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Association between the dry-land strength & power and the kick start kinetics in elite male and female swimmers

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ABSTRACT

The aim of this research was to determine the association between dry-land exercises and the start kinetics in elite swimmers. Fourteen swimmers (eight males and six females) included in a national team took part in this study. A fixed smith-machine was used to measure the maximal full squat strength (Smax). The height of squat (SJ) and countermovement (CMJ) jumps were collected with a contact mat. The ground reaction force of the kick starts in the three-dimensional axis (Fz horizontal; Fy, vertical; Fx, lateral) was obtained by an instrumented force plate in the starting block. Overall, the Smax showed a high and significant association with Fz ($r = 0.60$) and Fy ($r = 0.87$). Moderate and significant associations were found between Fy and SJ ($r = 0.51$) and CMJ ($r = 0.57$). While Smax in males showed high association with Fy ($r = 0.77$), the Smax for females showed greater association with Fz ($r = 0.84$). As conclusion, the full back squat seems to be the dry-land exercise with higher association with the kick start kinetics. While in males the full squat defines better the vertical component, for females it defines the horizontal one.

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Swimming start; performance; full squat; kinetics; testing

Introduction

Swimming start has been considered an important part of the race, accounting from 0.8% to 26.1% of the final time depending on the event (Cossor & Mason, 2001). At elite level, the start performance shows a larger effect in shorter distance events than longer ones (Born et al., 2021). Within this level of expertise, start performance depends on reaction time, impulse on the block or foot force orientation during the take-off (Vantorre et al., 2014). So, the swim start kinetics (i.e., applied forces) are a topic that deserves to be studied, and requires a deeper understanding along with other domains of performance.

The way how swimmers produce force on the starting block, i.e., the direction of the applied force on the block, determines how they will project the body in air and thus in the water entry. Literature reports that the front horizontal and the resultant peak force were

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significant predictors of average power of the start (e.g., Thng et al., 2021). The horizontal and the vertical peak forces in back and front plates, respectively, were identified as key performance indicators of the jump phase during the start (Burkhardt et al., 2020). Incidentally, elite swimmers tend to show a better start organisation as reflected by larger mechanical impulse in the direction of intended displacement, despite of exhibiting similar block phase durations than their less expert counterparts (Vantorre et al., 2010). Because the performance of a start seems to be largely dependent on the block phase, monitoring the peak forces against the block can be a good training strategy to work with over the season (Galbraith et al., 2008).

Strength and conditioning have been reported to have a positive effect on athletic performance including in the sports of swimming (Lum & Barbosa, 2019). To enhance the start, swimmers engage on a regular basis in specific dry-land strength programmes. The main goal of this strategy is to improve lower limbs' power. Some of the mainstream drills selected include heavy-loaded back squat and vertical jumps. Although the start technique may have changed over time (Thng et al., 2019), the track start seems to have room for improvement if one goes under a well-designed resistance training programme underpinned by vertical jump drills (Breed & Young, 2003).

To date, there is a solid body of knowledge relating dry-land resistance training to swim start performance. Evidence shows that sprint start performance (5-m, 15-m, and 25-m split times) can be improved after maximal squat strength training (Born et al., 2020). The start performance seems to be significantly related to maximal strength in squat or jump height skills (García-Ramos et al., 2016; West et al., 2011). An enhanced countermovement jump performance can also enhance dive distance (Calderbank et al., 2020). However, it is yet unclear the link between dry-land drills and kick start kinetics phenomena. One may argue that the on-block kinetics is the underlying factor. The enhancement of dry-land muscular strength and power may elicit improvements in the force produced and its resultant direction on the block, and setting the take-off direction. Moreover, a between-subject variability does exist when faster start times are analysed considering individual profiles (Seifert et al., 2010). Hence, one may argue that a gender gap may be found on how dry-land drills determine the on-block start kinetics and performance.

The aim of this study was to quantify the association between the dry-land lower limbs' strength and the start kinetics in both male and female swimmers. It was hypothesised that maximal squat strength would be the mainstream drill with significant and positive association with the kinetics of the start. Moreover, it was also hypothesised that this association between dry-land strength and the start kinetics would differ between males and females.

