Physiological and technical commitment during a 300-m in-line skating trial in athletes of different age categories

Pietro Luigi INVERNIZZI[1], Raffaele SCURATI[1], Matteo CROTTI[1], Andrea BOSIO[2], Stefano LONGO[1*], Fabio ESPOSITO[1]

[1]Department of Biomedical Sciences for Health, Università degli Studi di Milano, Via G. Colombo 71, 20133 Milan, Italy.

[2]Human Performance Laboratory, Mapei Sport Centre, Via Busto Fagnano 38, 21057 Olgiate Olona (Va), Italy.

*Corresponding Author:
Dr. Stefano Longo, PhD
Department of Biomedical Sciences for Health
Università degli Studi di Milano
Via Kramer 4/A
20129, Milan, Italy
Phone: +39-02-5031 5166
Fax: +39-02-5031 4630
E-Mail: stefano.longo@unimi.it

Keywords: Motor control-Training-Strength-Skill

ABSTRACT

BACKGROUND: This study investigated the differences in strength, technique and time performance in in-line skaters of three age categories during a 300 m trial. Possible correlations among these variables were also assessed.

METHODS: Thirty-six elite in-line skaters (Cadets, Juniors and Seniors, n=12 each; 14±1, 16±1, and 24±6 years of age, respectively) performed a 300-m trial on an outdoor oval track. Total time (T_{tot}), 100-m fractions and duration of each skating technique (initial acceleration phase, straight push and cross-over) were recorded. A squat jump (SJ) was performed before and after the trial. Heart rate, blood lactate concentration ($[La^-]$) and rate of perceived exertion (RPE) were collected before, during and at the end of the trial.

RESULTS: T_{tot} was longer and SJ lower in Cadets compared to the other groups. Seniors employed the cross-over technique for a longer period than the straight push technique, compared to Juniors and Cadets. T_{tot} correlated negatively with SJ in Seniors. The number of significant correlations between skating techniques' duration and both T_{tot} and SJ increased with age category. No differences among groups were found for heart rate, $[La^-]$ and RPE.

CONCLUSION: With increasing age category, leg strength appeared to be the more related aspect to skating performance. To improve 300-m in-line skating performance, trainers should pay particular attention to the enhancement of leg strength and cross-over skating technique.

Short title: Performance characteristics of in-line skating

TEXT

Introduction

In-line skating is a sport similar to ice skating and it is held either in 200-m tracks or in road circuits. Skating performance is influenced by many factors comprising strength, technique, pacing and level of experience.[1–4]

High levels of maximum strength of the lower limbs are necessary in this discipline as skaters assume a markedly squatted position to reduce of air friction, with small angles at both the hip and knee joints.[5,6] Skaters with higher strength and explosive power of the lower limbs perform better in terms of skating time and speed.[2,7] The prolonged muscle contraction imposed by the squatted posture induces also a blood flow restriction in the muscles,[8] as supported also by near infrared spectroscopy studies.[9] Consequently, blood lactate concentration ($[La^-]$) is higher in skating than in running at similar exercise intensity.[10]

In addition, skating technique plays a key role in determining skating performance. The propulsive actions during the straights of the track (straight push technique) are characterized by a marked abduction and external rotation of both lower limbs.[11] During the curves, when a cross-over technique is utilized, different involvement of the two lower limbs occurs, characterized by higher contraction intensity of the external lower limb and different ability in stabilizing the knee and ankle joints between the two limbs.[12] Consequently, the straight push and cross-over techniques imply different motor control requirements.[6]

Pacing strategy can widely affect performance during a race. The typical sprint race of in-line skating spans over 300 m and lasts less than 30 seconds. In events of this duration, an all-out strategy is usually applied.[3,13] This race is characterized by an initial acceleration phase followed by three sectors in which the cross-over and the straight push are adopted in sequence (Figure 1). Therefore, sudden transitions from straights to curves and *vice versa* imply quick changes from a straight push to a cross-over technique.[12] This can imply different modulation of trajectories and time spent in each of these sectors, defining a distinctive pacing strategy in this discipline to win the competition.

Physiological aspects and technical features during skating widely differ between beginners and elite athletes, suggesting that also the level of experience may affect skating performance.[4,5] In sport activities, motor development progressively switches and narrows from an initial technical learning (6-12 years) to a specific practice activity (13-15 years) and development of expertise (from 16 years on), as a function of age and level of experience.[14] Similarly, somato-functional maturation contributes to the increase in maximal force development during a specific action.[15]

However, strength and technique characteristics and their relationship with performance at different level of experience have never been investigated in in-line skating. Therefore, the study aims at assessing differences in strength, duration of each skating technique and time performance in three age categories during a 300-m race. Possible correlations among these variables were also assessed.

We hypothesized differences among age categories in the investigated parameters due to the maturation process and specific expertise. For the same reason, possible correlations among strength, technique, pacing strategy and time performance were also expected.

Material and Methods

Study design

This was a cross-sectional study testing three different age groups on their best 300 m performance trial. All participants underwent a familiarization and a testing session separated by at least one week. Both sessions were performed during spring on an outdoor oval track (length = 200 m; radius of curvature = 15 m; Durflex® 101 sp roller professional road rink, Monsano, Italy) used by the Federazione Italiana Hockey e Pattinaggio (FIHP) and the Fédération Internationale Roller Sports (FIRS) for official competitions. Participants were asked to abstain from training and heavy exercise for 48 hours prior to the testing session, to avoid ergogenic beverages, and to keep their usual diet on the day of the test. Tests were conducted in the afternoon of sunny days without wind to avoid the influence of circadian rhythms and climate. Anthropometric (body mass and stature) and resting heart rate (HR) measurements were carried out before the warm-up, consisting in 10 minutes of general warm-up of the lower limbs followed by 5 minutes of cool-down. Three squat jumps (SJ) were then performed. After the squat jump measurements, a specific 10-min warm-up with skates was conducted on the oval track, followed by 5 minutes of cool-down. A 300-m time trial was then completed. Immediately post-trial (within 1 minute), the perception of effort was asked to the participants using the CR-10 Borg scale.[16] Blood samples were collected from the ear lobe 1, 3 and 6 minutes after the end of the trial to determine [La^-]. Following the first blood sample collection a SJ test was performed to assess the presence of peripheral fatigue. The whole testing session lasted about 50 min. The experimental timeline is represented in Figure 2A.

