.

The jump and BADCAMP tests were performed in pairs alternatively to prevent a player from getting fatigued. These players then played a fifteen-minute match between themselves, and the flexibility, jump, and BADCAMP tests were repeated after the match. The pairs of players were chosen by the coach so that the players who competed against each other had the same level.

Strength test

On the second day of testing, incremental loading tests for the squat and bench press exercises were performed on a Smith machine, and the bar movement kinematics and muscle strength parameters were measured using an LPT (sampling frequency = 1000 Hz; T-Force System, Ergotech, Murcia, Spain) which was connected to a 16-bit analog-to-digital converter (MP100 Systems; BIOPAC Systems Inc, Goleta, CA).

The initial weight was 20 kg for the players (i.e., only the bar). The load was increased progressively by 10 kg for the males and 5 kg for the females, and the athletes performed 3 consecutive repetitions with each load (with a 3-min rest between loads). The loads were increased until a decrease in the mean propulsive power (MPP) of the action was recorded in two consecutive loads. The MPP is the average of the power values of the propulsive phase, defined as the portion of the concentric action during which the measured acceleration is greater than the acceleration due to gravity. The data was smoothed with a fourth-order low-pass Butterworth filter with no phase shift and a cut-off frequency of 10 Hz (Sanchez-Medina & González-Badillo, 2011). The trial with the highest MPP registered for each exercise was used for analysis, from which the bar displacement, velocity, force, and power were extracted for both the downward (eccentric) and upward (concentric) phases. Peak power and load at peak power were also determined for this trial. The 1-RM for each exercise was based on the equations described elsewhere was calculated (González-Badillo & Sánchez-Medina, 2010). The power (and peak power), force, load at peak power, and 1-RM were normalized to the body mass of each participant.

Analysis

The discrete variables from the flexibility, agility, and strength tests were tabulated and tested for normality using Shapiro-Wilk's test. The data from the flexibility and agility tests were compared before and after the match using the repeated measures t-test. Considering the morphological differences between males and females, they were treated as separate samples for this pre-post comparison. Nevertheless, the % Δ change before and after a match, and the normalized discrete strength variables were compared between males and females using an independent samples t-test. This statistical analysis was performed using the open-source Jamovi software (v 1.8.1, www.jamovi.org). with significance set at $p<0.05$ and effect sizes determined using Cohen's d.

Since looking at peak values alone does not give an adequate description of the entire movement performed, we preferred to analyze the time-series movement of the bar registered using Statistical Parametric Mapping (SPM). SPM is a relatively new statistical technique used for the analysis of continuous, time-series data in biomechanics (Pataky, 2010; Serrien et al., 2019; Thomas et al., 2021). SPM has been used for analyzing time-series data in gait (Sotelo et al., 2018), running (Nüesch et al., 2019; Takabayashi et al., 2019), side-cutting maneuvers (Sankey et al., 2015), cricket (Dutton et al., 2020), and football (Serrien et al., 2020), but none have looked at the complete movement patterns in badminton players and/or in exercises using LPTs. The bar displacement, bar velocity, force, and power of both the squat and the bench press were time normalized to 1001 data points based on when the movement began and ended. The starting point of the exercise was taken as the point when the bar velocity exceeded 0.01 m/s, and the movement was completed when the bar velocity reached below 0.02 m/s and did not increase or decrease after that. The downward displacement direction was considered to be negative and the upward displacement to be positive. The normalized variables were input into an Nx1001 array, where N represented the number of participants for either sex. One-dimensional statistical parametric mapping (1D-SPM) was used to determine differences between male and female waveforms for all variables. All 1D-SPM analyses were implemented using the open-source 1D-SPM code (v.M0.4, www. spm1d.org) in Matlab (R2020b, Mathworks Inc., Natick, MA, USA). Significance was set at $p < 0.05$.

Results

No differences in flexibility before and after the match were found (Table I). Significant differences were only found in the hip flexion for the non-dominant limb in male participants, finding a significant reduction (difference: -3.08°; p=0.046; IC: 0.07 to 6.08; ES: 0.55). In terms of jump height, only the single-leg CMJ for the right limb showed significant differences in female players (difference: +1.31 cm; p=0.038; IC: 0.09 to 2.53; ES: 0.47). No differences were found for the time taken to perform the BADCAMP test.

Table I: Differences pre and post-match for lower leg flexibility.

