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A multivariate regression and discriminant canonical analysis of Isometric Mid-Thigh Pull performance in cadet inline speed skaters

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ABSTRACT

This study measured the peak force (PF) in cadet inline speed skaters (ISS) and verified the physical measures that determine athletes' performance on the Isometric Mid-Thigh Pull Test (IMTP) through a multivariate regression and discriminant canonical analysis. A total of 36 high-performance male (*n*= 18; age= 17.4± 1.21 years; body mass= 65.1± 6.18 kg; height= 168.6± 5.1 cm) and female (*n*= 18; age= 17.4± 1.23 years; body mass= 55.5± 4.4 kg; height= 158.6± 5.2 cm) athletes were measured two times (with a 3-day interval). All participants performed the IMTP and sit-and-reach (SR) tests, and an evaluator performed anthropometric circumference measurements on their thighs and calves. The main results indicated that males showed a higher PF on the test (*m*= 59.0± 3.9 N/kg vs. *f*= 50.4± 5.8 N/kg; $p \leq 0.001$) and retest (*m*= 59.1± 4.2 N/kg vs. *f*= 51.9± 6.6 N/kg; $p \leq 0.001$). In the first, thigh circumference (χ^2= 29.01, $p \leq 0.001$, *R2*= 0.74) had an overall 91.7% prediction. The second model included using the SR and thigh circumference (χ^2= 49.91, $p \leq 0.001$, *R2*= 1.0) showed an overall prediction of 100.0%. The thigh circumference matrix showed better predictive power for (coefficient= 7.158) male and female IMTP performance. In conclusion, despite the gender differences, the thigh circumference is a good predictor for PF in cadet ISS athletes.

KEYWORDS: speed skating; performance; isometric exercise; physical fitness testing; probabilistic models.

INTRODUCTION

Inline speed skating is a sport that has been gaining fans over the years and received many athletes at the last world competitions. However, scientific knowledge regarding the sport is still limited (Stangier et al., 2016a). The athletes must be fast, maintain muscle power, and show a high aerobic capacity to achieve competitive success (Stangier et al., 2016a; 2016b). However, the analysis of specific characteristics regarding their specialized sport could help training prescriptions because a sprinting competition lasts approximately 16-18 seconds (200 m). In contrast, a marathon lasts between 60-70 min (Stangier et al., 2016b). Despite limited specific scientific literature regarding this sport, some authors have indicated that physiological, biomechanical (Wu, Hsu, Chu, Tsai, & Liang, 2017), and anthropometric measures (Knechtle, Knechtle, Rüst, Rosemann, & Lepers, 2012) can determine competitive success in ISS.

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Foster et al. (1999) showed that aerobic capacity alone does not determine competitive success in ISS, requiring specific strength work on the lower limbs to improve competitive performance (Juda, Yuki, Aoyanagi, Fujii, & Ae, 2007; Piucco, Santos, & Lucas, 2014; Stangier et al., 2016a, 2016b). Besides, higher strength levels enhance technical performance and result in competitive advantage (Yugay, 2015). Despite the importance of strength for ISS performance, few studies have investigated this variable, and the protocols did not measure power in the athletes of this sport (Piucco et al., 2014).

Among the methods used to measure strength, the Isometric Mid-Thigh Pull Test (IMTP) is valid and is potentially accurate (De Witt et al., 2018) for assessing maximal force (Dos'Santos et al., 2019). The peak force (PF) variable is a practical and more effective test than the 1-MR test (Townsend et al., 2019). Furthermore, the PF measured by the IMTP has been correlated (r= 0.704) with the sprinting ability (Townsend et al., 2019) and agility (r= -0.854) in other sports (Spiteri et al., 2014). However, to the best of our knowledge, no study has measured this variable in ISS. It is unknown what variables determine the PF in this group of athletes or gender differences. The results presented in this study can help coaches build specific and contextualized programs for athletes of this sport and learn which physical measure can predict PF in cadet ISS athletes. Therefore, the present study aimed to a) measure the PF in male and female cadet ISS athletes; and b) verify the physical measures which determine the performance of cadet ISS athletes on the IMTP through a multivariate regression and discriminant canonical analysis. We hypothesize that anthropometric measurements can determine the IMTP.