*** Figure 1 about here ***

Participants

Thirty-six male in-line skaters volunteered for this study. Their anthropometric and physical characteristics are shown in Table 1. Participants were specialized in 300-m distance and ranked in the first 5 positions at regional level and in the first 10 positions at Italian national level. Following the rules of the Federazione Italiana Hockey e Pattinaggio,[17] skaters were drawn from three different age categories: Cadets (n=12, eight years of competition experience), Juniors (n=12, 10 years of competition experience), and Seniors (n=12, more than 12 years of competition experience). Before testing, all the procedures were accurately explained to the athletes and an informed consent form was signed by each participant over 18 yrs and by a parent for athletes < 18 yrs. The study was conducted in accordance with the declaration of Helsinki and was approved by the local university ethics committee.

Procedures

Skating performance

The 300-m time trial adhered to the FIHP rules. Skaters wore their own in-line rollers and were instructed to cover the 300-m distance as fast as possible. Each participant was instructed as follow: "Perform the trial as fast as you can until the end, following the competition rules". The starting position was standing with both rollers on the ground. When ready, they started and skated for 1.5 laps for a total distance of 300 m. As shown in Figure 2B, the starting and finish points did not correspond. No feedback on the performance was given to avoid competition among athletes. The total time of the 300-m trial and its 100-m fractions were recorded by using a two-photocell system (Racetime2, Microgate®, Bolzano, Italy). The first photocell was placed at the starting line to record the start and the time at 200 m (T_{0-200}); the second one was placed at the end of the track to record the time at 100 m (T_{0-100}) and at the end of the trial (T_{tot}). The time between 100 and 200 m ($T_{100-200}$), 200 and 300 m ($T_{200-300}$), as well as the time of the last 200 m (the so-called "flying lap") were also calculated (T_{FL}). The trial was also recorded by two fixed camcorders positioned outside the track (300 frames·s^{-1}, Everio GZ-EX315SEU full HD, JVC, Yokohama, Japan,) to assess the duration of each skating technique. The first one was mounted on a tripod placed at the beginning of the first curve and the second one at the beginning of the second curve (Figure 2B) so that the entire trial was recorded.

*** Figure 2 about here ***

Squat Jump (SJ)

SJ was conducted using an optical measurement system (Optojump, Microgate, Bolzano, Italy; accuracy ± 0.001 s), which can record flight time. The height of the jump was indirectly calculated based on flight time.[18] Participants squatted down until the knees were bent at 90°. The knee angle was checked using a manual goniometer and the full knee extension was assumed to be 0°. Operators firmly encouraged participants to jump as high as possible and to land approximately at the point of takeoff. Three consecutive trials interspersed by 1-min recovery were performed before the skating time trial. The best SJ (SJ_{pre}) was considered for further analysis. At the end of the 300-m time trial, a single SJ was performed (SJ_{post}).

Heart Rate (HR)

Participants wore a HR monitor (Polar® Team[2] Pro, Kempele, Finland) during tests. Each participant lied down for 10 min to allow HR measurement at rest (HR_{rest}) defined as the minimum HR during the 10-min time. HR was also monitored during the skating trial and peak HR was used for the analysis.

Blood lactate concentration ($[La^-]$)

Arterialized blood samples (5 µl) were collected from the ear lobe at minute 1, 3 and 6 after the 300-m time trial. Samples were immediately analyzed using a portable system (Lactate Pro LT-1710, Arkray, Japan) to determine peak [La^-].

Rate of perceived exertion (RPE)

Participants were asked to rate their perceived effort immediately after the 300-m time trial using the Borg Category Ratio (CR–10) scale, with anchors 0: No exertion and 10: Maximal exertion; or even more (e.g., 11), giving the opportunity to rate a perceived exertion higher than the maximum ever experienced.[16] All the participants were familiarized to the use of the CR 10 scale using standard procedures.[19]

Duration of skating techniques

The recorded 300-m time trial was analyzed by using a free open source video analysis software (Kinovea software, v. 0.8.15). The duration of each different skating technique (acceleration phase, cross-over and straight push) was calculated. For the acceleration phase, the time between the start and the last straight step was considered (T_{acc}). For the cross-over, the time between the first cross-over step and the last one was calculated. Thereafter, the total time spent using the cross-over technique (T_{coTot}), the time of the first, second and third portions in cross-over (T_{co1}, T_{co2}, T_{co3}, respectively) were calculated. Likewise, the time between the first straight step after the cross-over phase and the last straight step was considered. The total time spent using the straight push technique (T_{spTot}), and the time of the first, second and third portions in straight push (T_{sp1}, T_{sp2}, T_{sp3}, respectively) were calculated. Each duration was represented as percentage of T_{tot}. The acceleration phase is present only at the beginning of the 300-m time trial when the athletes, from a standing and still position, have to start and gather speed. The cross-over and straight push techniques are used during skating in a curve or straight respectively.

Statistical analysis

The Statistical Package for Social Sciences 20.0 software (SPSS, Inc., Chicago, IL, USA) was used for statistical analysis. Based on a pilot study, a sample size of 36 participants was selected to ensure a statistical power higher than 0.80 with a type 1 error <0.05. The normal distribution of data was checked by the Shapiro-Wilk's test. Differences in groups' age, anthropometric characteristics and years of practice were analyzed by one-way analysis of variance (ANOVA) with Bonferroni's post-hoc. A series of one-way analysis of covariance (ANCOVA) using age, body mass and years of practice as covariates, were applied to assess differences among groups in skating performance, SJ pre-post difference (SJ_{delta}) (*SJ height at baseline - SJ height 1 min after the 300 m*), heart rate, RPE and duration of skating sector techniques. Bonferroni's post-hoc analysis was conducted for pairwise comparisons. In addition, a repeated ANCOVA and a paired samples Student's *t*-test with Bonferroni's post-hoc correction was used to compare the difference between SJ before and after the 300 m test. Partial correlations between performance and analyzed variables were assessed by Pearson's product-moment correlation coefficient (r) within each age category.

Correlations including all the participants (irrespective of the age category) were carried out to explore relations between skating performance and SJ, skating performance and techniques, skating techniques and SJ. According to Cohen,[20] correlations equal or higher than 0.5 were considered large, correlations between 0.5 and 0.3 were considered moderate, correlations between 0.3 and 0.1 were considered small and correlations lower than 0.1 were considered insubstantial. For the pairwise comparisons, Cohen's *d* effect size (ES) was also calculated with 95% confidence intervals (C.I.) and considered as trivial for ES values <0.2, small between 0.2-0.6, moderate between 0.6-1.2, large between 1.2-2.0, and very large when >2.0. Partial eta squared (η^2) was used as measure of effect size for the ANOVA and ANCOVA. The level of significance was fixed at $\alpha < 0.05$. Unless otherwise stated, results are expressed as mean ± SD.