	Male							Female						
	Pre (°)			Post (°)			*p value*	Pre (°)			Post (°)			*p value*
Ankle Dorsiflexion Non-Dominant	31.62	±	7.89	30.92	±	6.80	0.703	37.89	±	6.57	37.89	±	3.79	1.000
Ankle Dorsiflexion Dominant	32.00	±	8.12	30.77	±	6.91	0.544	36.78	±	7.73	39.33	±	4.09	0.092
Knee Flexion Non-Dominant	139.00	±	4.04	142.23	±	6.43	0.056	143.78	±	5.02	144.22	±	6.55	0.819
Knee Flexion Dominant	141.31	±	6.92	139.69	±	5.22	0.424	141.11	±	4.70	141.11	±	5.30	1.000
Hip Flexion Non-Dominant	136.31	±	5.34	133.23	±	5.78	0.046*	136.00	±	4.66	138.44	±	10.79	0.442
Hip Flexion Dominant	133.54	±	7.56	134.38	±	7.23	0.664	136.56	±	5.48	139.33	±	7.18	0.278
Straight Leg Hip Raise Non-Dominant	94.92	±	10.60	96.62	±	12.90	0.559	115.44	±	16.83	115.89	±	20.15	0.881
Straight Leg Hip Raise Dominant	93.62	±	9.18	96.15	±	9.19	0.172	117.33	±	13.49	115.22	±	18.40	0.527

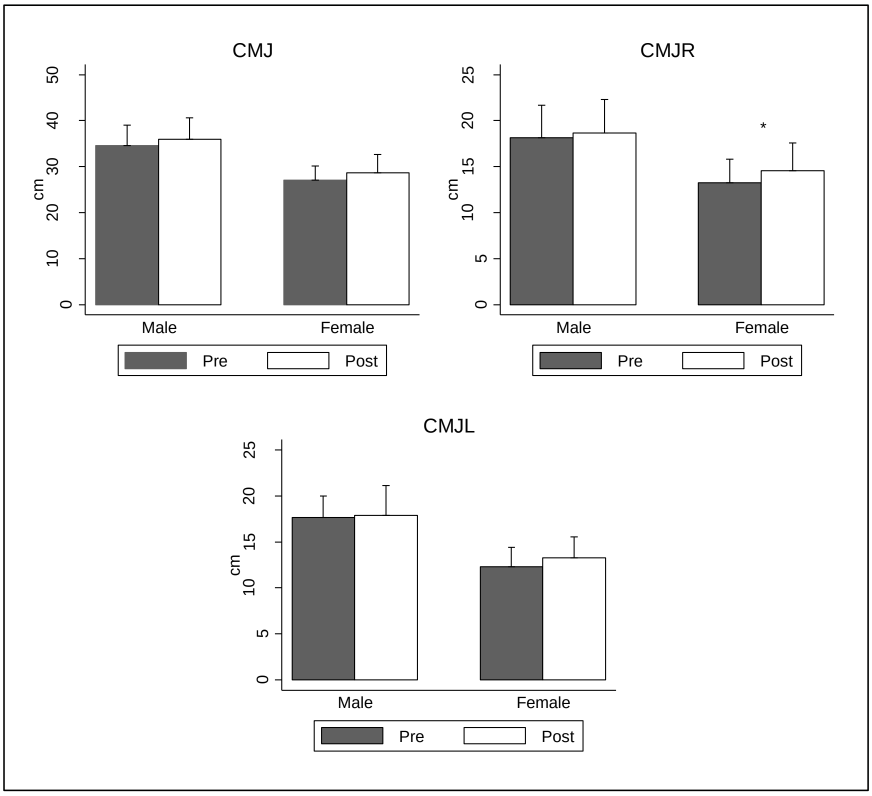

Figure 1. Differences pre-post-match in CMJ variables.

The differences between male and female players in the discrete strength variables (Table II) were seen for the peak velocity, peak normalized power, and normalized RM for the bench press.

Table II: Differences between discrete variables for the bench press and squat. Load and power variables have been normalized done by dividing the obtained variable by the body mass of the subject.

