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Physiological Differences Between Sprint- and Distance-Specialized Cross-Country Skiers

Thomas Losnegard and Jostein Hallén

Purpose: **S**print- (≤1.8 km) and distance-skiing (≥15 km) performance rely heavily on aerobic capacity. However, in sprint skiing, due to the ~20% higher speed, anaerobic capacity contributes significantly. This study aimed to identify the possible anthropometric and physiological differences between elite male sprint and distance skiers. ***Methods:*** Six sprint and 7 distance international-level cross-country skiers completed testing using the V2 skating technique on a roller-ski treadmill. Measurements included submaximal O_2 cost (5°, 3 m/s) and a 1000-m time trial (6°, >3.25 m/s) to assess VO_{2peak} and accumulated oxygen ($\sum O_2$) deficit. ***Results:*** The groups displayed similar O_2 cost during the submaximal load. The sprint skiers had a higher $\sum O_2$ deficit (79.0 ± 11.3 vs 65.7 ± 7.5 mL/kg, *P* = .03, ES = 1.27) and VO_{2peak} in absolute values (6.6 ± 0.5 vs 6.0 ± 0.5 L/min, *P* = .04, ES =1.23), while VO_{2peak} relative to body mass was lower than in the distance skiers (76.4 ± 4.4 vs 83.0 ± 3.2 mL · kg^{-1} · min^{-1}, *P* = .009, ES = 1.59). The sprint skiers were heavier than the distance skiers (86.6 ± 6.1 vs 71.8 ± 7.2 kg, *P* = .002, ES = 2.07), taller (186 ± 5 vs 178 ± 7 cm, *P* = .04, ES = 1.25), and had a higher body-mass index (24.9 ± 0.8 vs 22.5 ± 1.3 kg/m^2, *P* = .003, ES = 2.05). ***Conclusion:*** The elite male sprint skiers showed different anthropometric and physiological qualities than the distance skiers, with these differences being directly related to body mass.

Keywords: anaerobic capacity, maximal aerobic power, training

Cross-country (XC) skiing is a highly demanding endurance sport that consists of 2 main techniques (classic and free technique) and several race distances (1.8–50 km). Most male XC skiers compete in both sprint (£1.8 km) and distance (³15 km) races. However, results from the World Cup standing in 2011–12 show that only 2 male athletes were in the top 10 in both the sprint and distance cups.[1] Hence, a marked specialization is evident in male XC skiing, and these capacity differences have not, to date, been thoroughly investigated.

Performance in both sprint and distance XC skiing is highly related to maximal aerobic power (VO_{2peak}) and the O_2 cost of locomotion.[2–4] In addition, a significant O_2 deficit has been observed during the uphills, indicating a high anaerobic-energy contribution.[5,6] In sprint skiing, skiers perform 2- to 4-minute races at maximal effort where the aerobic versus anaerobic energy-supply ratio is close to 70:30.[7] This contribution of energy systems is comparable to other sports of similar durations.[8] In other endurance sports such as running and cycling, both aerobic power and anaerobic characteristics are clearly different between athletes competing in different events such as time trials or specialists such as climbers and sprinters.[9–12] Therefore, specialized sprint and distance skiers may have different aerobic and anaerobic characteristics.

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Studies over the last decades have shown that international-level distance XC skiers are among the endurance athletes with the highest VO_{2max}.[2,3] This is true also for sprint skiers.[4] However, in sprint races, the average speed is 20% higher than in distance races (race times >35 min),[1] and a high anaerobic capacity in addition to high aerobic power may be a prerequisite to achieve these speeds. The exercise intensity during sprint races can reach 120% to 160% of VO_{2peak} during uphill segments and therefore requires a significant anaerobic-energy turnover.[5,7] Distance skiing also relies on a high work rate in the uphills, but to a lesser extent (~100–120% of VO_{2peak}) than in sprint skiing.[6] Since anaerobic capacity is highly related to the muscle mass involved in the exercise,[13,14] differences in body mass may also occur between different types of athletes. For instance, the best climbers in road cycling have a significantly lower body mass, body height, and body-mass index and a higher VO_{2peak} normalized for body mass than time-trial specialists.[9] A similar trend could be found in today's XC skiing. Due to their shorter length, sprint courses normally have shorter uphills,[1] allowing speed to be higher since anaerobic capacity can contribute significantly.[8]

Although previous studies have investigated international-level versus national-level skiers in the 2 disciplines,[3,4] the differences between specialized skiers have not yet been studied. Such information is important for talent identification, training preparation, and test methodology. Therefore, the current study was designed

to investigate the anthropometric and physiological differences between elite male sprint and distance XC skiers.