Results

Groups' characteristics

As expected, one-way ANOVA revealed that the three groups presented significant differences in age (F_2=25.96, P<0.001, η^2=0.61) and body mass (F_2=17.92, P <0.001, η^2=0.52). For age, post-hoc analysis highlighted significant differences between Cadets and Juniors (P<0.001, ES=3.35, C.I.=2.02–4.45), Cadets and Seniors (P<0.001, ES=2.29, C.I.=1.20–3.23), and Junior and Seniors (P<0.001, ES=2.48, C.I.=1.19–3.22). For body mass, post-hoc showed significant differences between Cadets and Juniors (P=0.023, ES=1.46, C.I.=0.52–2.31), Cadets and Seniors (P<0.001, ES=2.48, C.I.=1.19–3.22), and Juniors and Seniors (P=0.008, ES=1.17, C.I.=0.26–1.99). Moreover, stature was significantly different among groups (F_2=6.64, P=0.004, η^2=0.29), with post-hoc analysis revealing differences between Cadets and Juniors (P=0.04, ES=1.59, C.I.=0.55–2.35), and Cadets and Seniors (P=0.004, ES=1.33, C.I.=0.40–2.16), without significant differences between Juniors and Seniors (P=1.00, ES=0.33, C.I.=-0.48–1.13). BMI was not significantly different among groups (F_2=3.03, P=0.062, η^2=0.15). Years of practice were significantly different among groups (F_2=30.2, P<0.001, η^2=0.65), with post-hoc analysis showing differences between Cadets and Seniors (P<0.001), Juniors and Seniors (P<0.001), but not between Cadets and Juniors (P=0.12). Data are reported in Table 1.

*** Table 1 about here ***

Skating performance

The one-way ANCOVA revealed significant differences among groups in T_{tot} (F_2=10.69, P<0.001, η^2=0.40) and its fractions (T_{0-100}: F_2=9.45, P=0.001, η^2=0.37; $T_{100-200}$: F_2=9.92, P<0.001, η^2=0.38; $T_{200-300}$: F_2=8.27, P=0.001, η^2=0.34; T_{0-200}: F_2=11.00, P<0.001, η^2=0.40; T_{FL}: F_2=9.82, P<0.001, η^2=0.38). Post-hoc analysis revealed differences between both Juniors and Seniors compared to Cadets (P<0.05 for all comparisons, Table 2). No differences were found between Juniors and Seniors in all parameters (ranges: P=0.11–0.43; ES=0.38–0.55, C.I.=-0.44–1.34).

*** Table 2 about here ***

Squat Jump

The one-way ANCOVA did not show statistical differences (F_2=0.09, P=0.914, η^2=0.006) in SJ_{delta} among groups (Cadets: 2.0±1.3; Juniors: 2.2±1.1; Seniors 2.0±1.1)**.** The ANCOVA for repeated measures showed significant differences between pre- and post- 300-m time trial (F_1=111.31, P<0.001, η^2=0.78), as well as among groups (F_2=7.15, P=0.003, η^2=0.31) in SJ. In pre-SJ, significant differences were found between Cadets and Seniors (P=0.004) and Cadets and Juniors (P=0.003) (raw data and ESs are reported in Table 2), whereas differences between Juniors and Seniors were not significant (P=0.43, ES=0.33, C.I.=-0.49–1.12). Between pre- and post-SJ, significant differences were found within each group (Cadets: 36.98±2.50 vs 34.95±3.09 cm, P<0.001, ES=1.81, C.I.=0.80–2.69; Juniors: 43.16±4.74 vs 40.96±4.83 cm, P<0.001, ES=1.97, C.I.=0.94–2.87; Seniors: 45.02±6.48 vs 42.99±6.88 cm, P<0.001, ES=1.96, C.I.=0.93–2.86).

Heart rate

No differences were found among groups in peak HR (Cadets: 195.92±8.07; Juniors: 192.92±8.59; Seniors 194.92±7.01; F_2=0.89, P=0.42, η^2=0.05).

Blood lactate concentration ([La$^-$])

After the 300-m time trial, peak [La$^-$] did not significantly differ among groups (Cadets: 11.77±3.08 mM; Juniors: 13.24±2.34 mM; Seniors: 12.69±0.88 mM; F_2=1.01, P=0.35, η^2=0.06).

Rate of perceived exertion (RPE)

After the 300-m time trial, CR-10 values did not differ significantly among groups (Cadets: 7.54±1.95 A.U.; Juniors: 7.67±1.72 A.U.; Seniors: 8.21±1.08 A.U.; F_2=0.06, P=0.94, η^2=0.004).

Duration of skating sector techniques

As reported in Table 3, the one-way ANCOVA and post-hoc analysis showed that, among the techniques considered, significant differences were found in the percentage duration of: i) T_{co1} (F_2=8.33, P=0.001, η^2=0.35) between Cadets and Seniors (P=0.001, ES=1.48, C.I.=0.53–2.33), and Juniors and Seniors (P=0.007, ES=1.30, C.I.=0.38–2.13); ii) T_{sp1} (F_2=11.83, P<0.001, η^2=0.43) between Cadets and Seniors (P<0.001, ES=1.77, C.I.=0.77–2.64) and between Juniors and Seniors (P=0.010, ES=1.15, C.I.=0.25–1.97); iii) T_{co2} (F_2=4.11, P=0.03, η^2=0.21) between Cadets and Seniors (P<0.001, ES=1.96, C.I.=0.93–2.85) and between Juniors and Seniors (P=0.012, ES=1.16, C.I.=0.26–1.98); iv) T_{sp2} (F_2=3.67, P=0.04, η^2=0.19) between Cadets and Seniors (P=0.027, ES=1.14, C.I.=0.25–1.96); v) T_{coTot} (F_2=6.01, P=0.006, η^2=0.28) between Cadets and Seniors (P=0.001, ES=1.65, C.I.=0.67–2.51), and between Juniors and Seniors (*P*=0.038, ES=0.98, C.I.=0.10–1.79); vi) T_{spTot} (F_2=7.07, *P*=0.003, η^2=0.31) between Cadets and Seniors (*P*=0.001, ES=1.64, C.I.=0.67–2.50). No significant differences were found in the other comparisons (ranges: *P*=0.07–0.45, ES=0.22–0.77, C.I.=-0.59–1.57).