Variable	Group	Mean ± SD	p-value	Cohen's d
Normalized Press Load	Female	0.38 ± 0.04	0.55	0.264
(kg/kg)	Male	0.37 ± 0.07		
Normalized Press Power	Female	3.02 ± 0.69	< .001	-2.517
(W/kg)	Male	4.76 ± 0.7		
Normalized Press RM	Female	0.67 ± 0.1	< .001	-2.632
(kg/kg)	Male	0.94 ± 0.1		
Press Velocity (m/s)	Female	0.75 ± 0.14	< .001	-2.245
	Male	1.12 ± 0.17		
Normalized Squat Load	Female	0.85 ± 0.17	0.18	-0.603
(kg/kg)	Male	0.98 ± 0.23		

Normalized Squat Power	Female	7.63 ± 1.18	0.107	-0.733
(W/kg)	Male	8.73 ± 1.68		
Normalized Squat RM	Female	1.22 ± 0.2	0.025	-1.054
(kg/kg)	Male	1.48 ± 0.27		
Squat Velocity (m/s)	Female	0.82 ± 0.07	0.738	-0.147
	Male	0.84 ± 0.1		

When comparing the variables over the entire bench press exercise (Figure 1), significant differences were observed for the displacement (Figure 2) between 40 and 65% of the movement, while no other significant differences between males and females were observed across the other three variables. In the case of the squat, no significant differences were observed for any of the variables measured between males and females.

Discussion

Force, velocity, and power generation are important factors that could impact sporting success. In the case of badminton, players must have the potential to generate these variables at both the upper and lower limbs, to face the demands of competition. In a sport where male and female players often train and compete together, the knowledge of differences between the sexes in the development of force, velocity, and power can help coaches fine-tune strength and conditioning sessions for each set of players. Twenty-two young, elite badminton players participated in this study where their strength, agility, flexibility, and power profiles were recorded. The results show that although there were no differences in flexibility and agility observed pre and post-match, or when comparing the differences in peak values across the sexes, the analysis of the entire movement pattern shows differences in the displacement pattern between males and females for the bench press with a greater displacement seen in male players. These findings can have an important consequence in defining strength and conditioning programs for male and female players.