METHODS

This study employed a test-retest design in which all participants performed two testing sessions separated by three days to analyze reliability and the impact of anthropometric characteristics and low-back and hamstring flexibility on the PF registered with the IMTP. The sit-and-reach test (SR) assessed flexibility, and the present study measure anthropometric variables: height, body mass, thigh, and calf circumference. Figure 1 shows the data collection chart.

Participants

Before the assessments, all participants were informed about the study's purpose and signed an informed consent form. The Local Scientific Ethics Committee approved the present research (protocol 79/2019). The inclusion criteria applied were: ≥ 3 years training; b) international competition experience; c) 6 days training/wk. d) ≥ 2 h/day. The exclusion criteria of athletes were: a) to present an injury which affected performance in the tests or participation in training; b) to be not able to complete all procedures and measures. The sample size was based on a previous study (Townsend et al., 2019). The required sample was 16 athletes in each group with 0.8 as the probability (power), 0.05 as type I error probability. The sample size was inflated by 10% to compensate for the dropouts. As a result, the final sample was composed of 36 cadet ISS athletes from a national team to participate in this study: n= 18 males (age= 17.4± 1.21 years; body mass= 65.1± 6.18 kg; height= 168.6± 5.1 cm); and n= 18 females (age= 17.4± 1.23 years; body mass= 55.5± 4.4 kg; height= 158.6± 5.2 cm).

Anthropometry

The anthropometric assessment performed included the following measurements: height with 1-cm precision (Stadiometer 222, Seca®, UK), body mass with 100-g precision (Digital Scales 878, Seca®, UK), thigh (midpoint between the inguinal fold and the anterior patella surface) and calf (most prominent point of the muscle) circumferences (anthropometric tape 203, Seca®, UK). Circumferences were corrected through ISAK equations to exclude adipose tissue, following the protocol described by Marfell-Jones, Stewart, and De Ridder (2012).

Sit-and-reach test

The SR was employed to assess the flexibility of the lower back and hamstrings. Although several test variations have been developed, we applied the classical test sit-and-reach test, since this test has been used in younger populations with almost perfect reliability (Henriques-Neto, Minderico, Peralta, Marques, & Sardinha, 2020). Participants sit up on the floor

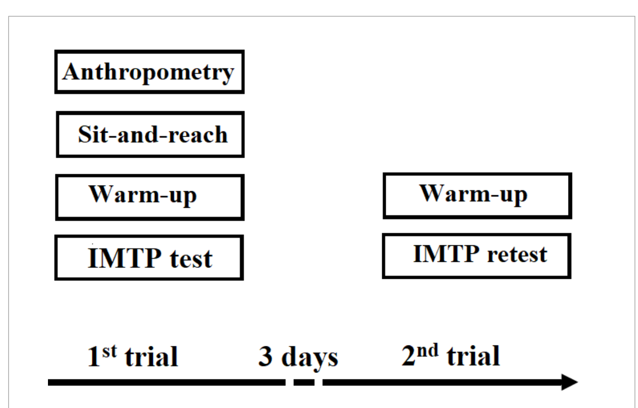

Figure 1. Chart of procedures and data collection.

with their knees extended and hips flexed 90º, placing their feet against the SR box test with dimensions: 76.2 × 33.0 × 10.2 cm (Model 12-1086, Baseline®, Fabrication Enterprise, UK). Participants had to flex their hips and trunk from the initial position, pushing the measurement board forward while maintaining both knees extended and staying in contact with the box. Researchers registered the farthest line reached of athletes with both hands. Two trials were performed in which the distance had to be maintained for at least two seconds to be valid. Preceding reports (Patterson, Wiksten, Ray, Flanders, & Sanphy, 1996) indicated an almost perfect correlation between the Sit-and-reach test and retest (*ICC*= 0.99, *p*≤ 0.001).

Isometric Mid-Thigh Pull test

The IMTP was used to assess lower-limb maximal PF. This test was performed on two portable force plates (type= PS-2142; sampling= 50-1,000 Hz; Range= -1,000 to 4,400 N over 6,600 N; Resolution= 0.34 N; dimensions= 350 mm × 350 mm, PASCO® Instrument Inc., USA) which were placed on a portable IMTP rack where the bar height could be adjusted (4 cm increments) at various heights above the force plate to adjust to each participant's height (Peterson Silveira et al., 2017). The sampling was set at 1,000 Hz since it has shown good reliability in force-time variables (Dos'Santos et al., 2019). The initial position was individualized to each athlete, grasping the barbell straight but with arms relaxed, setting the barbell at their mid-thigh height with a hip flexion angle between 140-145° and knee flexion angle between 125-145º while maintaining the trunk upright (Drake, Kennedy, & Wallace, 2017).

