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Research article

Do Maximal Roller Skiing Speed and Double Poling Performance Predict Youth Cross-Country Skiing Performance?

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Abstract
The aims of the current study were to analyze whether specific roller skiing tests and cycle length are determinants of youth cross-country (XC) skiing performance, and to evaluate sex specific differences by applying non-invasive diagnostics. Forty-nine young XC skiers (33 boys; 13.8 ± 0.6 yrs and 16 girls; 13.4 ± 0.9 yrs) performed roller skiing tests consisting of both shorter (50 m) and longer durations (575 m). Test results were correlated with on snow XC skiing performance (P_{XC}) based on 3 skating and 3 classical distance competitions (3 to 6 km). The main findings of the current study were: 1) Anthropometrics and maturity status were related to boys', but not to girls' P_{XC}; 2) Significant moderate to acceptable correlations between girls' and boys' short duration maximal roller skiing speed (double poling, V2 skating, leg skating) and P_{XC} were found; 3) Boys' P_{XC} was best predicted by double poling test performance on flat and uphill, while girls' performance was mainly predicted by uphill double poling test performance; 4) When controlling for maturity offset, boys' P_{XC} was still highly associated with the roller skiing tests. The use of simple non-invasive roller skiing tests for determination of P_{XC} represents practicable support for ski clubs, schools or skiing federations in the guidance and evaluation of young talent.

Key words: Adolescents; cycle length; cycle rate; diagnostics; maturity; roller skiing, validity.

Introduction

Although it is widely acknowledged that young athletes can safely and effectively engage in physical training, provided that any such training is appropriately structured and supervised (Faigenbaum, 2000; Faigenbaum et al., 2009; Matos and Winsley, 2007), responsible coaches need to be aware of the specific demands of working with elite child athletes (Oliver et al., 2011). It has been established that physiologically, children are not miniature adults (Armstrong and Welsman, 1997) and that any training should consider the unique way in which children will respond and adapt to that specific training (Faigenbaum et al., 2009; Mountjoy et al., 2008).

Globally, the current practice of developing elite child athletes is heavily influenced by three assertions; that it takes 10,000 hours to achieve mastery, that practice time must be focused on learning a particular skill by "highly structured activity" (Ericsson K et al., 1993), and by the model of long-term athlete development (LTAD) proposed by Balyi and Hamilton (2004). The LTAD model outlines a framework of stages for the development of motor-skills and physical skills of young athletes. Athletes who miss certain stages of training development might not reach their full potential due to over emphasis on competition and immediate results instead of training (Balyi and Hamilton, 2004).

Recent studies in adult elite cross-country (XC) skiers indicated that XC skiing performance is characterized not only by aerobic and anaerobic capacity, but also by maximal skiing speeds, explosive- or maximum-force, and muscular endurance power (Osteras et al., 2002; Stöggl et al., 2007a; 2007b, Mikkola et al., 2010; Andersson et al., 2010; Holmberg et al., 2005; Carlsson et al., 2012; 2014). Furthermore, over the past decades, the double-poling (DP) technique has been used to a greater extent, and today is a decisive technique for success in classical XC ski races (Holmberg et al., 2005; Sandbakk and Holmberg, 2014; Stöggl and Holmberg, 2011; Stöggl and Holmberg, 2016). In recent years several elite skiers have successfully employed the DP technique throughout an entire race, eliminating the need for the kick wax that was traditionally applied in connection with the classic diagonal stride technique (Stöggl and Holmberg, 2011; 2016). In addition, attributed to altered demands in XC skiing (e.g. higher skiing speeds, changes in skiing technique with greater emphasis on explosive strength and upper body capacity, etc.), the optimal age of high performance XC skiers was shown to slightly decrease within the past years (Stöggl and Stöggl, 2013). According to Stöggl et al. (2015), increases in skiing speeds and changes in skiing techniques emphasize the importance of speed, strength and coordinative aspects in children and youth XC skiers and, more than ever, stress the importance of practicing high quality training and testing processes within this age group.