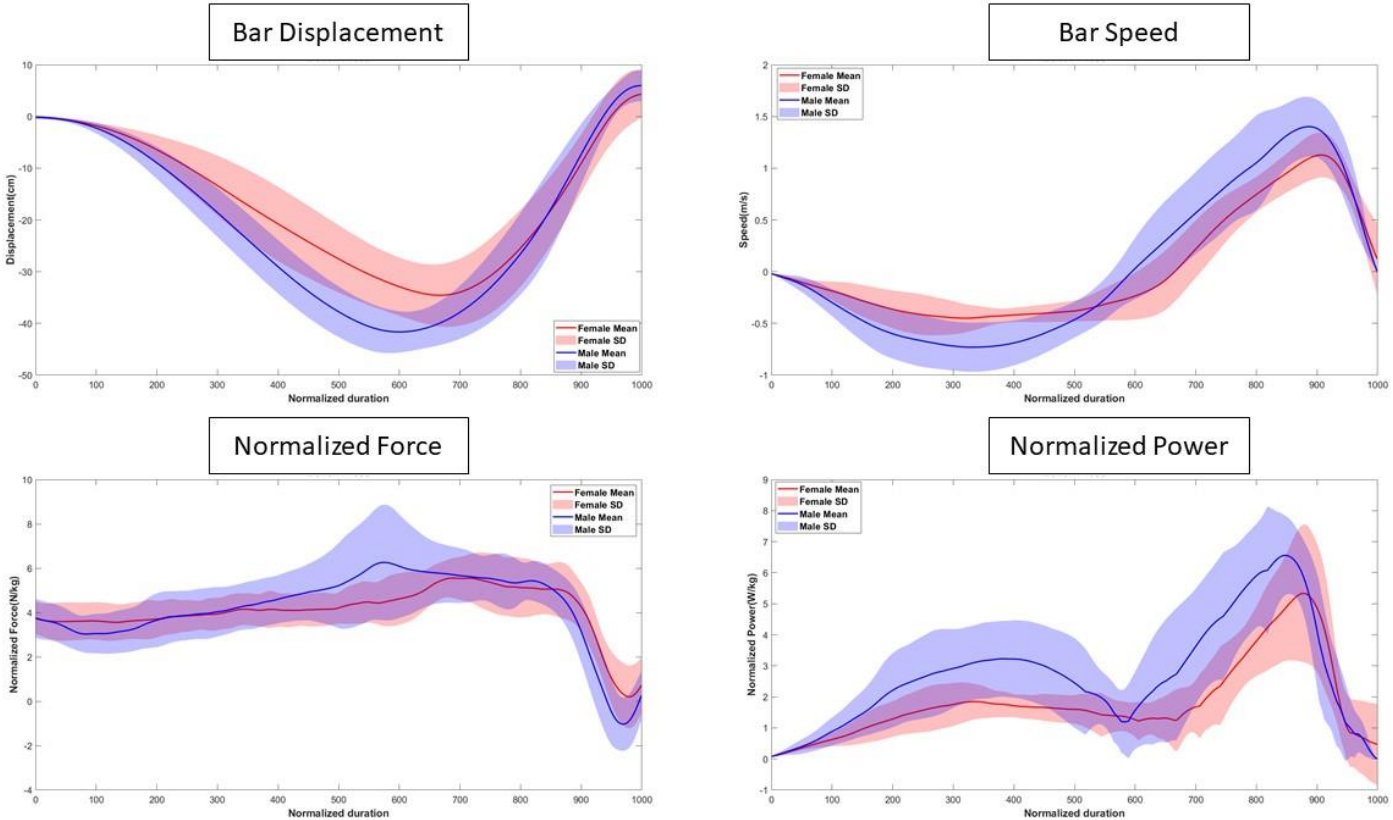

Figure 2: Mean (solid line) and standard deviation (shaded area) for the different variables registered during the bench press exercise. Data have been normalized to 1001 data points from the beginning of the cycle (downward movement of the bar) until the end (when bar velocity reached 0).

No differences in agility, flexibility, or discrete strength variables

This is the first study to provide data concerning the influence of a 15-min game on the physical performance in men and women badminton players and the relationship between multiple strength measures and jump, agility, and flexibility performance variation after the match. Only one study has analyzed the influence of the match on the physiological and biomechanical parameters in badminton players (Bravo-Sánchez et al., 2019) but no relationship with a different kind of strength has been previously analyzed. The main finding was the limited effect of the 15-m game on the physical performance of male and female badminton players. No differences were identified between men and women according to the variation in the performance after the game. These results are consistent with previous research when reporting the importance of maximal strength on agility and jump performance in athletes (Peterson et al., 2006; Wisløff et al., 2004), due to the execution of efficient changes of direction often determines playing performance in badminton players (Phomsoupha & Laffaye, 2015).

Differences were observed in the unilateral CMJ jump parameters, with a significant increment in the right leg. A majority of the players were right-dominant, and in badminton, the dominant leg is most important in initiating and pivoting movements. The increment in these values indicates the lack of effect of fatigue, probably due to they only playing a 15-minute game, similar to the results of Abian-Vicen et al. (2019) who did not find significant differences in the CMJ performance after a badminton match. This finding could be explained by a reduced warm-up (Girard et al., 2006), an increase in muscle temperature with a better transmission of the nerve impulses (Bishop, 2003), or post-activation potentiation effect elicited by badminton specific actions on the players (Boullosa & Tuimil, 2009). On the opposite side, Phomsoupha et al. (2019) evidenced a reduction in the jump performance after 30 minutes of play in badminton players, suggesting that muscle fatigue in an intermittent sport like a badminton match starts after 50 minutes of play. The left limb values in this study also increase by 4.86 and 5.83 % for the bilateral CMJ height and 1.17 and 8.77 % for the unilateral left CMJ height in men and women badminton players, respectively, but no significant differences were observed. These increments could be associated with the activation related to the 15-minute game, as previous studies in badminton have demonstrated (Abián-Vicén et al., 2012). These authors suggested that badminton matches do not produce muscle fatigue in either the lower or upper limbs and evidenced a similar increment in the bilateral CMJ performance after the match (4.5±7.3%), except when the duration of the match is higher than 50 minutes because of the recovery time between rallies is not enough to recover phosphocreatine and adenosine triphosphate (ATP) (Glaister, 2005).

Differences in bench press displacement patterns

This research study also presents a novel study of variables obtained from linear position transducers, as this is, to the best of the authors’ knowledge, the first study to analyze the variation of displacement, velocity, force, and power curve in both, the lowering and upward phases of a squat and bench press. Normally, studies using linear position transducers have compared peak values to determine strength differences (Gil-Cabrera et al., 2021; Orange et al., 2020; Valenzuela et al., 2021). Similarly, in this study differences in peak strength values were found between male and female players for the upper limb strength, findings in line with previous research on Polish badminton players (Ferreira et al., 2020). Data obtained from this study provides an additional dimension to these differences, as seen with earlier relative time to peak velocity and peak power, as well as greater bar displacement in the bench press for male players as compared to their female counterparts. These results indicate that the male players can carry out the entire eccentric-concentric (downward and upward) movement faster than female players, and along with the greater displacement, can generate faster velocities of movement and generate more relative power with the upper limbs.