*** Table 3 about here ***

Correlations

When data were pooled (that is, irrespective of the age category), significant negative correlations were found between T_{tot} and SJ at baseline (r=-0.707, *P*<0.001) and between T_{tot} and T_{coTot} (r=-0.717, *P*<0.001), while a significant positive correlation was found between T_{tot} and T_{spTot} (r=0.738, *P*<0.001). Moreover, a significant positive correlation was found between SJ at baseline and T_{coTot} (r=0.813, *P*<0.001), while a significant negative correlation was found between SJ at baseline and T_{spTot} (r=-0.795, *P*<0.001). No significant correlations were found between peak [La^-] and: T_{tot} (r=-0.16, *P*=0.34), T_{coTot} (r=-0.01, *P*=0.96) and T_{spTot} (r=0.02, *P*=0.89).

When data were separated within each category, significant correlations were found between T_{tot} and peak [La^-] in Seniors (r=-0.61, *P*=0.05), but not in Cadets (r=0.56, *P*=0.07) and Juniors (r=-0.21, *P*=0.54). Moreover, T_{tot} significantly correlated: in Cadets with T_{co3} (r=-0.69, *P*=0.018), T_{sp2} (r=0.80, *P*=0.003), T_{sp3} (r=0.66, *P*=0.03), and T_{spTot} (r=0.61, *P*=0.047); in Seniors with, T_{co1} (r=-0.87, *P*=0.001), T_{co2} (r=-0.73, *P*=0.016), T_{co3} (r=-0.74, P=0.015), T_{coTot} (r=-0.87, *P*=0.001), T_{sp1} (r=0.94, *P*<0.001), and T_{spTot} (r=0.82, *P*=0.004). No significant correlations were found in Juniors (*P*>0.05). Concerning SJ values at baseline, significant correlations were found with T_{tot} (r=-0.862, *P*<0.001) in Seniors, whereas no correlations were found for both Cadets (r=-0.408, P=0.21) and Juniors (r=-0.117, *P*=0.73).

When correlating SJ and skating techniques' duration, significant correlations were found in: Juniors with T_{co2} (r=0.75, *P*=0.009), T_{co3} (r=0.82, *P*=0.002), T_{coTot} (r=0.84, *P*=0.001), T_{sp2} (r=-0.61, *P*=0.05) and T_{spTot} (r=-0.72, *P*=0.03); Seniors with, T_{co1} (r=0.70, *P*=0.02), T_{co2} (r=0.81, *P*=0.005), T_{co3} (r=0.85, *P*=0.002, T_{coTot} (r=0.87, *P*=0.001), T_{sp1} (r=-0.74, *P*=0.001), T_{sp2} (r=-0.70, *P*=0.02) and T_{sp3} (r=-0.74, *P*=0.01), and T_{spTot} (r=-0.88, *P*=0.001). No significant correlations were found in Cadets (*P*>0.05). Correlations of T_{tot} and SJ within each age category are presented in Table 4.

When correlating peak [La$^-$] and skating techniques' duration, significant correlations were found in Cadets with T_{coTot} (r=-0.60, *P*=0.04) and T_{spTot} (r=0.60, *P*=0.05). In Seniors, a tendency for a positive correlation was found with T_{coTot} (r=0.62, *P*=0.056), and a negative correlation with T_{spTot} (r=-0.62, *P*=0.058). No significant correlations were found in Juniors (r=0.13, P=0.70 and r=-0.17, P=0.61, T_{coTot} and T_{spTot}, respectively).

*** Table 4 about here ***

Discussion

The main findings of the present study were that: i) time trial performance was longer and jump height (both at baseline and after performance) was lower in Cadets compared to the other two groups; ii) Seniors employed the cross-over technique for a longer relative period than the straight push technique compared to Juniors and Cadets; and iii) significant correlations were found between time trial performance and other specific and non-specific variables. In particular, considering all participants, time trial performance correlated negatively with SJ and T_{coTot}, and positively with T_{spTot}; SJ correlated positively with T_{coTot} and negatively with T_{spTot}. When considering each age category, T_{tot} correlated negatively with SJ only in Seniors and the number of correlations between skating techniques' duration and SJ increased with age categories. Altogether, these results suggest that in-line skating 300-m time trial was strongly linked to the relative duration of the cross-over technique, which, in turn, seemed to be associated to jumping performance.

Skating performance and physiological responses

In Cadets, T_{tot} was higher and SJ performance was lower compared to Juniors and Seniors. These findings agree with a previous study,[7] in which skating performance and explosive power were lower in 15-17 years old athletes compared to 18-19 years old skaters, and reveal that jump height may be an important prerequisite for skating performance. Hormone levels related to growth and strength expression have been shown to be different in adolescents than in older groups,[15] and may therefore play a role in explaining the present results.[21]

The lack of differences in 300 m performance between Juniors and Seniors suggests that the performance of the athletes towards the end of the physical maturation is close to the level of older and expert athletes. The discrepancy in categories between international and national competitions should be taken into account. In fact, the international Senior group is determined by athletes >20 years, whereas the national level requires to be >18 years, meaning that some of the Italian elite athletes (between 18 and 19 years) compete in both categories.[17,22] Therefore, the training level between some elite Italian Junior and Senior athletes may result very similar.

At the end of the 300-m time trial, peak HR and $[La^-]$ values did not differ among categories and were similar to previous values of in-line speed skaters.[23] In particular, as cycling exercise have physiological responses comparable to running and in-line skating,[23] the results of [La^-] are in line with studies reporting no differences between adolescents and adults in response to a maximum Wingate anaerobic test.[24] Accordingly, RPE values displayed a very high level of effort exerted by the skaters of all groups, which is also supported by the similar SJ_{delta} among groups.