The athletes performed a warm-up and familiarization with the IMTP test before testing, which was divided into three phases: general warm-up, dynamic warm-up, and specific warm-up, according to (Comfort et al., 2019). All athletes received standard instructions for the test, which was to pull "as fast and hard as possible and push their feet directly into the force plate" (Halperin, Williams, Martin, & Chapman, 2016). A minimal pre-tension was allowed before they started (< 50 newtons above their body weight) to ensure there was no slack in the body before the first pull (Comfort et al., 2019). Once the body position was verified, the test was started with the sign of "3, 2, 1, pull," and maintaining the maximal effort for five seconds. They were verbally encouraged during the test to enhance the maximal effort. Figure 2 shows the correct starting position for performing the IMTP.

The present research examined the reliability of IMTP, verifying the association between a test and retest with three days between them (Drake et al., 2017). The intraclass correlation coefficient (ICC) and Pearson correlation verified the association between the test and retest. The coefficients assume values between -1 and 1, as the closer, it gets to 1, the more concordance will exist between tests for IMTP. Correlation analysis indicated a strong correlation between the IMTP test and retest (*r*= 0.84, *IC*= 0.95, *p*≤ 0.001).

Experienced analysts collected the vertical ground reaction force data during ten seconds of each trial using the Capstone 2.0 program (Pasco company, California, United States). After that, researchers calculated the PF and normalized to athletes' body mass, using the MATLAB (MathWorks®, Inc., Natick, Massachusetts, United States). The athletes performed two trials with a 3-minute interval. The present research uses the best result between the two attempts for the analyzes. A cut-off point of intraclass correlation coefficient (*ICC*= ≥ 0.7, *p*≤ 0.001) between test and retest was used for internal validation as maximum effort performed, as suggested by Drake et al. (2017). Those with ICC< 0.7 repeated the tests on another day.

Statistical analysis

Descriptive data are presented as mean and standard deviation (SD) values, and the Student's t-test was conducted to compare dependent variables between male and female athletes. Furthermore, a multivariate logistic regression analysis was used to confirm the effects of dependent variables on the dichotomous variable gender (male vs. female). In addition, a discriminant analysis was employed to verify the predictor variables (pooled within-groups matrices of correlations), and a summary of canonical discriminant

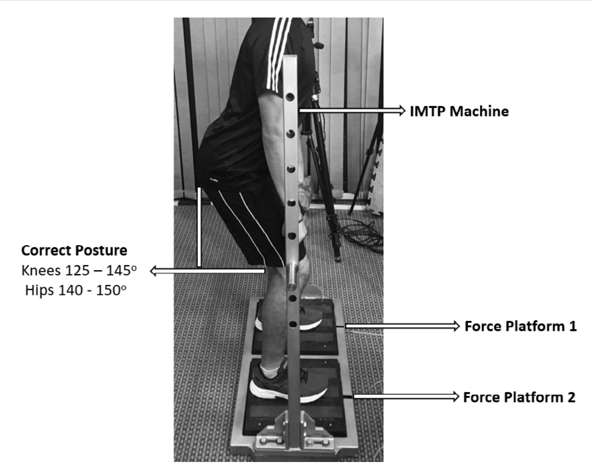

Figure 2. Starting position to perform the Isometric Mid-Thigh Pull test (IMTP).

function was performed. A significance level of $p \leq 0.05$ was used. All analyses were conducted using SPSS 20.0 for Windows.

RESULTS

Analysis indicated a significant and moderate correlation between the IMTP with Thigh circumference (r= 0.52, $p \leq$ 0.001) and Calf circumference (r= 0.42, p= 0.011). Table 1 shows the descriptive and inferential analysis of IMTP performance in male and female cadet ISS athletes.

The multivariate logistic regression analysis of IMTP performance in male and female cadet ISS athletes was composed of four steps. We only included significant models in the results. The first model used thigh circumference (χ^2= 29.01, $p \leq$ 0.001, $R2$= 0.74) and had an overall prediction of 91.7% (88.9% male and 94.4% for female). The second model included showed the SR test and thigh circumference (χ^2= 49.91, $p \leq$ 0.001, $R2$= 1.0) as prediction variables with an overall prediction of 100% (100% male and female). Table 2 shows the significant models obtained by the multivariate logistic regression analysis.