Methods

Subjects

Thirteen elite senior XC skiers were assigned to 1 of 2 groups: sprint skiers (n = 6) or distance skiers (n = 7). The 2 groups were similar according to performance based on results from the Norwegian Championship, World Cup races, and their respective FIS (International Ski Federation) points (sprint or distance; Table 1). All skiers were considered to be at an international standard. The subjects included 1 FIS World Champion, 1 skier with several FIS World Cup victories, and 2 skiers with several top-5 rankings in FIS World Cup races, and all skiers had top-10 rankings in the Norwegian Championships. The subjects had regularly participated in roller-ski treadmill testing (1–4 y) using a protocol identical to that described following. All subjects competed in both the classic and freestyle techniques, and none were classic or freestyle specialists. The classic and freestyle FIS points during the 3 best races that particular season were 38 ± 11 and 37 ± 11 (P = .89) for the distance skiers and 54 ± 12 and 51 ± 10 (P = .26) for the sprint skiers, respectively. The study was approved by the Regional Ethics Committee of Southern Norway, and the subjects gave their written consent before study participation.

Design

Submaximal assessments included measurement of steady-state oxygen uptake (speed 3 m/s, incline 3.5–6.5°), while during a 1000-m time-trial test (speed 3.25–5 m/s, 6°) VO_{2peak} and the accumulated oxygen deficit ($\sum O_2$ deficit) were measured. All these tests used the V2 skating technique that consists of a simultaneous arm and leg push on both sides. This technique has been shown to be appropriate for the inclines and speeds used in the current study.[7] All tests were performed from September to February, a period that seems most appropriate to detect differences between elite skiers.[2]

Methodology

Submaximal Tests. Before the start, subjects warmed up for 15 minutes at 3° and 2.25 m/s (~60–75% of HR_{peak}). All submaximal tests were performed at 3 m/s, with 5 minutes duration and with 2-minute breaks between trials. The speed was set high enough to induce a relevant technique at moderate inclines but low enough to ensure a steady-state VO_2 (<90% of VO_{2peak}). Subjects started at 3.5°, and the incline was subsequently increased 4 to 6 times by 0.5° (depended on the skier's work capacity) every 5 minutes until they reached a lactate concentration (La^-) of ≥2.5 mmol/L or a rating of perceived exertion (RPE; Borg scale 6–20) of ≥15. This was done to avoid any possible interference with the 1000-m test, with regard to a residual fatiguing effect. Only the workload performed at 5° incline, which was the highest workload all subjects completed, was used for the subsequent O_2-cost analysis. However, all submaximal workloads performed by an individual subject were used to determine the O_2 demand at supramaximal workloads. O_2 cost in the current study was defined as the average oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$) between 2.5 and 4.5 minutes at each incline. Heart rate (HR) was measured in the same 2-minute period, and blood for evaluation of La^- was taken 30 seconds after each bout.

1000-m Time and VO_{2peak}. The 1000-m test has been described in detail previously[2] and was conducted 8 minutes after the last submaximal trial. The incline was 6°, and the subjects controlled the speed (0.25-m/s increment or decrement) by adjusting their fore–aft position on the treadmill relative to laser beams situated in front of and behind the skier. VO_2 was measured continuously (5-s

Table 1 FIS (International Ski Federation) Points and Physical Data of the 2 Groups, Mean ± SD (Range)

Variable	Sprint skiers (n = 6)	Distance skiers (n = 7)	Cohen's *d* ES
FIS points (distance)	99.1 ± 30.2 (67.6–156.7)*	28.5 ± 11.0 (11.5–44.0)	2.03
FIS points (sprint)	37.3 ± 19.2 (9.1–58.9)*	84.9 ± 32.5 (46.1–127.2)	2.25
Age (y)	24.8 ± 1.6 (23–27)	24.1 ± 2.7 (22–27)	0.29
Body height (cm)	186 ± 5 (181–194)*	178 ± 7 (172–187)	1.25
Body mass (kg)	86.6 ± 6.2 (77.8–92.7)*	71.8 ± 7.2 (62.5–82.0)	2.07
Body-mass index (kg/m^2)	24.9 ± 0.9 (23.8–26.1)*	22.5 ± 1.3 (20.9–23.5)	2.01
Hb mass (g)	1249 ± 113 (1045–1375)	1117 ± 147 (981–1425)	0.94
Hb mass (g/kg)	14.4 ± 1.4 (13.4–16.2)	15.6 ± 1.3 (13.8–17.4)	0.86

Abbreviations: ES; effect size: <0.2 trivial, 0.2–0.6 small, 0–6-1.2 moderate, 1.2–2.0 large, >2.0 very large.