Duration of skating techniques

The duration of the initial acceleration phase did not show differences among groups, while differences were found between Seniors and both Cadets and Juniors in cross-over and straight push technique phases, highlighting the importance of single technique duration. Both Cadets and Juniors spent more time using the straight push and less time using the cross-over technique than Seniors. This observation becomes more evident when comparing Cadets with Seniors, where nearly all techniques' durations were different between groups (see Table 3). Seniors were faster than Cadets but not faster than Juniors (Table 2), and had higher experience (Table 1) than the other groups; this may explain why Seniors use the more complex cross-over pattern for a longer period. Compared to the straight push, the cross-over technique is employed during the curving phases of the race, and requires body inclination with a low position, asymmetric leg actions and strength regulation to bear the centrifugal forces.[2,12] For this reason, it involves an integration of strength and coordinative abilities not yet developed in the younger athletes.[15] Moreover, it means that experienced athletes had the ability to swap from the straight push to the cross-over technique when they were still in the straight part of the track and came back to straight push technique later than younger and less experienced athletes. This might also imply the use of different trajectories in different categories. Experienced athletes likely had the capacity to choose the most effective technique in the different phases of the race based on a previous knowledge of their own abilities.[25–28]

Correlations

As previously exposed, when participants' results were pooled, a large negative correlation (r=-0.707) was found between SJ and T_{tot}. These results confirm the importance of lower limb strength in successful skating propulsion, as previously reported.[1,2,7]

Considering each age category, this correlation was found in Seniors but not in Juniors and Cadets. A possible explanation for the lack of correlations in the two youngest categories may reside in strength development for the Cadets, and compromised coordination for the Juniors. Indeed, the physiological maturation of Cadets could have not reached its peak, not allowing them to express leg strength at its best for performance. Conversely, the relevant somato-functional changes (e.g., height and strength) occurring at Junior's age compared to the previous age category as well as the resulting difficulties to adapt the altered physical and motor constraints involved in the skating task, may have compromised the appropriate neuromuscular regulations of the best performance. From a practical point of view, the overall negative correlation between T_{tot} and SJ from the pooled data of the three groups shows how much importance the somato-functional maturation has on strength and its effect on speed skating performance.

Regarding the duration of each technique, when considering pooled results, the positive correlation between SJ at baseline and T_{coTot} and the negative correlation between T_{Tot} and T_{coTot} highlight that participants spending more time with the cross-over technique were stronger and had better performance of the lower limbs. The opposite happened during the straight push technique. These data suggest that only skaters with higher strength in the lower limbs are able to sustain the muscular requirements due to the centripetal acceleration of the trajectories entailing longer curves.[12] Moreover, skaters who spent more time using the cross-over technique likely pursued trajectories favouring small decelerations and smoother changes of direction.[2]

When considering separately each age category, a higher number of correlations between technique duration and both SJ and T_{tot} was found in Seniors compared to Junior and Cadets. These results in senior athletes show that relative time in cross-over technique increases, and relative time in straight push technique decreases, as strength and performance on 300 m increase. This suggests that athletes manage the skating technique duration through a proper use of leg strength for a better propulsion efficacy and a subsequent lower T_{tot}.[7] As far as junior athletes are concerned, correlations were observed only between SJ and skating techniques duration, in line with the correlations obtained in Senior athletes. Differently, the only correlations observed in Cadets concerned T_{tot} and skating techniques. It is likely that the condition of somato-functional stability in Cadets allowed them, differently from Juniors, to better dispose of their technical capacities during in-line skating task.

A significant and large negative correlation (r=-0.61) was found between T_{tot} and peak $[La^-]$ only in Seniors, showing that $[La^-]$ increases as performance improves. The longer relative time spent using the cross-over technique may have likely implicated a longer blood flow restriction to the lower limbs determined by the position hold. Consequently, a higher blood lactate accumulation may have occurred.[29]

This study has some limitations. For example, the Seniors' age presents greater variability compared to the other categories. Therefore, a more homogeneous sample may lead to different results. Another limitation is the lack of a longitudinal perspective. The evolution and maturation of skaters throughout the different age categories could be of great interest to get more insights on the effects of the level of expertise on the considered variables.

Conclusions

The present study clearly highlights that significant differences in physiological, technical and performance characteristics exist among in-line skaters of different age categories during a 300-m trial. Specifically, Cadets had longer in-line skating 300-m time trial performance and lower jump height than Juniors and Seniors. As age category increases, cross-over technique and leg strength (indirectly assessed through jump height during SJ) seem to be more associated to skating performance. While T_{tot} performance did not differ between Juniors and Seniors, Seniors employed the cross-over technique for a longer period. Therefore, coaches and practitioners should acknowledge and take into account these differences on planning specific and targeted training programs.

REFERENCES

1. Allinger TL, Van den Bogert AJ. Skating technique for the straights, based on the optimization of a simulation model. Med Sci Sport Exerc 1997;29:279–86.

2. Felser S, Behrens M, Fischer S, Heise S, Baumler M, Salomon R, et al. Relationship between strength qualities and short track speed skating performance in young athletes. Scand J Med Sci Sport 2016;26:165–71. https://doi.org/10.1111/sms.12429.

3. Abbiss CR, Laursen PB. Describing and understanding pacing strategies during athletic competition. Sport Med 2008;38:239–52.

4. Slater L V, Vriner M, Zapalo P, Arbour K, Hart JM. Difference in agility, strength, and flexibility in competitive figure skaters based on level of expertise and skating discipline. J Strength Cond Res 2016. https://doi.org/10.1519/JSC.0000000000001452.

5. Konings MJ, Elferink-Gemser MT, Stoter IK, van der Meer D, Otten E, Hettinga FJ. Performance Characteristics of Long-Track Speed Skaters: A Literature Review. Sport Med 2015;45:505–16. https://doi.org/10.1007/s40279-014-0298-z.

6. Akahane K, Kimura T, Cheng GA, Fujiwara T, Yamamoto I, Hachimori A. Relationship between Balance Performance and Leg Muscle Strength in Elite and Non-Elite Junior Speed Skaters. J Phys Ther Sci 2006;18:149–54. https://doi.org/10.1589/jpts.18.149.

7. de Greeff MJW, Elferink-Gemser M, Sierksma G, Visscher C. Explaining the performance of talented youth speed skaters. Ann Res Sport Phys Act 2011;1:83–99.

8. Foster C, Rundell KW, Snyder AC, Stray-Gundersen J, Kemkers G, Thometz N, et al. Evidence for restricted muscle blood flow during speed skating. Med Sci Sport Exerc

1999;31:1433–40.

9. Hesford CM, Laing SJ, Cardinale M, Cooper CE. Asymmetry of quadriceps muscle oxygenation during elite short-track speed skating. Med Sci Sport Exerc 2012;44:501–8. https://doi.org/10.1249/MSS.0b013e31822f8942.

10. Rundell KW. Compromised oxygen uptake in speed skaters during treadmill in-line skating. Med Sci Sport Exerc 1996;28:120–7.

11. Chang R, Turcotte R, Pearsall D. Hip adductor muscle function in forward skating. Sport Biomech 2009;8:212–22. https://doi.org/10.1080/14763140903229534.

12. Felser S, Behrens M, Fischer S, Baeumler M, Salomon R, Bruhn S. Neuromuscular Activation During Short-Track Speed Skating in Young Athletes. Int J Sport Physiol Perform 2016;11:848–54. https://doi.org/10.1123/ijspp.2015-0344.