While there are several studies that deal predominantly with male elite level XC skiers, almost no research was found relevant to the testing and training of younger athletes (10 – 17 yrs). Gaskill et al. (1999) examined upper body power (DP ergometer) and race velocity including 124 16-yr old male (n = 55) and female (n = 69) high school XC skiers and 34 adult XC skiers. Furthermore upper body power of the high school XC skiers was compared to that of high school runners (n = 37). A strong sex-independent relationship (r = 0.89) to race velocity was found. Further, youth runners achieved only 46% of the mean upper body power of youth XC skiers. They strongly recommended that XC skiers should focus

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a large portion of their training on the development of upper body power.

Furthermore, only limited data about elite female skiers and female youth skiers, in particular, exists. To the best of our knowledge, our research group study is the only one that includes validation of motor ability tests and anthropometrics in connection with youth XC skiing performance (girls and boys 12.5 to 14 yrs.) (Stöggl et al., 2015). Our groups prior findings demonstrated clear correlations between measures of general strength, speed and coordination to XC skiing performance. Boys' overall performance was related to upper-body and trunk power (medicine ball throw, push-ups and pull-ups), maximal speed and agility (20-m sprint, and hurdle boomerang run) and jumping power (standing long and triple jump), while girls performance was related to 3000-m run, push-ups and maximal speed. Maturity was a major confounding variable in boys, but not in girls. However, while strength abilities definitely are more apparent in boys, there is still potential for improving the XC skiing performance of girls by increasing their overall strength levels (Stöggl et al., 2015).

Corresponding research about specific XC skiing test concepts in youth age is missing. The development and altered demands in adult elite XC skiing should not be applied to youth training and the respective lack of research about young male and female XC skiers emphasizes the need for specific performance diagnostics to detect the strengths and weaknesses of youths related to XC skiing performance (P_{XC}), which could improve the training processes. Therefore, the specific aims of the current study were: 1) Determine if XC skiing-specific test concepts including maximal roller skiing speed, DP performance and gross kinematics are determinants of XC skiing performance in youth athletes; 2) Establish how maturational status effects XC skiing performance in youth athletes and analyse if there are sex specific differences; 3) Establish non-invasive diagnostics.

Methods

Participants

A total of 49 male and female youth XC skiers (33 males and 16 females) volunteered to take part in this study. The pre-selection of participants was based on a) attending a special school for XC skiing (after passing a qualifying motor skills test) or being a member of a regional XC skiing team, and b) practicing and competing in XC skiing for more than three years. Participants were regional top athletes, as well as podium winners in the Austrian National Championships. Participants' characteristics are presented in Table 1. All participants volunteered to take part and were fully acquainted with the nature of the study; in addition, informed, written consent was given by the parents. The study was conducted in accordance with the Declaration of Helsinki and approved by the local Ethics Committee of the University of Salzburg.

Overall study design

For determination of specific peak velocity and double-poling performance in flat and uphill terrain, the following test concepts were used: a 350 m DP on flat terrain, a 225 m uphill DP (both outdoor) and three 50 m maximal speed tests on an indoor track using DP, V2 and leg skating. For all tests, roller skiing time, cycle rate, cycle length and anthropometric data were measured. Time (t350, t225 and t50) was measured by fixed light sensors (ALGE-TIMING, Lustenau, Austria).

All participants were familiar with both the indoor and outdoor roller skiing tests.

The outdoor and indoor tests were performed on two separate days one month before the start of the competition season. Furthermore, all participants had to compete in six selected XC skiing competitions (3 classic and 3 skating).

The selected maximal speed roller skiing tests were reported to show high test–retest reliability (r > 0.98) and validity compared with simulated sprint test performance in elite junior and adult XC skiers (1000-m DP and 1100-m classical sprint: r > 0.85) (Stöggl et al., 2006). Comparable tests were used previously in different international test concepts with respect to adult XC skiers prior to the current study (Andersson et al., 2010; Mikkola et al., 2010; Sandbakk et al., 2011Stöggl et al., 2006; 2007b).

Test concepts

All tests were performed on roller skis (START 71, Lahti, Finland), with every subject using one of 10 roller skis with equal rolling resistance selected out of 15 almost new roller skis from a gliding test prior to the study [20 m downhill gliding in crouched position through fixed light sensors (ALGE-TIMING, Lustenau, Austria)]. All five roller skis were warmed up prior to the start of the testing

Table 1. Age and anthropometrics.