Methods

Participants

Swimmers of both sexes were recruited on the basis of the following inclusion criteria: (i) more than 5 years of competitive experience in the sport of swimming; (ii) racing at international (European and/or World) competitions; (iii) perform the track start technique as preferred type for the start in individual events; (iv) not have any injury or disease in the past six months previous to the data collection. A total of fourteen elite swimmers (eight males and six females) were recruited from the national swimming team at the end of the third macrocycle (i.e., season´s peak performance) (Table 1). The swimmers had regular swimming (n = 9) and dry-land (n = 4) sessions per week, respectively. All procedures were in accordance with the Declaration of Helsinki and approved by the University Institutional Ethics Committee.

Table 1. Swimmers´ demographics.

	Overall (*n* = 14) M ± 1SD	Males (*n* = 8) M ± 1SD	Females (*n* = 6) M ± 1SD
Age (years-old)	21.15 ± 3.65	23.57 ± 3.21	18.33 ± 1.37
Body mass (kg)	70.34 ± 10.50	77.14 ± 7.81	61.28 ± 5.36
Height (m)	1.77 ± 0.10	1.83 ± 0.07	1.68 ± 0.06
Body mass index (kg/m^2)	22.38 ± 1.35	22.93 ± 1.36	21.64 ± 0.99
FINA points*	718 ± 85	764 ± 40	665 ± 95

Note: * in the 100m long course freestyle event.

Study procedures and sessions

The study comprised the attendance of the swimmers to the pool in three different days. All performed a low-intensity training in the two days before the assessments. In the first session anthropometrics was collected and fulfilled the medical examination. The swimmers arrived in a well-rested condition and did not show any symptoms of fatigue. Body composition (in kg) and height (in cm) were measured, and then asked, a few minutes later asked for health issues. The second session was used for dry-land strength and power testing using a progressive load test based on a full squat exercise and, few hours later for vertical jump tests. The third session was an in-pool session for the swimming starts testing.

Progressive loading test for full squat

A progressive loading test in a full squat exercise (Figure 1, panel A) was selected to estimate the maximal strength (Smax, in kg) of the lower limbs. A fixed smith-machine (Multipower Fitness Line, Peroga, Murcia, Spain) with a linear encoder attached (T-Force Force Measurement System, Ergotech Murcia, Spain) was used for that purpose. A standardised warm-up and five repetitions of full squats without load attached were initially done. The comprehensive description of the full squat test has been reported elsewhere (Sánchez-Medina et al., 2017). The swimmers started from an upright position descending in a continuous velocity until the posterior section of thighs and calves made contact, then inverting motion for the ascending phase until reach again the upright position. While the descending phase was done at a normal and controlled velocity, the ascending phase was asked to be done in maximal intended velocity. The initial load was set at 10 kg for all swimmers and was progressively increased by 10 kg, 5 kg and 1 kg until attaining a mean propulsive velocity (MPV) of ≤ 0.80 m/s (Marques et al., 2020). A 3-min rest was provided for light and medium loads, and 6-min for the heaviest one. Verbal cues were constantly delivered by evaluators to make sure participants would adhere to squat criteria during testing. The heaviest load properly lifted to the full extension of knees without external help was considered for further analysis. The Smax was estimated for each individual from the MPV attained against the heaviest load lifted in the progressive test as previously suggested (Sánchez-Medina et al., 2017): (100 × load)/(−5.961 × MPV2) - (50.71 × MPV) + 117.