*Significant differences between the 2 groups (P < .05).

epochs), and the average over the 12 highest continuous VO_2 values (60 s) was taken as VO_{2peak}.

Calculations of $\sum O_2$ Deficit. The calculation of the $\sum O_2$ deficit with adjustments for O_2 stored has been described in detail previously.[7] The $\sum O_2$ demand at the supramaximal speeds was estimated by extrapolation of the individual linear relationship between the work rate and steady-state O_2 cost from at least 4 trials between 3.5° and 6° for each subject individually, modified from Medbø et al.[15] The calculations are based on the assumption that the ratio of O_2 cost to work rate is constant with increasing speed. The $\sum O_2$ deficit was calculated as $\sum O_2$ demand minus $\sum O_2$ uptake.[15] Power was calculated as the sum of the power against gravity (P_g) and the power against rolling friction (P_f), in a coordinated system moving with the treadmill belt at a constant speed. P_g was calculated as the increase in potential energy per time, $P_g = m \cdot g \cdot \sin(\alpha) \cdot v$, and P_f was calculated as the work against Coulomb frictional forces at a given tangential speed, $P_f = \mu \cdot m \cdot g \cdot \cos(\alpha) \cdot v$, where μ is the coefficient of friction, m is the total mass of the skier and equipment, g is gravitational acceleration, v is the belt speed, and α is the treadmill incline.

After the onset of exercise, the O_2 stored in the venous blood is reduced, and this aerobic contribution to total energy release was in our measurements part of the $\sum O_2$ deficit. We measured hemoglobin (Hb) mass in every subject (Table 1) and calculated the reduction in O_2 stored.[7] The total O_2 stored in the blood was estimated to decrease by 713 ± 87 mL (range 594–863 mL), or 9.1 ± 0.8 mL/kg. These values were subtracted individually from the $\sum O_2$ deficit to estimate the anaerobic contribution.

Performance Level. The FIS points (sprint or distance points) the skiers had at the time of testing were used for subsequent data analysis. According to FIS,[1] a skier's rank is relative to a 0-point standard established by the top-ranked skier in the world. A skier's total points for a given race are determined by adding race points (from comparing the individual skier's time with the winner's time) and race penalty based on the FIS points of the 5 best competitors in the competition. Hence, better skiers have lower FIS points.

Training-History Survey. Training history for the annual training cycle (12 months; May to May) was recorded based on the skiers' training diaries and categorized into intensity zones according to the session-goal method.[16] Endurance training and competition intensity were monitored by HR and categorized into 3 intensity zones: low-intensity training (LIT; 60–81% of HR_{max}), moderate-intensity training (MIT; 82–87% of HR_{max}), and high-intensity training (HIT; >88% of HR_{max}). The intensity during continuous workouts was quantified using the average HR during the whole session. For high-intensity interval training, the average peak HR during the interval bouts was used to determine the intensity zones. In addition, training time during strength training (general and maximal) and speed training was recorded.

Apparatus. VO_2 was measured by an automatic ergospirometry system (Oxycon Pro Jaeger Instrument, Hoechberg, Germany), which has been evaluated by Foss and Hallén.[17] La^- was measured in unhemolyzed blood from capillary fingertip samples (YSI 1500 Sport, Yellow Springs Instruments, Yellow Springs, OH). The lactate analyzer and the Oxycon Pro Jaeger instrument were calibrated according to the instruction manual and described in detail previously.[18] Roller-ski testing was performed on a treadmill with belt dimensions of 3 × 4.5 m (Rodby, Sodertalje, Sweden). The treadmill gradients and speed were checked before, during, and after the testing period. Swix CT1 poles (Swix, Lillehammer, Norway) with a tip customized for treadmill roller skiing were used (pole length 170 ± 5 and 161 ± 6 cm, corresponding to 91% ± 1% and 90% ± 1% of body height, sprint and distance skiers, respectively). Two different pairs of Swenor Skate roller skis (Swenor, Sarpsborg, Norway) with wheel type 1 were used depending on the binding system the skiers normally used (NNN, Rottefella, Klokkarstua, Norway or SNS, Salomon, Annecy, France). The rolling friction coefficient (after 15 min prewarming: $\mu = 0.020$ for both binding systems) of the skis was tested before, during, and after the project using a towing test.[19] The subjects' body mass and body height were measured before each treadmill test (Seca, model 708 Seca, Hamburg, Germany). Hb mass was measured by the optimized CO-rebreathing method as described by Schmidt and Prommer.[20]