	BOYS (n = 33)			GIRLS (n = 16)				
	Mean (±SD)	MIN	MAX	Mean (±SD)	MIN	MAX	Diff. %	P values
Age (yrs)	13.8 (.6)	12.5	14.8	13.4±0.9)	12.1	14.8	-3.1	.10
Body height (m)	1.62 (.8)	1.46	1.76	1.61 (.08)	1.49	1.77	-.7	.63
Body mass (kg)	52.8 (9.0)	39.6	72.5	51.2 (8.6)	40.8	69.6	-3.0	.55
BMI (kg·m^{-2})	20.0 (2.0)	16.5	23.4	19.7 (2.3)	17.2	26.5	-1.5	.65
Subischial leg length (cm)	80.6 (4.0)	74.5	88	78.9 (4.3)	74.5	89	-2.1	.18
Sitting height (cm)	81.1 (6.1)	70.5	92	81.8 (4.9)	74.5	90	.8	.70
Estimated peak height velocity (yrs)	14.3 (.7)	13.2	15.5	12.2 (.5)	12.9	11.2	-14.5	<0.001
Maturity offset (yrs)	-.48 (1.01)	-2.29	1.51	1.17 (.87)	-0.13	2.48	344.4	<.001
Pole length CL (cm) (DP 350-m / 225-m / 50-m)	138.4 (8.1)	124	159	137.8 (7.8)	127	156	-0.4	.83
Pole length SK (cm) (50-m V2)	149.8 (6.4)	140.5	162.5	143.6 (7.2)	133	158	-4.1	<.05

SD, standard deviation; BMI, body mass index; CL, classic; SK, skating; DP, Double Poling; V2, V2 skating technique. Diff. %: Difference of girls vs. boys session to prevent a warm-up effect of the wheels and bearings during testing. All subjects also underwent a short warm-up phase on the track using the same type of roller skis. Subjects used their own poles and pole length was recorded.

Flat and uphill DP field testing on roller skis: On the first testing day, two separate tests for determination of DP performance in flat and uphill terrain on a paved road were performed. First was the 350-m DP test flat (DP350-m flat): participants performed a distance of 350 m as fast as possible on a flat, straight paved road by using only the DP technique. Second was the 225-m DP uphill test (DP225-m up): athletes had to complete by DP an uphill distance of 225 m with only a slight inclination for acceleration on the first 25 meters (0 - 1°), increasing to 4 - 5° incline for the remainder of the distance. The sum of 350 m flat plus 225 m uphill was calculated (DP575-m total). For each test, only one maximal trial was performed. The course was measured with a calibrated wheel, and the incline was measured with an inclinometer. Weather conditions were stable and dry. Recovery time between 350 m flat and 225 m uphill was 30 minutes.

On the second testing day, short-duration sprint performance with DP, V2 and leg skating was measured via 50-m indoor sprint tests on roller skis. All 50-m tests were performed on a flat, straight indoor tartan track of 80 m. For each technique (DP, V2 and leg skating) participants completed three trials after one testing trial for each test situation. Testing order and recovery between the single tests was controlled by bibs starting with number one, followed by sequential numbers in groups of 10. The result of the best trial within each technique was taken for further analysis. Starting position was standardized by positioning the roller ski with the front wheel at the starting line and placing the poles on the ground. Time measurement started when the athlete passed through the first light sensor installed at the starting line, and ended after passing the 50 m mark.

Determination of cycle rate and length: For all test concepts, mean cycle rate and mean cycle length were determined (the number of cycles in the DP350-m flat and DP225-m uphill were counted by an accompanying person riding a bicycle; the sum of cycles in the 50-m tests were measured by the starter). Mean cycle length was calculated by dividing the distance by the number of movement cycles.

Determination of anthropometrics and maturity status: Anthropometric measurements consisted of: body height, bodyweight, BMI, subischial leg length, and sitting height. A measuring tape and a stadiometer were used to measure all body dimensions. For subischial leg length the participant stood with back against a wall and feet shoulder width apart with a large book between the legs, its spine firmly up against the crotch; the distance from the floor to the spine of the book was then calculated. Sitting height was measured from the vertex of the head to the seated buttocks. To control for possible confounding effects of maturation, age from peak height velocity (PHV) and the maturity offset as chronological age were calculated from chronological age, body height, sitting height and body mass according to Mirwald et al. (2002).