Although the differences in displacement and velocities could be due to anthropometric differences between the sexes, it is important to note that these differences were not seen in the squat. The only difference was seen in the case of the peak (normalized) 1-RM estimation, which was higher in male players. Badminton is a sport where success depends on reaching different parts of the court as quickly as possible, and a lot of emphases is given to lower limb strength and agility training, often being carried out on the court. Since both male and female players train these skills together across multiple sessions, this can explain the lack of differences seen between the variables. It appears that the female players use their relatively similar lower limb strength to pace themselves and play longer rallies as compared to male players (Gomez et al., 2020). However, considering that greater smash velocities are seen in male players compared to female players (Ferreira et al., 2020), the differences seen in the displacement, velocity, and power generated in the upper limb could be attributed to factors that are not anthropometric alone, according to Armstrong et al. (2015) who showed that sexual duality is apparent in several physiological variables that influence youth sports performance.

The stretch-shortening cycle (SSC) is known to be an important part of generating higher power and velocities (Newton et al., 1997; Turner & Jeffreys, 2010). The SSC performance increases with age according to the improvement in neuromuscular function and the structure of the musculotendon unit (Radnor et al., 2018). A greater range of displacement as seen in male players in a shorter amount of time during the bench press indicates that the male players appear to maximize this SSC in their movements. Previous research in badminton has shown that the acceleration of the shuttle depends on the elbow joint torque (Rambely & Osman, 2005) and shoulder strength (Ferreira et al., 2020). Thus, it remains to be seen if specifically targeting female players with bench press can potentially improve their shot velocities, given that the muscles around the shoulder and elbow joint are actively trained in the bench press. ´

Limitations

Although the results of this novel study seem promising, one must consider the limitation of the sample size which was half of the originally recruited sample as a result of the COVID-19 pandemic. Nevertheless, this is the first study to look at the force-velocity-power profile in elite badminton players. Although the sample size is limited to twenty-two players, these are players from an elite academy in India, a country with many high-ranked badminton players, with thirteen players who have played a professional tournament, and the others have played in international U-19 and U-17 tournaments.

Conclusion

The results indicate that a 15-min game has no real effect on the physical performance of men and women badminton players on measures of jump, agility, and flexibility performance. Moreover, when the strength variables were normalized for the body mass, no differences were observed between male and female badminton players. Nevertheless, differences between male and female players were seen in the displacement patterns for the bench press exercise, which could provide an indication where training in young female badminton players can be focused to improve their smash velocities.

References

Abian-Vicen, J., Aparicio-García, C., Ruiz-Lazaro, P., Simon-Martinez, C., Bravo-Esteban, E., & Gómez-Soriano, J. (2019). Test-retest reliability and responsiveness of a comprehensive protocol for the assessment of muscle tone of the ankle plantar flexors in healthy subjects. *Isokinetics and Exercise Science*, *27*(2), 107-115.

Abián-Vicén, J., Del Coso, J., González-Millán, C., Salinero, J. J., & Abián, P. (2012). Analysis of dehydration and strength in elite badminton players. *Plos One*, *7*(5), e37821.

Alam, F., Chowdhury, H., Theppadungporn, C., Subic, A., & Khan, M. M. K. (2009). Aerodynamic properties of badminton shuttlecock. *International journal of mechanical and materials engineering*, *4*(3), 266-272.

Armstrong, N., Barker, A. R., & McManus, A. M. (2015). Muscle metabolism changes with age and maturation: How do they relate to youth sport performance? *British journal of sports medicine*, *49*(13), 860-864.

Behm, D. G., Young, J. D., Whitten, J. H. D., Reid, J. C., Quigley, P. J., Low, J., Li, Y., Lima, C. D., Hodgson, D. D., & Chaouachi, A. (2017). Effectiveness of traditional strength vs. power training on muscle strength, power and speed with youth: a systematic review and meta-analysis. *Frontiers in physiology*, *8*, 423.

Bishop, D. (2003). Warm up I: Potential mechanisms and the effects of passive warm up on exercise performance. *Sports medicine*, *33*(6), 439-454.