13. Stoter IK, MacIntosh BR, Fletcher JR, Pootz S, Zijdewind I, Hettinga FJ. Pacing Strategy, Muscle Fatigue, and Technique in 1500-m Speed-Skating and Cycling Time Trials. Int J Sport Physiol Perform 2016;11:337–43. https://doi.org/10.1123/ijspp.2014-0603.

14. Côté J, Baker J, Abernethy B. From play to practice: A developmental framework for the acquisition of expertise in team sport. In: Starkes J, Ericsson KA, editors. *Expert performance in sports: Advances in research on sport expertise*. Champaign, IL: Human Kinetics, 2003.p.89–113.

15. Naughton G, Farpour-Lambert NJ, Carlson J, Bradney M, Van Praagh E. Physiological issues surrounding the performance of adolescent athletes. Sports Med 2000;30:309–25.

16. Borg G. Borg’s Perceived Exertion and Pain Scales. Champaign, IL: Human Kinetics, 1998.

17. FIHP. FIHP, Corsa - Regolamento Tecnico 2016 [Internet]. Pattinaggio F-FIH e, editor. Vol. 34. 2016. Available from: http://www.fihp.org/corsa/regolamenti-di-settore.html

18. Bosco C, Luhtanen P, Komi P V. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol 1983;50:273–82.

19. Noble BJ, Robertson RJ. Perceived exertion. Champaign, IL: Human Kinetics, 1996.

20. Cohen J. Statistical Power Analysis for the Behavioral Sciences, 2nd ed. Mahwah, NJ: Lawrence Erlbaum Associates, 1988.

21. Baldari C, Di Luigi L, Emerenziani GP, Gallotta MC, Sgro P, Guidetti L. Is explosive performance influenced by androgen concentrations in young male soccer players? Br J Sport Med 2009;43:191–4. https://doi.org/10.1136/bjsm.2007.040386.

22. FIRS. FIRS, Speed Technical Committee - STC General Regulations Edition 2016 [Internet]. Sports F-FIR, editor. Vol. 72. 2016. Available from: http://www.rollersports.org/component/phocadownload/category/39-regulation

23. Stangier C, Abel T, Mierau J, Hollmann W, Struder HK. Effects of Cycling Versus Running Training on Sprint and Endurance Capacity in Inline Speed Skating. J Sport Sci Med 2016;15:41–9.

24. Beneke R, Hutler M, Jung M, Leithauser RM. Modeling the blood lactate kinetics at maximal short-term exercise conditions in children, adolescents, and adults. J Appl Physiol 2005;99:499–504. https://doi.org/10.1152/japplphysiol.00062.2005.

25. Broadbent DP, Causer J, Williams AM, Ford PR. Perceptual-cognitive skill training and its transfer to expert performance in the field: future research directions. Eur J Sport Sci 2015;15:322–31. https://doi.org/10.1080/17461391.2014.957727.

26. Invernizzi PL, Limonta E, Bosio A, Scurati R, Veicsteinas A, Esposito F. Effects of a

25-km trial on psychological, physiological and stroke characteristics of short- and mid-distance swimmers. J Sport Med Phys Fit 2014;54:53–62.

27. Invernizzi PL, Longo S, Bizzi M, Benedini S, Merati G, Bosio A. Interpretation and perception of two different kumite fighting intensities through an integrated approach training in international level karatekas: an exploratory study. Percept Mot Skills 2015;121:333–49. https://doi.org/10.2466/30.06.PMS.121c19x4.

28. Invernizzi PL, Longo S, Scurati R, Maggioni MA, Michielon G, Bosio A. Interpretation and perception of slow, moderate, and fast swimming paces in distance and sprint swimmers. Percept Mot Skills 2014;118:833–49. https://doi.org/10.2466/27.29.PMS.118k23w0.

29. Takarada Y, Takazawa H, Sato Y, Takebayashi S, Tanaka Y, Ishii N. Effects of resistance exercise combined with moderate vascular occlusion on muscular function in humans. J Appl Physiol 2000;88:2097–106.

Authors' contribution. – Pietro Luigi INVERNIZZI: Conception and design of the experiments; collection, analysis and interpretation of data; drafting the article and revising it critically for important intellectual content; final approval of the version to be published. Raffaele SCURATI: Analysis and interpretation of data; drafting the article and revising it critically for important intellectual content; final approval of the version to be published. Matteo CROTTI: Collection, analysis and interpretation of data; revising the article critically for important intellectual content; final approval of the version to be published. Andrea BOSIO: Analysis and interpretation of data; revising the article critically for important intellectual content; final approval of the version to be published. Stefano LONGO: Analysis and interpretation of data; drafting the article and revising it critically for important intellectual content; final approval of the version to be published. Fabio ESPOSITO: Conception and design of the experiments; analysis and interpretation of data; drafting the article and revising it critically for important intellectual content; final approval of the version to be published.

Conflict of interests. – The authors have no conflicts of interest to disclose.

Congresses. – Data from this work have been presented at the VIII SISMES (Società Italiana delle Scienze Motorie e Sportive) Congress held in Rome, Italy, 7^{th}-9^{th} October 2016.

Acknowledgments. – We would gratefully like to thank Andrea Mantegazza and all the athletes who participated in this study for their committed effort in the project.

TITLES OF TABLES

Table I. – Characteristics of participants.

Table II. – Details of strength of the lower limbs and skating performance

Table III. – Duration of different skating techniques in percentage and absolute values.

Table IV. – Correlations within each age category between the duration of techniques and: i) performance (T_{tot}); ii) SJ, controlled for years of practice.

TITLES OF FIGURES

Figure 1 – Technical features of in-line speed skating events: a) acceleration phase after the start; b) cross-over technique used in the curves; c) straight push technique used in the straights.

Figure 2. – Panel A. Timeline of the experimental procedure. Panel B. Experimental setting and graphic representation of the time laps in the 300-m trial.

Table I. Characteristics of participants

	Cadets (N=12)	Juniors (N=12)	Seniors (N=12)
Age (yrs)	14.4 ± 0.5	16.4 ± 0.7[a]	23.8 ± 5.8[a,b]
Body mass (kg)	61.4 ± 5.0	69.5 ± 6.0[a]	78.8 ± 9.5[a,b]
Stature (cm)	169.9 ± 3.3	176.1 ± 4.8[a]	178.3 ± 8.3[a]
BMI (kg m^{2-1})	22.3 ± 3.7	22.4 ± 1.7	24.8 ± 2.4
Years of practice (yrs)	6.3 ± 1.0	9.2 ± 0.9	16.8 ± 5.7 [a,b]

Characteristics of participants (36 males) divided in three groups. BMI, body mass index. Significant differences among groups determined with One-Way ANOVA and Tukey's post-hoc are shown. [a], P<0.05 vs Cadet; [b], P<0.05 vs Junior.