Cross-country skiing competitions: For determination of relationships between measured roller skiing tests and anthropometrics to XC skiing performance, three different distance competitions (length of 3 to 6 km), in each the classical technique and the skating technique, were performed by all participants. The competitions selected were chosen from 10 competitions in total, based on stable weather and snow conditions, individual start intervals, and total compliance of the participants. Overall XC skiing performance determined out of all six races (P_{XC}) was calculated as follows: Firstly, the skiing times of each race were z-standardized (all data normalized by using the equation $(x_i - \bar{x})/s$) and secondly, the mean value of these six z-values was calculated representing P_{XC}. All selected races were part of the Austrian National Cup and/or Regional Cup of Salzburg, with all subjects participating in all six races.

Statistical analyses

All data were normally distributed, checked with the Shapiro-Wilk Test and are presented as means and standard deviations (±SD). Due to differences in skiing time and race distance between the single XC skiing competitions, the raw data for each of the races was z-standardized, and the mean across the six races was taken for calculation of P_{XC}. In view of the differences in XC skiing competition distances of girls and boys, this procedure was performed separately for the girls and for the boys. To determine relationships between test performance and P_{XC}, Pearson's Product Moment Correlations (r_{xy}) were calculated. Based on the multiple comparisons, the Bonferroni-Holm Step Down Correction was applied. Additionally, in case of correlations between age or estimated maturity status and P_{XC}, partial correlations (r_{xy-z}) with maturity offset as confounder variable were applied. In a further step, variables significantly correlated to PXC were analyzed by stepwise multiple regression to determine the most significant factors contributing to PXC. Sex differences in roller skiing results and anthropometric variables were established using t-tests for independent samples. The r values were categorized as follows: excellent, 0.9-1.0; high, 0.8-0.9; moderate, 0.7-0.8; acceptable 0.6-0.7; and low, <0.6. The statistical level of significance was set at $\alpha < 0.05$. All statistical tests were processed using SPSS 22.0 Software (SPSS Inc, Chicago, IL) and Office Excel 2010 (Microsoft Corporation, Redmond, WA).

Results

Race performance

The competitions selected were chosen from ten competitions in total based on stable weather and snow conditions, individual start intervals, and total compliance of the participants. Distances and finishing times for girls' skating (4 km, 13:21 ± 01:06 / 3.3 km, 11:14 ± 0:55 and 4 km, 12:05 ± 0:20) and classic competitions (4 km, 12:07

± 0:57 / 3 km, 13:04 ± 01:00 and 4 km, 13:46 ± 01:19) were different (all p < 0.001) from the distances and finishing times for boys' skating (6 km, 17:19 ± 01:10 / 5.3 km, 17:09 ± 1:21 and 5 km, 13:15 ± 0:56) and classic competitions (6 km, 16:35 ± 01:28/ 6 km, 23:33 ± 1:50 and 6 km, 18:56 ± 2:03).

Anthropometrics, age and maturity status

The anthropometric, maturity or age related data for the female youths did not show any correlations with P_{XC}. However, the age and anthropometrics of the male youths, like height, weight, sitting height, estimated PHV and maturity offset, demonstrated low to moderate correlations with P_{XC} (r = 0.52 to 0.74, all p < 0.05 to < 0.001) (Table 2).

Table 2. Bonferroni-Holm adjusted correlations between calendar age, anthropometric data and P_{XC} (boys and girls).

	BOYS (n = 33)	GIRLS (n = 16)
Age (yrs)	.52*	-.07
Body height (cm)	.67***	-.12
Body weight (kg)	.57**	-.46
BMI (kg m^{-2})	.31	-.56
Pole length (cm)	.46	.27
Subischial leg length (cm)	.19	.12
Sitting height (cm)	.74***	-.30
Estimated PHV (yrs)	-.61**	.24
Maturity offset (yrs)	.74***	-.20

BMI, body mass index; PHV, peak height velocity; *p < 0.05, **p < 0.01, *** p < 0.001.

Roller skiing tests

Detailed information about times, speeds and cycle characteristics of the various roller skiing tests are presented in Table 3. Correlations to P_{XC} and between variables of the single tests are shown in Table 4. For the boys, significant high correlations to P_{XC} were found between DP350-m flat, DP225-m uphill and the combination of both (r = 0.80 to 0.85, all p < 0.001) while for the girls, only DP225-m uphill and the sum of both was highly related (r = 0.83 and 0.81, p < 0.01).