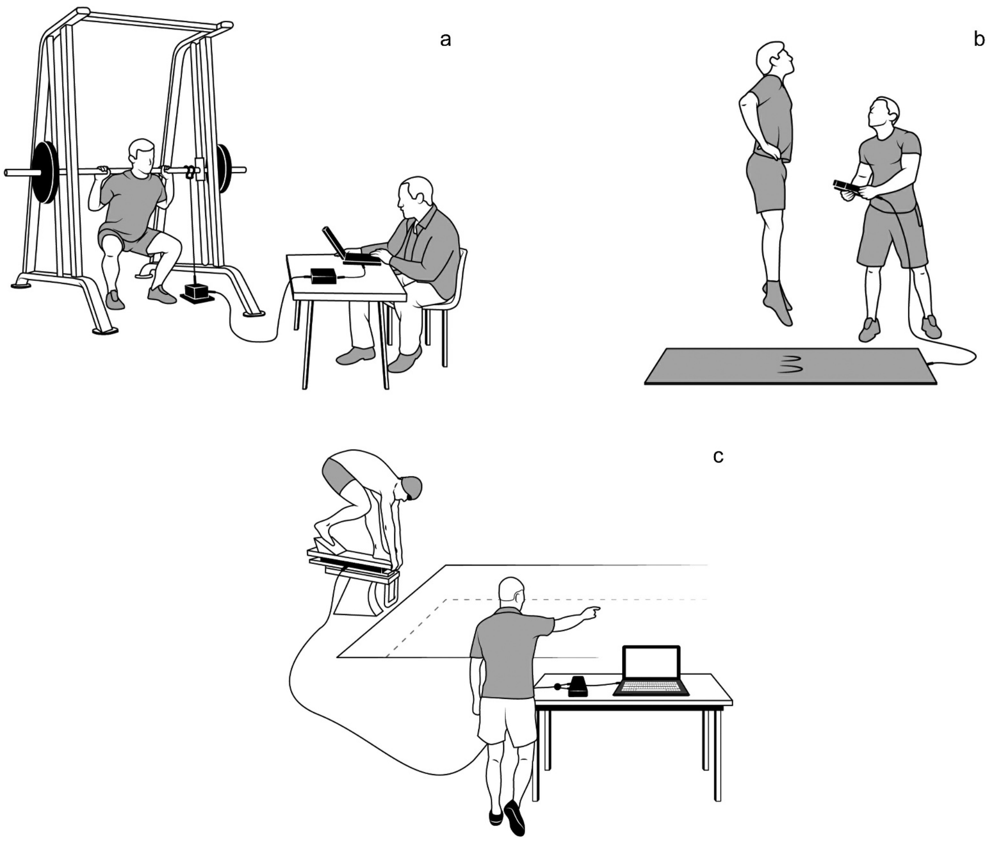

Figure 1. Dry-land exercises and in-pool start test. Panel A: progressive loading test for full squat (Smax); Panel B: vertical jump test (SJ and CMJ); Panel C: kick start technique.

Vertical jump test

The squat (SJ) and countermovement (CMJ) jumps (Figure 1, panel B) were chosen as part of the dry-land drills to evaluate the lower-limbs strength and power. Previous to testing, the swimmers performed a warm-up that comprised five SJ and CMJ (20s interval). Then, they were randomly assigned to perform three maximal SJ and CMJ on a contact mat (Ergojump Digitime 1000, Digest, Finland). Hands were kept on the hips and from a squat or upright initial position for the SJ or CMJ, respectively. A 2-min rest was employed between repetitions and 15-min between each test. The maximum height (in m) of the jumps (i.e., vertical displacement) was selected for further analysis.

In-pool start test

At the beginning of the session, all swimmers underwent a standardised warm-up at low intensity including starts as carried out as part of their competition routine. Thereafter, they were instructed to perform a set of three all-out kick starts as in an official race (2-min rest interval between trials). After the verbal cue 'take your marks', the starting signal was produced by a starter device (Alge Timing, Lustenau, Austria). The starting block (Omega OSB11) with a back plate (Figure 1, panel C) was used for the start. A dynamometric plate (Plux, Lisboa, Portugal) with a surface of 0.45 × 0.60 m, sensitivity of 2 N, error < 1% and a frequency of 500 Hz was mounted in the block platform, registering the force data from the front foot. A low-pass Butterworth of 100 Hz was used to filter force-time series. The peak forces (in N) in the three-dimensional axis (Fz, horizontal; Fy, vertical; Fx, lateral) were obtained from the best repetition and considered for further analysis.

Statistical analysis

Shapiro-Wilk and Levene tests were used to assess the normality and homoscedasticity, respectively. A log transformation (Log10) was performed if the assumption of normality was violated. Data were back transformed from the log scale for presentation in the results. Mean plus one standard deviation (M ±1SD) was computed as descriptive statistics and the dataset for each variable was split-up into three groups: overall ($n = 14$), males ($n = 8$), and females ($n = 6$). Unpaired t-test was used to verify mean differences between sexes. Cohen's d was selected as a standardised effect size (d) and interpreted as: trivial if $|d| < 0.2$, medium if $0.2 > |d| < 0.5$, and large if $|d| \geq 0.5$ (Cohen, 1988). Pearson Correlation Coefficient (r) between dry-land and start kinetic variables was calculated and interpreted as: high if $r \geq 0.60$, moderate if $0.30 \geq r < 0.60$, and low if $r < 0.30$ (Malina, 2001). All statistical analysis were performed in the SPSS software (v.27, IBM, SPSS Inc., Chicago, IL, USA) and GraphPad Prism (v.9, GraphPad Software, San Diego, CA, USA). The statistical significance was set at $p \leq 0.05$. The meaningfulness of the significance was treated as suggested by Winter (2008) and reported as 'meaningful'.