Table 3 shows the matrix correlations between the anthropometry and physical tests and canonical coefficients. The main matrices showed a better predictive power for thigh circumference (coefficient= 7.158), as this measurement showed a higher predicting value for the models presented in Table 2.

DISCUSSION

The IMTP measures the PF, and the results of this test are associated with sprinting (Brady, Harrison, Flanagan, Haff, & Comyns, 2019) and lower limb agility performance (Thomas, Comfort, Jones, & Dos'Santos, 2017). Thus, we believe that the IMTP can be a good predictor of performance in ISS. However, to the best of our knowledge, no studies have been performed using this measure in male and female ISS athletes. The present study measured the PF in cadet ISS athletes and performed an analysis to learn the physical tests which determine the IMTP performance in cadet ISS athletes. The main results indicated significant differences between female and male athletes for all variables, except for the SR. A multivariate logistic regression analysis revealed thigh circumference as the main factor in predicting

Table 1. Descriptive analysis and t-test of Isometric Mid-Thigh Pull performance in cadet inline speed skating athletes separated by gender.

Measure	Gender	Mean± SD	T	p-value	95%CI (Lower; Upper)
IMTP Test PF (N/kg)	Male	60.6± 3.8	0.23	≤ 0.001	(5.3–12.0)
	Female	52.6± 5.9			
Sit-and-reach test (cm)	Male	17.9± 5.1	0.86	0.398	(-5.6–2.3)
	Female	19.6± 6.5			
Thigh circumference (cm)	Male	53.2± 2.8	0.44	0.002	(1.2–4.7)
	Female	50.3± 2.3			
Calf circumference (cm)	Male	33.0± 1.5	0.13	≤ 0.001	(1.6–3.6)
	Female	30.5± 1.7			

SD: standard derivation; IMTP: Isometric Mid-Thigh Pull; PF: peak force; 95%CI: 95% confidence interval.

Table 2. Multivariate logistic regression analysis between gender, sit-and-reach test and Isometric Midthigh Pull performances.

Model	Predictor	B	SE	Wald	F	P-value	Exp (B)	95%CI for EXP (B)	
								Lower	Upper
1	Thigh	0.5	0.216	6.165	1	0.013	0.584	0.383	0.893
	Constant	4.7	10.2	5.866	1	0.015	55.7×10^9		
2	Sit and reach	1.6	771.8	0.002	1	0.967	50.8×10^{12}	0.0	
	Thigh	50.7	1.231	0.002	1	0.967	0.0	0.0	
	Constant	1,713	41.810	0.002	1	0.967			

B: regression coefficient; SE: standard error; DF: degrees of freedom; Exp (B): exponentiation of B; 95%CI: 95% confidence interval.

Table 3. Pooled within-groups matrices of correlations, standardized canonical discriminant function coefficients and the structure matrix.

	IMTP retest	Sit-and-reach	Thigh circumference	Calf circumference
IMTP test PF	0.63	0.112	0.11	-0.036
Sit-and-reach			0.285	0.45
Thigh circumference				0.105
Standardized Canonical Discriminant Function Coefficients			Structure Matrix	
Predictors	Function		Predictors organized by absolute size	Function
	1			1
IMTP test	0.797		IMTP test	0.36
Sit-and-Reach	-0.717		Sit and Reach	0.341
Thigh circumference	7.158		Thigh circumference	0.343
Calf circumference	-0.24		Calf circumference	-0.033

IMTP: Isometric Mid-Thigh Pull; PF: peak of force.

gender differences of IMTP performance in cadet ISS athletes, differentiating male and female groups. The strength levels are directly related to this sport (Stangier et al., 2016a, 2016b), mainly of the thigh and gluteus muscles (Stangier et al., 2016b). To the best of our knowledge, this is the first study to measure IMTP in ISS athletes. Our results showed an anthropometric performance predictor (thigh circumference), which can be monitored by coaches. We emphasize that there is a limitation in our study regarding the use of our results. We did not measure competitive performance. However, the PF is a performance indicator in sports that require speed (Brady et al., 2019), agility, strength (Thomas et al., 2017; De Witt et al., 2018; Townsend et al., 2019), and muscle power (Townsend et al., 2019).