Cycle rate during DP350-m flat and DP225-m uphill demonstrated no correlation to P_{XC} while cycle length (DP225-m and DP575-m total) was acceptably related with P_{XC} only for the boys (r = 0.68 to 0.64, all p < 0.01).

All roller skiing 50 m speed tests (DP, V2 and leg skating) were significantly acceptably to highly related to P_{XC} (Boys r = 0.67 to 0.88, all p < 0.01 to < 0.001; Girls r = 0.75 to 0.83, all p < 0.05 to < 0.01). Again only boys' cycle length during the three sprint tests showed significant correlations with P_{XC} (r = 0.54 to 0.64, all p < 0.05 to < 0.01).

With maturity offset as a confounding variable in the boys, the DP350-m flat, DP225-m uphill and DP575-m total test performance and P_{XC} remained significantly related ($r_{xy\text{-}z}$ = 0.56 to 0.65, all p < 0.01 to < 0.001). All other roller skiing sprint tests (DP, V2 and leg skating) were significantly related to P_{XC} ($r_{xy\text{-}z}$ = 0.47 to 0.71, all p < 0.05 to < 0.001) (Table 4).

Multiple stepwise regressions

Multiple stepwise regression analysis of roller skiing tests revealed the following predicting models for P_{XC} of boys and girls.

Boys:

P_{XC} = *1.050 (DP350-m flat [m/s]) -6.467*
R^2*=0.78 (p < 0.001), SEE=0.44*

Girls:

P_{XC} = *1.682 (DP225-m uphill [m/s]) -5.462*
R^2*=0.72 (p < 0.001), SEE=0.57*

Sex differences

While no differences between girls' and boys' anthropometrics or calendar age were found, boys' PHV was later

Table 3. Sex comparison in roller skiing performance.

		BOYS (n = 33)			GIRLS (n = 16)			
		Mean (±SD)	MIN	MAX	Mean (±SD)	MIN	MAX	Diff. %
Times (sec)	**tDP 350-m flat**	60.2 (7.3)	46.9	73.3	63.3 (6.1)	55.5	74.4	5.1
	tDP 225-m up	63.3 (11.1)	43	92.3	72.5 (12.0)*	56.3	100.0	13.9
	tDP 50-m	9.94 (.71)	8.55	11.25	10.73 (.78)**	9.89	12.35	7.9
	tV2 50-m	9.11 (.64)	7.79	10.18	10.1 (.78)***	9.30	11.62	10.9
	tLeg Skating 50-m	9.68 (.52)	8.61	10.6	10.88 (.69)***	10.02	11.94	12.4
Speeds (m/s)	**vDP 350-m flat**	5.90 (.74)	4.77	7.46	5.58 (.53)	4.70	6.31	-5.4
	vDP 225-m up	3.65 (.67)	2.44	5.23	3.18 (.51)*	2.25	4.00	-12.8
	vDP 50-m	5.05 (.37)	4.44	5.85	4.68 (.33)**	4.05	5.06	-7.3
	vV2 50-m	5. 52 (.40)	4.91	6.42	4.98 (.37)***	4.30	5.38	-9.8
	vLeg Skating 50-m	5.18 (.28)	4.72	5.81	4.61 (.29)***	4.19	4.99	-10.9
Cycle rate (Hz)	**Cycle Rate DP 350-m flat**	.98 (.13)	0.73	1.27	.99 (.12)	.79	1.21	1.3
	Cycle Rate DP 225-m up	1.05 (.13)	0.87	1.40	.95 (.11)*	.77	1.12	-9.1
	Cycle Rate DP 50-m	1.33 (.11)	1.14	1.6	1.30 (.16)	1.04	1.61	-2.7
	Cycle Rate V2 50-m	1.48 (.12)	1.2	1.8	1.42 (.12)	1.23	1.65	-4.4
	Cycle Rate Leg Skating 50-m	2.33 (.27)	1.83	2.79	2.16 (.21)*	1.83	2.49	-7.5
Cycle length (m)	**Cycle Length DP 350-m flat**	6.07 (.72)	4.27	7.78	5.69 (.82)	4.79	7.14	-6.3
	Cycle Length DP 225-m up	3.49 (.50)	2.68	4.41	3.35 (.43)	2.42	4.33	-3.9
	Cycle Length DP 50-m	3.82 (.40)	2.78	4.55	3.65 (.42)	2.94	4.17	-4.3
	Cycle Length V2 50-m	3.74 (.38)	2.94	4.55	3.52 (.23)*	3.13	3.85	-6.0
	Cycle Length Leg Skating 50-m	2.25 (.27)	1.79	2.63	2.15 (.18)	1.79	2.50	-4.3