Boullosa, D. A., & Tuimil, J. L. (2009). Postactivation potentiation in distance runners after two different field running protocols. *The Journal of Strength & Conditioning Research*, *23*(5), 1560-1565.

Bravo-Sánchez, A., Abián, P., Jiménez, F., & Abián-Vicén, J. (2019). Myotendinous asymmetries derived from the prolonged practice of badminton in professional players. *Plos One*, *14*(9), e0222190.

Brzycki, M. (1993). Strength testing—predicting a one-rep max from reps-to-fatigue. *Journal of physical education, recreation & dance, 64*(1), 88-90.

Cabello, D., Padial, P., Lees, A., & Rivas, F. (2004). Temporal and Physiological Characteristics of Elite Women's and Men's Singles Badminton. *International Journal of Applied Sports Sciences*, *16*(2).

Campos, F. A. D., Daros, L. B., Mastrascusa, V., Dourado, A. C., & Stanganelli, L. C. R. (2009). Anthropometric profile and motor performance of junior badminton players. *Brazilian journal of biomotricity*, *3*(2), 146-151.

Chin, M.-K., Wong, A. S. K., So, R. C., Siu, O. T., Steininger, K., & Lo, D. T. (1995). Sport specific fitness testing of elite badminton players. *British journal of sports medicine*, *29*(3), 153-157.

Couppe, C., Thorborg, K., Hansen, M., Fahlström, M., Bjordal, J. M., Nielsen, D., Baun, M., Storgaard, M., & Magnusson, S. P. (2014). Shoulder rotational profiles in young healthy elite female and male badminton players. *Scandinavian journal of medicine & science in sports*, *24*(1), 122-128.

Dorrell, H. F., Moore, J. M., Smith, M. F., & Gee, T. I. (2019). Validity and reliability of a linear positional transducer across commonly practised resistance training exercises. *Journal of sports sciences*, *37*(1), 67-73.

Dutton, M., Gray, J., Prins, D., Divekar, N., & Tam, N. (2020). Overhead throwing in cricketers: A biomechanical description and playing level considerations. *Journal of sports sciences*, *38*(10), 1096-1104.

Fernandez-Fernandez, J., Jose, G., Moya-Ramon, M., Cabello-Manrique, D., & Mendez-Villanueva, A. (2013). Gender differences in game responses during badminton match play. *The Journal of Strength & Conditioning Research*, *27*(9), 2396-2404.

Fernandez-Fernandez, J., Nakamura, F. Y., Moreno-Perez, V., Lopez-Valenciano, A., Del Coso, J., Gallo-Salazar, C., Barbado, D., Ruiz-Perez, I., & Sanz-Rivas, D. (2019). Age and sex-related upper body performance differences in competitive young tennis players. *Plos One*, *14*(9), e0221761.

Ferreira, A., GÓRski, M., & Gajewski, J. (2020). Gender differences and relationships between upper extremity muscle strength, lower limb power and shuttle velocity in forehand smash and jump smash in badminton. *Acta of Bioengineering & Biomechanics*, *22*(4).

Gil-Cabrera, J., Valenzuela, P. L., Alejo, L. B., Talavera, E., Montalvo-Pérez, A., Lucia, A., & Barranco-Gil, D. (2021). Traditional versus optimum power load training in professional cyclists: a randomized controlled trial. *International Journal of Sports Physiology and Performance*, *1*(aop), 1-8.

Girard, O., Lattier, G., Micallef, J.-P., & Millet, G. P. (2006). Changes in exercise characteristics, maximal voluntary contraction, and explosive strength during prolonged tennis playing. *British journal of sports medicine*, *40*(6), 521-526.

Glaister, M. (2005). Multiple sprint work. *Sports medicine*, *35*(9), 757-777.

Gomez, M. A., Leicht, A. S., Rivas, F., & Furley, P. J. P. o. (2020). Long rallies and next rally performances in elite men's and women's badminton. *Plos One*, *15*(3), e0229604.

González-Badillo, J. J., Pareja-Blanco, F., Rodríguez-Rosell, D., Abad-Herencia, J. L., del Ojo-López, J. J., & Sánchez-Medina, L. (2015). Effects of velocity-based resistance training on young soccer players of different ages. *The Journal of Strength & Conditioning Research*, *29*(5), 1329-1338.

González-Badillo, J. J., & Sánchez-Medina, L. (2010). Movement velocity as a measure of loading intensity in resistance training. *Int J Sports Med*, *31*, 347-352.