Furthermore, in sports for which the ability to sprint is a differential in the athlete's performance (Beckham et al., 2013; Brady et al., 2019), such as rugby, weightlifters (Beckham et al., 2013), and sprint cycling (Stone et al., 2004), PF has proven to be able to differentiate athletes regarding the competitive level. Stone et al. (2004) observed that the strongest athletes in cyclists of the national team had significantly higher PF (4,590± 314 vs. 2,551± 466 N) compared to the weakest, and the faster athletes also showed a significant difference (4,164± 803 vs. 2,795± 528 N) versus the slowest. Through these results, we believe that ISS athletes can also have a direct relationship between performance level and PF in IMTP.

Previous studies in ISS have directed attention to biomechanical and anthropometric indicators, determining the performance (Knechtle et al., 2012; Stangier et al., 2016b). Juda et al. (2007) demonstrated a relationship between technical aspects and the increase of aerodynamics. In contrast, findings indicated that plantar pressure could determine the foot and ankle's best angle, which results in increased speed (Wu et al., 2017). Anthropometric measures (Knechtle, Knechtle, Rosemann, & Lepers, 2010) in ISS athletes observed that the leg's height and length (r= 0.61 for both variables) have a direct association with the competitive performance. However, another study by the same group of researchers indicated that anthropometric variables could not predict ISS (Knechtle et al., 2012). The present research suggests further investigations about the relationship between ISS specific movements and IMTP performance, considering female and male athletes.

Few studies have observed the predictive capacity of anthropometric indicators and the PF in IMTP. McMahon, Stapley, Suchomel, and Comfort (2015) observed that the thickness of the dominant leg's vastus lateralis in male college athletes is directly related to the performance in IMTP (R^2= 0.38). In this same line, Secomb et al. (2015) observed a correlation between IMTP and vastus lateralis thickness (R^2= 0.45), vastus lateralis pennation angle (R^2= 0.21), and lateral gastrocnemius (R^2= 0.29) in adolescent surfers (male and female). An increased pennation and thickness of vastus lateralis enable higher lower limb strength and muscle power. There will be a higher number of sarcomeres and cross-bridges, which increases muscle strength (Secomb et al., 2015).

Still, regarding the prediction models, the second significant variable (Table 2) showed that the sit-and-reach test associated with the thigh circumference could increase the prediction for IMTP, regardless of gender. Studies have shown that the hamstrings' flexibility levels can increase or decrease the lower limb power (Aguilar et al., 2012; Medeiros, Cini, Sbruzzi, & Lima, 2016) because the shortening affects the quadriceps extensibility (Aguilar et al., 2012). As hamstrings are a muscle that is favourable to shortening, coaches must monitor this measurement. Besides, there is a higher risk of injury in athletes with hamstring shortening (Medeiros et al., 2016). Our results indicated no differences between genders, but the means were lower than those observed in other elite athletes (Aedo-Muñoz et al., 2019).

The calf circumference was not predictive in any model. In contrast, Mishra and Chahal (2013) analysis indicated a positive correlation (*r*= 0.48) between calf circumference and lower limb power in male throwers. Among the limitations of the present study is the absence of direct performance in ISS competition and the lack of analysis separated in a sprinter and long-distance ISS athletes. Future studies can measure how IMTP can predict competition performance. Furthermore, the progress of ISS science can help coaches of other sports, since even though the characteristics of ISS are not entirely transferable (Piucco et al., 2014), it can be a training alternative for skiing athletes in seasons without snow (Piucco et al., 2014; Stangier et al., 2016b).

Practical application

This study was the first to show these results in ISS. Statistical analysis demonstrated significant differences between female and male athletes in peak power, associated with lower limbs' circumference, inversely to flexibility. The evidence presented here may be applied in new investigations to establish the thigh circumference cut-points to estimate the IMTP performance. IMTP demonstrated high reliability and accuracy between test and retest with a practical application for ISS institutions. Furthermore, for coaches in general, we recommend that thigh circumference be used in initial evaluation to verify the real PF and PF's respective prediction, which can be a simple and effective indicator for potential talent in ISS athletes. Our study's main advantage measured the thigh circumference, which is more comfortable and more accessible to coaches and athletic commissions. Thigh circumference was the primary variable and had the most extensive coefficient matrix in our two prediction models.

CONCLUSIONS

Based on our aims, methods, and results, we can conclude those male athletes showed a higher PF and thigh circumference as the main factors to predict gender differences of IMTP performance in cadet ISS athletes.

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