Results

Descriptive statistics for the pooled sample were 0.33 ± 0.06 m, 0.36 ± 0.07 m, and 48.64 ± 24.37 kg in SJ, CMJ, and Smax, respectively. Figure 2 depicts dry-land strength between sexes. Meaningful differences were found in SJ (Males: 0.36 ± 0.05 m, Females: 0.28 ± 0.04 m; $p < 0.01$, $d = 2.09$), CMJ (Males: 0.40 ± 0.06 m, Females: 0.30 ± 0.04 m; $p < 0.01$, $d = 2.02$) and Smax (Males: 64.88 ± 18.33 kg, Females: 27.00 ± 9.53 kg; $p < 0.01$, $d = 2.68$).

Descriptive statistics for swim start variables according to the pooled sample were 1001 ± 198 N, 628 ± 151 N, and 4 ± 6 N in Fz, Fy and Fx, respectively. The sex comparison is shown in Figure 3. Meaningful differences were found in Fy (Males: 724 ± 131 N, Females: 499 ± 24 N; $p < 0.01$, $d = 2.41$); whereas Fz (Males: 1072 ± 201 N, Females: 908 ± 162 N) and Fx (Males: 4 ± 7 N, Females: 4 ± 6 N) yielded no differences.

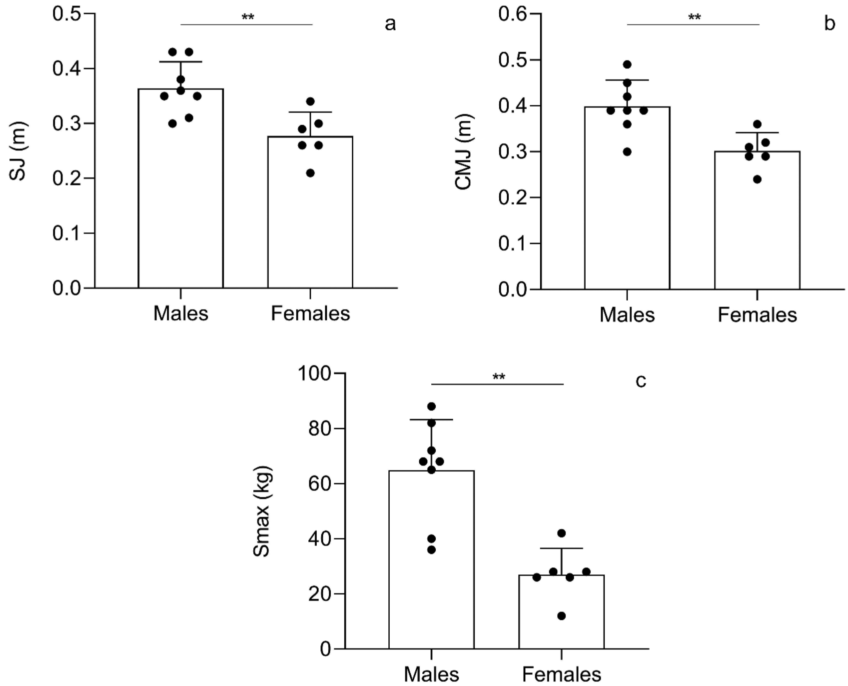

Figure 2. Comparison in dry-land strength tests between sexes. Panel A: squat jump (SJ); Panel B: countermovement jump (CMJ); Panel C: maximal strength in full back squat (Smax). *, p ≤ 0.05; **, p ≤ 0.01; m, metre; kg, kilogram.