Grgic, J., Lazinica, B., Schoenfeld, B. J., & Pedisic, Z. (2020). Test–retest reliability of the one-repetition maximum (1RM) strength assessment: a systematic review. *Sports Medicine-Open*, *6*(1), 1-16.

Harris, N. K., Cronin, J., Taylor, K.-L., Boris, J., & Sheppard, J. (2010). Understanding position transducer technology for strength and conditioning practitioners. *Strength & Conditioning Journal*, *32*(4), 66-79.

Hong, Y., Wang, S. J., Lam, W. K., & Cheung, J. T.-M. (2014). Kinetics of badminton lunges in four directions. *Journal of Applied Biomechanics*, *30*(1), 113-118.

Ida, H., Kusubori, S., & Ishii, M. (2005). Kinematics and kinetics of the racket-arm during the soft-tennis smash under match conditions. *Journal of Applied Biomechanics*, *21*(4), 334-347.

Kraemer, W. J., Ratamess, N. A., Fry, A. C., & French, D. N. (2006). Strength testing: Development and evaluation of methodology. In P. J. Maud & C. Foster (Eds.), *Physiological Assessment of Human Fitness;* (pp. 129). Human Kinetics.

Lees, A. (2003). Science and the major racket sports: a review. *Journal of sports sciences*, *21*(9), 707-732.

Lesinski, M., Prieske, O., & Granacher, U. (2016). Effects and dose–response relationships of resistance training on physical performance in youth athletes: a systematic review and meta-analysis. *British journal of sports medicine, 50*(13), 781-795.

López-Segovia, M., Andrés, J. M. P., & González-Badillo, J. J. (2010). Effect of 4 months of training on aerobic power, strength, and acceleration in two under-19 soccer teams. *The Journal of Strength & Conditioning Research*, *24*(10), 2705-2714.

Loureiro Jr, L. d. F. B., Dias, M. O. C., Cremasco, F. C., da Silva, M. G., & de Freitas, P. B. (2017). Assessment of specificity of the badcamp agility test for badminton players. *Journal of human kinetics*, *57*, 191.

Maloney, S. J. (2018). Review of the badminton lunge and specific training considerations. *Strength & Conditioning Journal*, *40*(4), 7-17.

Mann, R., & Herman, J. (1985). Kinematic analysis of Olympic sprint performance: men's 200 meters. *Journal of Applied Biomechanics*, *1*(2), 151-162.

Mayhew, J. L., Ball, T. E., Arnold, M. D., & Bowen, J. C. (1992). Predictor of bench press strength in college men. *Journal of Applied Sport Science Research*, *6*(4), 200.

Newton, R. U., Murphy, A. J., Humphries, B. J., Wilson, G. J., Kraemer, W. J., & Häkkinen, K. (1997). Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *European journal of applied physiology and occupational physiology*, *75*(4), 333-342.

Nüesch, C., Roos, E., Egloff, C., Pagenstert, G., & Mündermann, A. (2019). The effect of different running shoes on treadmill running mechanics and muscle activity assessed using statistical parametric mapping (SPM). *Gait & posture*, *69*, 1-7.

Ooi, C. H., Tan, A., Ahmad, A., Kwong, K. W., Sompong, R., Mohd Ghazali, K. A., Liew, S. L., Chai, W. J., & Thompson, M. W. (2009). Physiological characteristics of elite and sub-elite badminton players. *Journal of sports sciences*, *27*(14), 1591-1599.

Orange, S. T., Metcalfe, J. W., Marshall, P., Vince, R. V., Madden, L. A., & Liefeith, A. (2020). Test-retest reliability of a commercial linear position transducer (GymAware PowerTool) to measure velocity and power in the back squat and bench press. *The Journal of Strength & Conditioning Research*, *34*(3), 728-737.

Orange, S. T., Metcalfe, J. W., Robinson, A., Applegarth, M. J., & Liefeith, A. (2019). Effects of in-season velocity-versus percentage-based training in academy rugby league players. *International Journal of Sports Physiology and Performance*, *15*(4), 554-561.

Pataky, T. C. (2010). Generalized n-dimensional biomechanical field analysis using statistical parametric mapping. *Journal of biomechanics*, *43*(10), 1976-1982.

Pereira, M. I. R., & Gomes, P. S. C. (2003). Movement velocity in resistance training. *Sports medicine*, *33*(6), 427-438.