Statistical Analyses

All data were checked for normality with a Shapiro–Wilk test and presented as mean and standard deviation (SD). First, the traditional approach of determining statistical significance, via *P* values, was used. Differences between groups were calculated with an independent *t*-test procedure. A *P* value ≤.05 was considered statistically significant. The magnitude of differences between sessions was expressed as standardized mean differences (Cohen's *d* effect size; ES). The criteria to interpret the magnitude of the ES were 0.0 to 0.2 trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large, and >2.0 very large.[21] Statistical calculations were performed with Microsoft Excel and SigmaPlot 11 software.

Results

Performance Level and Anthropometric and Training Characteristics

The sprint skiers' specialized-sprint FIS points did not differ compared with the distance skiers' specialized-distance FIS points ($P = .32$, ES = 0.51). However, both groups had a higher international ranking (lower FIS points) in their specialized than their nonspecialized discipline (Table 1). The sprint skiers had a significantly greater body height ($P = .04$), body mass ($P = .002$), and body-mass index ($P = .009$) than the distance skiers (Table 1).

There was a nonsignificant ($P = .12$) and moderate effect size in Hb mass relative to body mass (g/kg) between the 2 groups (Table 1). In terms of training, there were no significant differences in total annual training volume over 12 months in LIT ($P = .97$), MIT ($P = .82$), HIT ($P = .97$), or total volume ($P = .78$) between groups. The sprint skiers had a significantly higher volume of speed training ($P = .02$) and tended to have a higher volume of strength training ($P = .08$) than the distance skiers (Table 2).

Physiological Characteristics

Submaximal Tests. At 5° incline and 3 m/s, the total O_2 cost (L/min) was higher for the sprint skiers, but relative to body mass the O_2 cost was identical in the 2 groups. Since the VO_{2peak} relative to body mass was lower in sprint skiers than distance skiers, the sprint skiers worked at a higher relative intensity. This is illustrated by a large effect size in relative HR and a small to moderate effect size in respiratory exchange ratio, La^-, and RPE (Table 3).

Maximal Test. The distance skiers were faster than the sprint skiers for the 1000-m test (Table 4). The sprint skiers displayed a significantly higher absolute VO_{2peak} ($P = .04$). However, the distance skiers showed a significantly higher VO_{2peak} relative to total body mass ($P = .009$) but not in $mL \cdot kg^{-2/3} \cdot min^{-1}$ ($P = .42$). The sprint skiers showed a significantly higher anaerobic capacity, estimated by the $\sum O_2$ deficit, in both absolute ($P = .0006$) and relative values ($P = .03$), compared with distance skiers. Furthermore, the sprint skiers were able to work at a higher relative intensity (O_2 demand/VO_{2peak}) than the distance skiers ($P = .09$). Notably, despite a significantly lower $\sum O_2$ deficit, the distance skiers showed a moderate effect size in higher La^- than the sprint skiers ($P = .13$).

The coefficient of variation (CV; SD/mean) for the different VO_{2peak} units was lowest for $mL \cdot kg^{-2/3} \cdot min^{-1}$ (3.2%), followed by when expressed as $mL \cdot kg^{-1} \cdot min^{-1}$ (3.9%), for the distance skiers. A similar pattern was found for the sprint skiers, although the variation was higher than for the distance skiers (CV for $mL \cdot kg^{-2/3}$

Table 2 Annual Training (12 mo) Characteristics of the Sprint and Distance Skiers, Mean ± SD

	Sprint Skiers (n = 6)		Distance Skiers (n = 7)	
	Total training (h)	% of total training	Total training (h)	% of total training
Low-intensity training (<81% of HR_{max})	553 ± 59	81 ± 2	555 ± 117	83 ± 4
Moderate-intensity training (82–87% of HR_{max})	30 ± 15	4 ± 2	32 ± 15	5 ± 2
High-intensity training (>88% of HR_{max})	37 ± 4	6 ± 1	37 ± 8	6 ± 2
Strength	49 ± 11	7 ± 2	37 ± 10	6 ± 2
Speed	17 ± 8*	2 ± 1*	5 ± 5	1 ± 1
Total	686 ± 73		667 ± 130	

Abbreviations: HR_{max} = maximal heart rate.