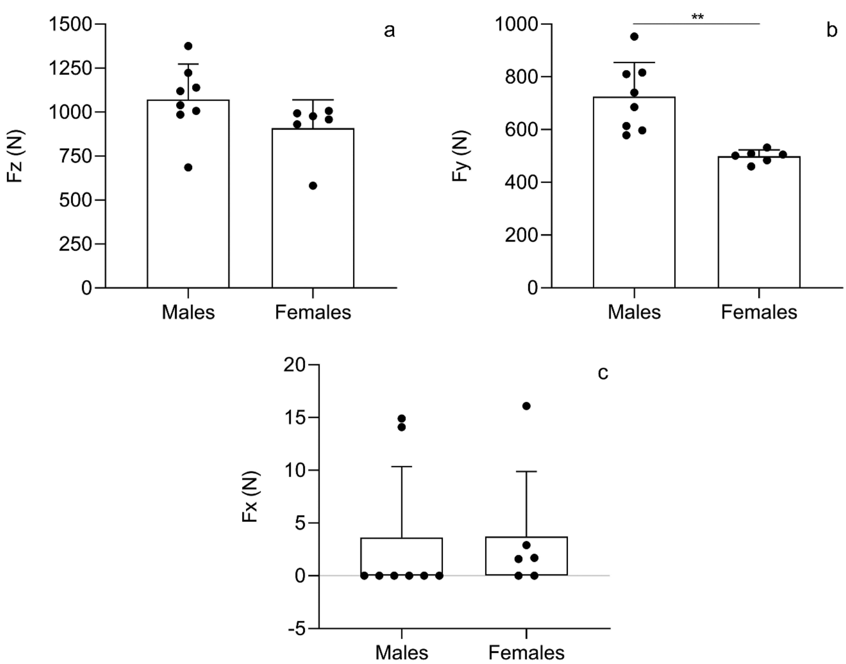

Figure 3. Comparison of swim start kinetics between sexes. Panel A: Fz, horizontal ground reaction force; Panel B: Fy, vertical ground force reaction; Panel C: Fx, lateral ground reaction force. *, p ≤ 0.05; **, p ≤ 0.01; N, Newton.

The Pearson Correlation Coefficients between dry-land strength and swim start kinetics (n = 14) showed moderate and significant associations between Fy and the lower-limbs strength power (SJ: r = 0.51, p ≤ 0.05; CMJ: r = 0.57, p ≤ 0.05). The Smax showed a high and significant association with Fz (r = 0.60, p ≤ 0.05) and Fy (r = 0.87, p ≤ 0.01). High and significant associations were also found between the Smax and both dry-land jumps (SJ: r = 0.78, p ≤ 0.01; CMJ: r = 0.79, p ≤ 0.01). However, no association was found between Fx and the remaining variables. Figure 4 displays the associations according to both sexes. Males had larger and significant associations between the Smax and Fy (Figure 4, panel A), whereas females had between the Smax and Fz (Figure 4, panel B).

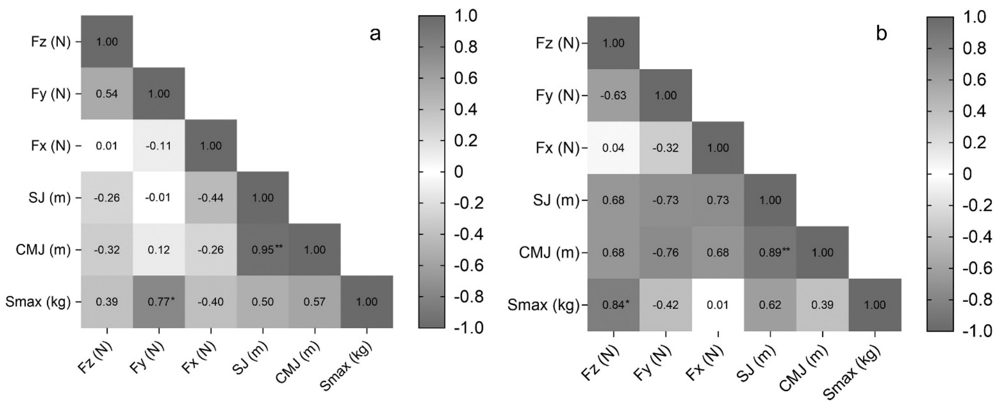

Figure 4. Pearson Correlation Coefficient (r) matrix between dry-land strength and swim start kinetics. Panel A: males (n = 8); Panel B: females (n = 6). Fx, horizontal ground reaction force; Fy, vertical ground force reaction; Fz, lateral ground reaction force; SJ, squat jump; CMJ, countermovement jump; Smax, maximal strength in full back squat; * p ≤ 0.05, **, p ≤ 0.01; N, Newton; m, metre; kg, kilogram.

Discussion and implications

The aim of this research was to determine the association between the lower limbs′ strength & power and kick start kinetics in elite swimmers. It was found that the full back squat is strongly associated with the kick start kinetics in both genders. While in males the full squat associates better with vertical component of the start, conversely, for female counterparts was the horizontal component.