SD, standard deviation; t, time; v, speed; DP, Double Poling; V2, V2 skating technique; Diff. %: Difference of girls vs. boys; *p < 0.05, **p < 0.01, ***p < 0.001.

(p < 0.001) leading to a negative maturity offset compared with a positive in the girls (p < 0.001) (Table 1). In all other tests measuring skiing time and speed, with the exception of DP350-m flat, there were significant differences between sexes with better performance by the boys (Table 2). Cycle rate during DP225-m up, 50 m leg skating and 50 m V2 showed differences between girls and boys, with higher cycle rates and longer cycle lengths in the boys'.

The largest sex differences were found for the DP225-m uphill time (13.9%) and 50-m leg skating time (12.4%), with better values for boys compared with girls, while DP350-m flat time showed a lesser difference (5.1%) (Table 2).

Table 4. Bonferroni-Holm adjusted correlations (r_{xy}) and partial correlations (r_{xy-z}: maturity offset as confounder) between roller skiing test performance and P_{XC}.

	BOYS (n = 33)		GIRLS (n = 16)
	r_{xy}	r_{xy-z}	r_{xy}
Outdoor DP tests			
DP 350-m flat (m/s)	.85***	.65***	.67
DP 225-m uphill (m/s)	.80***	.56**	.83**
DP 575-m total (m/s)	.83***	.62***	.81**
Cycle rate 350-m flat (Hz)	.41	.17	.19
Cycle rate 250-m uphill (Hz)	.43	.34	.50
Cycle rate 575-m total (Hz)	.44	.37	.39
Cycle length 350-m flat (m)	.45	.28	.29
Cycle length 225-m uphill (m)	.68**	.32	.59
Cycle length 575-m total (m)	.64**	.32	.46
50 m Sprint tests			
DP 50-m (m/s)	.88***	.71***	.82**
V2 50-m (m/s)	.84***	.63***	.83**
Leg Skating 50-m (m/s)	.67**	.47*	.75*
Cycle rate DP 50-m (Hz)	.00	.06	.25
Cycle rate V2 50-m (Hz)	.05	.07	.60
Cycle rate Leg Skating 50-m (Hz)	-.35	-.01	.66
Cycle length DP 50-m (m)	.59*	.28	.23
Cycle length V2 50-m (m)	.54*	.28	.17
Cycle length Leg Skating 50-m (m)	.64**	.27	-.25

DP, double poling; V2, V2 skating technique; *p < 0.05, **p < 0.01, ***p < 0.001.

Discussion

The main findings of the current study were; 1) Moderate to high correlations between young girls' and boys' short duration maximal roller skiing speed (DP, V2 skating and leg skating) and P_{XC} were found; 2) The best predictors of boys' P_{XC} was were DP350-m flat and DP225-m up, while girls' P_{XC} was best predicted by DP225-m uphill performance, and 3) Anthropometric or age related data of the female youths did not show any correlations with P_{XC}, while for the males, estimated PHV, maturity offset and anthropometrics such as height, sitting height and weight demonstrated low to moderate correlations.