Table II. Details of strength of the lower limbs and skating performance

	Cadets	Juniors	Seniors	ES Cadets-Juniors (95% C.I.)	ES Cadets-Seniors (95% C.I.)
SJ (cm)	36.98±2.50	43.16±4.74[a]	45.02±6.48[a]	1.63 (0.66–2.49)	1.64 (0.67–2.50)
T_{tot} (s)	28.63±1.10	26.96±0.82[a]	26.53±0.97[a]	1.72 (0.73–2.59)	2.02 (0.98–2.93)
T_{0-100} (s)	11.15±0.43	10.54±0.33[a]	10.39±0.39[a]	1.59 (0.62–2.44)	1.86 (0.85–2.74)
$T_{100-200}$ (s)	8.79±0.38	8.24±0.28[a]	8.12±0.32[a]	1.65 (0.68–2.51)	1.89 (0.87–2.78)
$T_{200-300}$ (s)	8.68±0.40	8.18±0.32[a]	8.02±0.27[a]	1.41 (0.47–2.25)	1.96 (0.93–2.86)
T_{0-200} (s)	19.95±0.72	18.70±0.56[a]	18.51±0.71[a]	1.80 (0.80–2.68)	2.00 (0.96–2.90)
T_{FL} (s)	17.48±0.73	16.41±0.57[a]	16.14±0.58[a]	1.62 (0.65–2.48)	2.02 (0.98–2.92)

Squat jump (SJ) height before the 300-m time trial. Total time of the trial (T_{tot}) with its fractions are reported for all groups. T_{0-100}, time between the start and the first 100 m; $T_{100-200}$, time between the first 100 m and the 200 m distance; $T_{200-300}$, time between the 200 m and the end of the trial; T_{0-200}, time between the start and the time at 200 m; T_{FL}, time of the last 200 m of the trial ("flying lap"). ES, effect size; 95% C.I., confidence interval at 95% for effect size; [a] $P<0.05$ *vs* Cadets.

Table III. Duration of different skating techniques in percentage and absolute values.

	Cadets	Juniors	Seniors
Total skating techniques			
Acceleration phase (s)	9.4 %	9.5 %	8.9 %
	(2.68±0.24)	(2.56±0.23)	(2.45±0.27)
Cross-over total (s)	59.8 %	62.6 %	66.8 % [a,b]
	(17.13±0.87)	(16.89±0.97)	(17.72±0.81)
Straight total (s)	30.8 %	27.9 %	24.3 % [a]
	(8.82±1.11)	(7.53±1.05)	(7.46±1.49)
Sequence of techniques			
Acceleration phase (s)	9.4 %	9.5 %	8.9 %
	(2.68±0.24)	(2.56±0.23)	(2.45±0.27)
Cross-over 1 (s)	19.0 %	19.5 %	21.6 % [a,b]
	(5.45±0.48)	(5.26±0.32)	(5.74±0.38)
Straight push 1 (s)	12.3 %	11.3 %	9.1 % [a,b]
	(3.52±0.39)	(3.05±0.46)	(3.42±0.71)
Cross-over 2 (s)	20.2 %	21.3 %	23.1 % [a,b]
	(5.77±0.30)	(5.75±0.37)	(6.13±0.36)
Straight push 2 (s)	9.5 %	8.0 %	7.7 % [a]
	(2.71±0.47)	(2.17±0.46)	(2.04±0.51)
Cross-over 3 (s)	20.6 %	21.8 %	22.1 %
	(5.91±0.42)	(5.88±0.46)	(5.85±0.32)
Straight push 3 (s)	9.0 %	8.6 %	7.5 % [a]
	(2.59±0.41)	(2.31±0.36)	(2.00±0.43)

Skating techniques' durations expressed as percentages of the total 300-m time trial. Absolute values are given in parentheses. Statistical analysis was conducted on percentages: [a], $P<0.05$ vs Cadet; [b], $P<0.05$ vs Junior.

Table IV. Correlations within each age category between the duration of techniques and: i) performance (Ttot); ii) SJ, controlled for years of practice.

	Cadets (n=12)				Juniors (n=12)				Seniors (n=12)			
	T_{tot}		SJ		T_{tot}		SJ		T_{tot}		SJ	
	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*	r	*P*
Acceleration phase	-0.469	*0.146*	0.307	*0.358*	0.333	*0.316*	-0.500	*0.117*	0.507	*0.135*	-0.214	*0.554*
Cross-over 1	0.105	*0.759*	-0.4.93	*0.1231*	-0.274	*0.414*	0.386	*0.241*	-0.874*	*0.001*	0.703*	*0.023*
Straight push 1	-0.092	*0.788*	-0.188	*0.580*	-0.235	*0.487*	-0.403	*0.219*	0.944*	*<0.001*	-0.744*	*0.014*
Cross-over 2	-0.438	*0.178*	0.467	*0.148*	-0.038	*0.911*	0.745*	*0.009*	-0.731*	*0.016*	0.806*	*0.005*
Straight push 2	0.802*	*0.003*	-0.233	*0.490*	0.234	*0.488*	-0.605*	*0.049*	0.582	*0.078*	-0.696*	*0.025*
Cross-over 3	-0.694*	*0.018*	0.326	*0.328*	-0.049	*0.886*	0.823*	*0.002*	-0.739*	*0.015*	0.850*	*0.002*
Straight push 3	0.658*	*0.028*	-0.117	*0.731*	0.236	*0.485*	-0.524	*0.098*	0.415	*0.232*	-0.741*	*0.014*
Cross-over total	-0.463	*0.152*	0.108	*0.752*	-0.146	*0.668*	0.839*	*0.001*	-0.870*	*0.001*	0.874*	*0.001*
Straight total	0.608*	*0.047*	-0.228	*0.499*	0.087	*0.799*	-0.718*	*0.013*	0.816*	*0.004*	-0.880*	*0.001*

r = Pearson's correlations; * significant correlation ($P < 0.05$)