Male swimmers included in this study showed a higher dry-land lower limbs strength than their female counterparts. This was somehow expected because it is consensual that men regularly show greater strength values than women in both land and water exercises (e.g., Morouço et al., 2015; Stoll et al., 2000). While in males there is a prevalence of type-II fibres with a faster contractile function, the women's expression is more related to type-I fibres translating into a slower contractile function (Bottinelli et al., 1996). Along this, testosterone (Cardinale & Stone, 2006) and body fat percentage (Caia et al., 2016) may help interpreting this favourable trend for males. Previous reports about explosiveness determined by ballistic actions like the countermovement jump (Hackett et al., 2021) or the back squat (Mehls et al., 2022), denoted a clear advantage for males comparing to females. Thus, the results in the present research are in agreement with previous findings.

The way how force was applied to the block also denoted that men were able to yield larger values. Men showed larger vertical peak forces than women. It is expected that men would translate better their strength ability showed in land for the start action. The swimmers that possess greater specific force development at absolute and relative levels on land, tend to be able to be faster at the 10 m mark after swim start (Beretić et al., 2013). The majority of the exercises used in this study for dry-land strength assessment encompass mostly vertical displacement by concentric muscle action. So, the result of vertical force component was expected to act as happens on dry-land scenario. At some point this vertical component of the start remains desirable to avoid a so short water entry.

There were no differences in the horizontal component of force, but males were prone to deliver more than females. Previous data already found that differences in start performance between males and females can be explained by differences in the horizontal velocity at toe off (Shepherd et al., 2021). Here it seems that the ability of males to use the block stage based on the Newton's third law is better than females. This is similar to what we experience for land-based vertical actions. Again, the muscle fibre typology (i.e., faster muscle type), which is highly relevant in men when compared to women (Mallett et al., 2021), may help explaining such actions. This translates into a better start when pooling together both vertical and horizontal components of force, leading into a greater aerial phase of the start and, as a consequence, a larger dive distance to make men faster than women until the 10 m mark (Beretić et al., 2013).

At the end there was an attempt to find the most appropriate and complete dry-land exercise that would explain the kick start kinetics. From the pooled sample the maximal estimated strength retrieved by the full squat showed an association with both horizontal and vertical force components. The jump height from the SJ and CMJ just showed association with the vertical force component. West et al. (2011) found similar results for the association between the two force components (Fz and Fy) and 1RM back squat in male international sprinters. Since the start depends on both vertical and horizontal peak forces generation (Burkhardt et al., 2020) we may say that the full back squat can be considered the most appropriate exercise to potentiate kick start orientation. This seems a similar behaviour to what high jumpers exhibit by translating the horizontal to vertical velocity in the high jump skill. In the case of swimmers, the squat exercise seems to provide a similar motor reorganisation and force generation during the block phase of the start.

It is worth noting that when considered the associations by sex the results showed that Smax had a high association with the vertical component in males, whereas for females was the horizontal component. It has been suggested that marginal improvements in the vertical component, rather than in horizontal one, might lead to an increase in swimming start performance (Cuenca-Fernández et al., 2019). Still, a vertical and horizontal symmetric profile in forces seems to be preferable to have an optimum projection angle to obtain a maximal horizontal displacement range (Mourão et al., 2015). Nevertheless, due to different strength profiles, it is expected that male and female swimmers utilise somewhat differing strategies during the swim start and may require a more individualised training for such purpose (Thng et al., 2020). Different muscular activations should be expected during the squat, by men recruiting the biceps femuralis in a greater extent than women (Mehls et al., 2022). The strength & conditioning professionals along with the swimming coaches should take some care when defining dry-land training strategies to potentiate the start. For instance, while the squat seems to be appropriate for males, this not seems to give so much benefits for females. This suggests that women probably require other dry-land exercises to potentiate the kick start orientation in the different force vectors.

Some limitations can point out new studies direction: (i) the small size of this convenience sample made only of international swimmers enrolled in a national team; (ii) not presenting the force data normalised to the swimmer's body mass; (iii) not reporting the start kinematics or a performance outcome, as for instance, the time at a given mark (e.g., 5 m mark); and (iv) not include a larger spectrum of dry-land drills to see associations with swim kinetics and performance.

Conclusion

The findings in the current study highlight the importance of specific dry-land exercises in the kick start kinetics in elite swimmers. The full back squat seems to be the dry-land exercise with highest association with the start. However, coaches should be aware that the squat exercise might potentiate different strength behaviours when males and females are considered in kick start analysis.

Disclosure statement

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