Roller skiing tests

Short duration maximal speed tests: Short duration maximal speed over 50 m in DP, V2 skating and leg skating was related to P_{XC} for both young girls (13.4 ± 0.9yrs) and boys (13.8 ± 0.6yrs). For the boys, this result was found even when maturity offset was used to control for the confounding effects of maturation. This finding is in accordance with several studies in adult skiers (Andersson et al., 2010; Carlsson et al., 2012; 2014; Mahood et al., 2001; Sandbakk et al., 2011; Stöggl et al., 2006; 2007a; 2007b). Stöggl et al. (2007b; 2006) demonstrated in elite adult XC skiers that short-duration maximal speed in DP (maximal speed test on the treadmill) predicted DP sprint performance over a 1000-m race distance. In addition, short-duration maximal speed in DP and the diagonal stride was highly related to performance in a sprint simulation in the classical style on the treadmill over 1100 m (Stöggl et al., 2007a). Sandbakk et al. (2011) demonstrated that peak speed during a short-duration incremental test in male world-class sprint skiers was higher when compared with national level sprint skiers using the V2 technique, however, no differences were found in peak acceleration (30 m skating sprint) and maximal strength. From a skiing technical perspective, Andersson et al. (2010) found that maximal speed in DP and V2 skating was positively related to percent of racing time using the V2 technique during a sprint race. In line with the various findings in elite XC skiers, short duration maximal speed is a time economic and highly P_{XC} predicting test concept, independent of age and sex. This result implies also the necessity to focus on the development of maximal speed abilities already in youth XC skiers.

DP tests over longer distance: The current study demonstrated that DP performances over longer distance (225 m up, 575 m total) were among the highest Pxc predicting test concepts in youth XC skiers, independent of sex. It is worth noting that only the boys DP350-m flat test, and for girls and boys, the DP225-m uphill test were discriminating factors for P_{XC}. Stöggl and Holmberg (2016) reported that during uphill DP, elite skiers produced greater peak pole forces, distinctly greater force impulses and greater power output when compared with DP on flat terrain. These greater pole forces might be explained by the slower skiing speeds enabling longer generation of force (56% longer poling time), as well as by the enhanced pull of gravity that must be overcome during uphill DP. This indicates that in youths, the more force related DP uphill performance is highly related to P_{XC}. This finding is in accordance with Stöggl et al. (2015) showing high correlations between a push-up test and P_{XC} for both boys and girls. Furthermore, Gaskill et al. (1999) found a strong sex-independent relationship (r = 0.89) between upper body performance and race velocity in high school and adult XC skiers. They strongly recommended that XC skiers should focus a large portion of their training on the development of upper body power.

These results are in line with studies in adult XC skiers depicting correlations between DP performance over longer duration with P_{XC} (Carlsson et al., 2012; 2014; Fabre et al., 2010; Holmberg and Nilsson, 2008; Mahood et al., 2001; Mikkola et al., 2010; Sandbakk et al., 2016). In the study of Mahood et al. (2001), 1 km DP time trial performance exhibited the strongest correlation to both a rank order based on competition performance during the winter (r = 0.95), and a 10-km roller skiing time trial (r = 0.92). Mikkola et al. (2010) investigated the performance-predicting factors of a simulated XC skiing sprint competition (4 x 850 m) in elite male XC skiers on roller skis using the V2 skating technique on an indoor tartan track, and a 2 x 2 km DP test. It was demonstrated that the 2 x 2 km DP test was the best single performance-predicting factor for sprint performance indicating that sprint skiers should emphasize sport-specific upper body training and training skiing economy at high speeds. Fabre et al. (2010) indicated that peak speed of an incremental DP test in female elite XC skiers (4% grade test duration of 7 - 8 min) was related to competition performance (Italian Ski Federation Points). This finding coincides with the present study showing that the girls‘, as well as the boys', DP225-m uphill performance was strongly related to P_{XC}. Carlsson et al. (2014) investigated relationships between a 2 km uphill DP test and competitive performance capacity in both male and female XC skiers (FIS junior ranking points for distance and sprint competitions). For both male and female XC skiers, FIS-sprint and FIS-distance points were moderately to highly (r = 0.77 - 0.86) correlated with the DP uphill test, concluding that roller skiing time trials are useful tests for accurately predicting the performance capacity of junior XC skiers. Recently, Sandbakk et al. (2016) demonstrated that in elite female XC skiers, classical time trial performance over 10 km was strongly correlated to the covered distance during a 3 min roller-skiing test with DP. The fact that only the boys' DP350-m flat test predicted P_{XC}, while the girls' DP350-m flat test showed acceptable insignificant correlations (r = 0.67), can be explained by a greater sample of boys.