Peterson, M. D., Alvar, B. A., & Rhea, M. R. (2006). The contribution of maximal force production to explosive movement among young collegiate athletes. *The Journal of Strength & Conditioning Research*, *20*(4), 867-873.

Phomsoupha, M., Ibrahime, S., Heugas, A.-M., & Laffaye, G. (2019). Physiological, neuromuscular and perceived exertion responses in badminton games. *International Journal of Racket Sports Science*, *1*(1), 16-25.

Phomsoupha, M., & Laffaye, G. (2015). The science of badminton: game characteristics, anthropometry, physiology, visual fitness and biomechanics. *Sports medicine*, *45*(4), 473-495.

Radnor, J. M., Oliver, J. L., Waugh, C. M., Myer, G. D., Moore, I. S., & Lloyd, R. S. (2018). The influence of growth and maturation on stretch-shortening cycle function in youth. *Sports medicine*, *48*(1), 57-71.

Rambely, A. S., & Osman, N. A. A. (2005, 2005). The contribution of upper limb joints in the development of racket velocity in the badminton smash. 23rd International Symposium on Biomechanics in Sports, Beijing, China.

Sanchez-Medina, L., & González-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and science in sports and exercise*, *43*(9), 1725-1734.

Sankey, S. P., Azidin, R. M. F. R., Robinson, M. A., Malfait, B., Deschamps, K., Verschueren, S., Staes, F., & Vanrenterghem, J. (2015). How reliable are knee kinematics and kinetics during side-cutting manoeuvres? *Gait & posture*, *41*(4), 905-911.

Serrien, B., Goossens, M., & Baeyens, J.-P. (2019). Statistical parametric mapping of biomechanical one-dimensional data with Bayesian inference. *International Biomechanics*, *6*(1), 9-18.

Serrien, B., Tassignon, B., Verschueren, J., Meeusen, R., & Baeyens, J.-P. (2020). Short-term effects of differential learning and contextual interference in a goalkeeper-like task: Visuomotor response time and motor control. *European journal of sport science*, *20*(8), 1061-1071.

Shariff, A. H., George, J., & Ramlan, A. A. (2009). Musculoskeletal injuries among Malaysian badminton players. *Singapore medical journal*, *50*(11), 1095.

Sotelo, M., Eichelberger, P., Furrer, M., Baur, H., & Schmid, S. (2018). Walking with an induced unilateral knee extension restriction affects lower but not upper body biomechanics in healthy adults. *Gait & posture*, *65*, 182-189.

Sturgess, S., & Newton, R. U. (2008). Design and implementation of a specific strength program for badminton. *Strength & Conditioning Journal*, *30*(3), 33-41.

Sun, B., & Yan, C. (2019). Strengthen badminton training and improve students' physique. *Frontiers in Educational Research*, *2*(11).

Takabayashi, T., Edama, M., Inai, T., & Kubo, M. (2019). Gender differences in coordination variability between shank and rearfoot during running. *Human movement science*, *66*, 91-97.

Thomas, C., Dos' Santos, T., Warmenhoven, J., & Jones, P. A. (2021). Between-Limb Differences During 180° Turns in Female Soccer Players: Application of Statistical Parametric Mapping. *Journal of Strength and Conditioning Research*.

Tomaszewski, P., Kęska, A., Tkaczyk, J., Nowicki, D., & Sienkiewicz-Dianzenza, E. (2017). Somatic characteristics and motor fitness of elite and sub-elite Polish male badminton players. *The Journal of sports medicine and physical fitness*, *58*(10), 1456-1464.

Turner, A. N., & Jeffreys, I. (2010). The stretch-shortening cycle: Proposed mechanisms and methods for enhancement. *Strength & Conditioning Journal*, *32*(4), 87-99.

Valenzuela, P. L., Gil-Cabrera, J., Talavera, E., Alejo, L. B., Montalvo-Pérez, A., Rincón-Castanedo, C., Rodríguez-Hernández, I., Lucia, A., & Barranco-Gil, D. (2021). On-versus off-bike power training in professional cyclists: a randomized controlled trial. *International Journal of Sports Physiology and Performance*, *16*(5), 674-681.

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *British journal of sports medicine*, *38*(3), 285-288.

Zhang, B., Li, F., & Jiang, W. (2013). Mixed doubles match technical and tactical analysis of world badminton champion based on mathematical statistics. *Advances in Physical Educational*, *3*(4), 154-157.