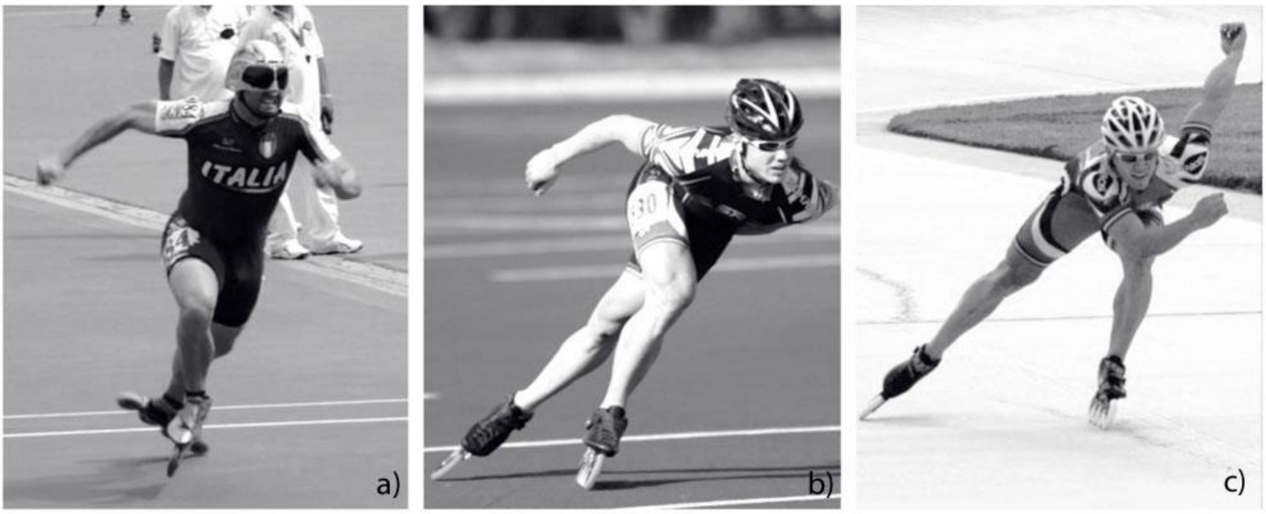

Fig. 1

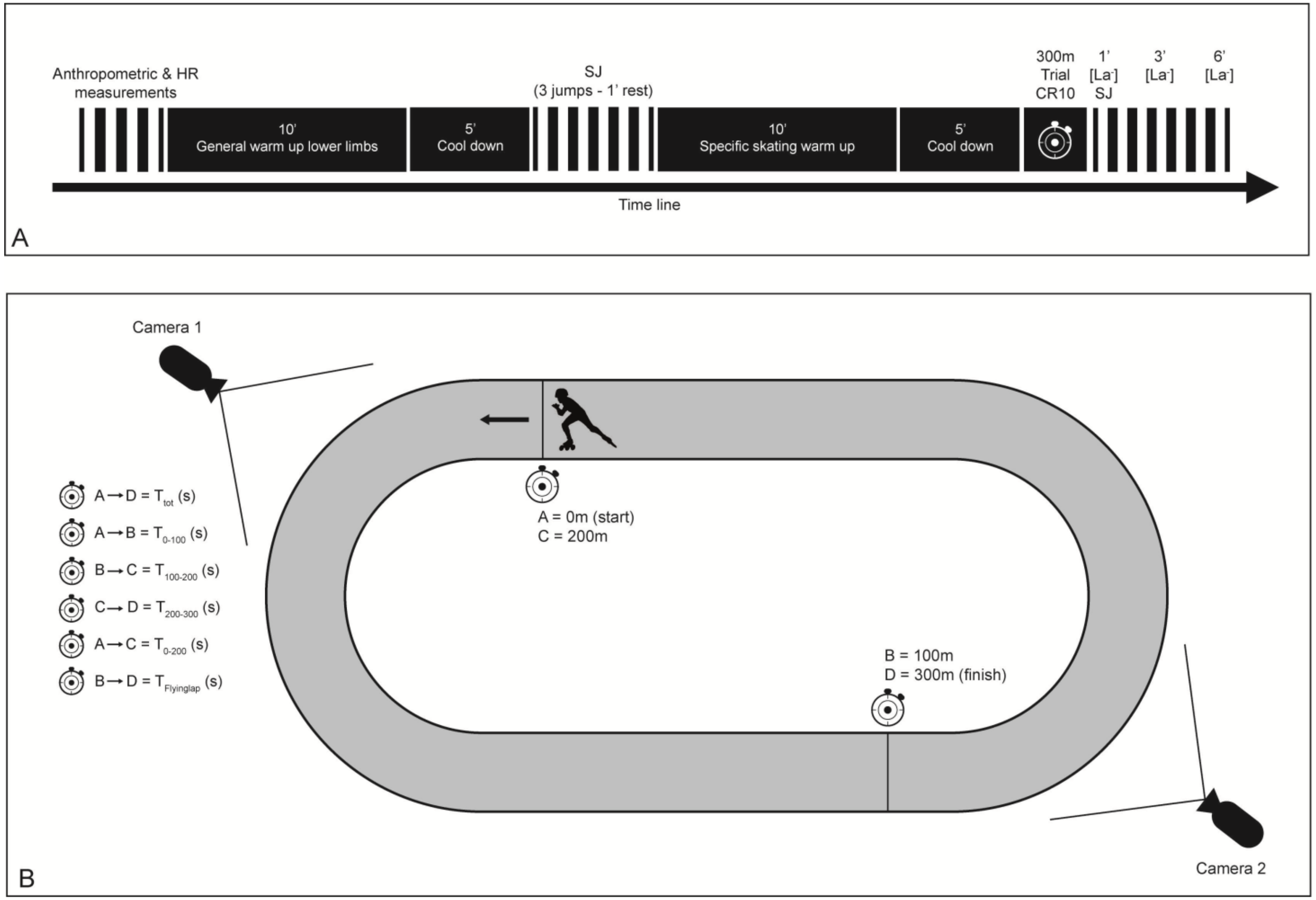
Anthropometric & HR measurements
10' General warm up lower limbs
5' Cool down
SJ (3 jumps - 1' rest)
10' Specific skating warm up
5' Cool down
300m Trial CR10
1' [La⁻] SJ
3' [La⁻]
6' [La⁻]
Time line
A
Camera 1
A → D = T_{tot} (s)
A → B = T_{0-100} (s)
B → C = $T_{100-200}$ (s)
C → D = $T_{200-300}$ (s)
A → C = T_{0-200} (s)
B → D = $T_{Flyinglap}$ (s)
A = 0m (start)
C = 200m
B = 100m
D = 300m (finish)
Camera 2
B

Fig. 2