All these findings, in concert with the developments and altered demands in adult elite XC skiing as reported above, support the aspect that young skiers also should focus on DP training and emphasize sport-specific upper body training, short duration maximal skiing speeds, and develop skiing economy at high speeds based on fundamental (roller)skiing techniques (Mikkola et al., 2010; Stöggl et al., 2007a; 2007b). This conclusion is supported by previous findings of our group (Stöggl et al., 2015) showing that P_{XC} of boys was predominantly influenced by upper body and trunk strength capacities (medicine ball throw, push-ups, and pull-ups) and jumping power (standing long and triple jump).

Only boys' cycle lengths (DP225-m up, DP 575-m total and all 50 m sprints) were related with P_{XC} while for the girls', only cycle length during DP225-m uphill showed a low but insignificant correlation (r = 0.59). The importance of cycle length for P_{XC} was documented previously in different studies (Bilodeau et al., 1996; Boulay et al., 1994; Smith et al., 1989), and was further strengthened by Stöggl and Müller (2009), who demonstrated a skier's ability to produce up to 75% longer cycle lengths at up to 45% higher skiing speeds in DP and the V2 skating techniques compared with former literature. To be added here, that cycle length can only be seen as a predictor of skiing speed and power output as long as the cycle rate can be maintained, or a critical rate is achieved. However, it is important to mention here that when using maturity offset as a confounder resulted (with the exception of V2 50 m), in only non-significant correlations (Table 4). It seems that within this age group, various combinations of cycle rate and length result in a high P_{XC} (especially in the girls). Thus, within this age group, and especially in the girls, a lack of cycle length can be compensated by an augmented cycle rate, which might no longer be beneficial if skiing over longer distances and mean skiing speeds are greater (e.g. elite adult skiers).

Sex differences

While no differences between girls' and boys' anthropometrics or calendar age were found, boys' PHV later led to a negative maturity offset compared with a positive in the girls. With the exception of DP350-m flat there were significant differences between the sexes with better roller skiing performance in the boys. The highest sex differences were found for DP225-m uphill (13.9%) and 50 m leg skating (12.4%) time, with better values for boys compared with girls. This is in accordance with the study of Sandbakk et al. (2014), where greater relative sex differences were found in exercise modes where the upper body was involved to a greater extent.

The absence of a sex difference during DP 350-m flat might be based on the fact that girls' DP flat performance already is determined by a well-developed and economic DP technique. While during uphill DP and short duration sprints, higher force impulses, maximal forces and power output (Stöggl and Holmberg 2016), and the ability to rapidly accelerate are crucial. These factors are strongly related to strength capabilities shown to be higher in boys compared with girls (Stöggl et al., 2015) and emphasize the great potential for improvement in girls' P_{XC} by increasing uphill DP performance and upper body strength as mentioned above.

Conclusion

In the present study, performance in the different DP tests (350 m flat, 225 m uphill) and short duration 50 m maximal speed tests (DP, V2 skating and leg skating) were the best P_{XC} predicting factors in girls and boys. These findings in youths are in line with adult studies in XC skiing that show the importance of upper body strength and endurance capacities predominantly expressed by DP performance. The lack of the effect of maturation on P_{XC} in girls indicates that they are almost fully matured at the age of 13 and that their performance might be influenced to a greater extent by skiing technique, while boys are able to compensate for poorer technique by strength abilities. Even when controlling for maturity offset, boys P_{XC} was still highly associated with roller skiing performance. Therefore, these semi-specific roller skiing test concepts are stable and valid measures and are suitable for the prediction of youth P_{XC} on snow. In conclusion, the increases in skiing speeds and changes in skiing techniques in elite XC skiers emphasize the importance of the development of specific and semi-specific speed and coordinative aspects early on in children and youth XC skiers. The test concepts presented should provide practicable support for ski clubs, schools or skiing federations in the guidance and evaluation of young talents, being aware of confounders like maturity status, especially in boys.

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Key points

- Double poling tests on flat and uphill terrain and short duration maximal speed tests were the highest cross-country skiing predicting factors in girls and boys.
- Only in the boys there was an effect of maturation on the performance outcomes, pointing out that girls seem to be almost fully matured at the age of 13 in contrast to the boys.
- Roller skiing tests over short distance (50-m) and longer distance 225 m and 350 m are stable and valid measures and suitable for performance prediction in youth cross-country skiers.

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