*Significantly different from distance skiers ($P < .05$)..

Table 3 Power Output and Physiological Response During Submaximal Skiing at 5° and 3 m/s, Mean ± SD (Range)

Variable	Sprint skiers (n = 6)	Distance skiers (n = 7)	Cohen's *d* ES
Power output (W)	285 ± 21 (262–303)*	237 ± 24 (205–268)	2.03
Power output (W/kg)	3.30 ± 0.04	3.30 ± 0.02	0.13
O_2 cost (L/min)	4.9 ± 0.3 (4.7–5.2)*	4.0 ± 0.4 (3.4–4.7)	2.24
O_2 cost ($mL \cdot kg^{-1} \cdot min^{-1}$)	56.1 ± 1.4 (54.8–58.6)	56.1 ± 2.3 (53.4–59.5)	0.02
Hear rate (% of maximal)	89 ± 4 (82–93)*	84 ± 4 (77–88)	1.27
Respiratory exchange ratio	0.90 ± 0.04 (0.85–0.96)	0.89 ± 0.03 (0.85–0.93)	0.44
Blood lactate concentration (mmol/L)	1.8 ± 0.5 (0.9–2.3)	1.4 ± 0.3 (1.0–1.9)	0.80
Rating of perceived exertion	14 ± 2 (11–16)	13 ± 2 (10–15)	0.49

Abbreviations: ES; effect size (<0.2 trivial, 0.2–0.6 small, 0–6-1.2 moderate, 1.2–2.0 large, >2.0 very large).

*Significantly different from distance skiers ($P < .05$).

Table 4 Power Output and Physiological Response During the 1000-m Time Trial, Mean ± SD (Range)

Variable	Sprint skiers (n = 6)	Distance skiers (n = 7)	Cohen's *d* ES
1000-m time (s)	253.3 ± 5.6 (245.2–258.5)*	241.8 ± 5.5 (234.5–250.3)	1.89
Power output (W)	453 ± 13 (441–461)*	379 ± 33 (326–417)	1.89
Power output (W/kg)	5.01 ± 0.11 (4.92–5.17)*	5.29 ± 0.14 (5.08–5.48)	2.02
VO_{2peak} (L/min)	6.6 ± 0.5 (5.8–7.3)*	6.0 ± 0.5 (5.2–6.6)	1.23
VO_{2peak} ($mL \cdot kg^{-1} \cdot min^{-1}$)	76.4 ± 4.4 (71.8–82.2)*	83.0 ± 3.2 (79.5–87.8)	1.59
VO_{2peak} ($mL \cdot kg^{-2/3} \cdot min^{-1}$)	337 ± 19 (315–364)	344 ± 11 (328–361)	0.41
VE_{peak} (L/min^{1})	210 ± 15 (194–228)	193 ± 18 (178–210)	0.96
VE/VO_2 (L/min)	32 ± 3 (28–35)	32 ± 1 (30–35)	0.25
Peak heart rate (beats/min)	188 ± 5 (179–193)	181 ± 10 (169–196)	0.83
Respiratory exchange ratio	1.13 ± 0.06 (1.06–1.20)	1.11 ± 0.06 (1.05–1.20)	0.33
La^{-}_{peak} (mmol/L)	8.2 ± 1.1 (7.5–9.6)	9.0 ± 0.7 (8.2–10.3)	0.82
$\sum O_2$ deficit (L)	6.8 ± 0.9 (5.4–7.9)*	4.7 ± 0.7 (3.8–5.7)	2.38
$\sum O_2$ deficit (mL/kg)	79.0 ± 11.3 (58.8–91.0)*	65.7 ± 7.5 (57.6–74.7)	1.27
Fractional utilization (%)	85.9 ± 2.1 (83.7–88.3)	85.9 ± 1.6 (84.3–88.7)	0.00
Relative intensity (O_2 demand/VO_{2peak})	110 ± 4 (106–115)	106 ± 4 (101–111)	0.99

Abbreviations: ES; effect size (<0.2 trivial, 0.2–0.6 small, 0–6-1.2 moderate, 1.2–2.0 large, >2.0 very large); VO_{2peak}, peak oxygen uptake; VE_{peak}, peak ventilation; La^{-}_{peak}, ; $\sum O_2$, accumulated oxygen.

*Significantly different from distance skiers ($P < .05$).

$\cdot min^{-1}$ 5.6%, CV for $mL \cdot kg^{-1} \cdot min^{-1}$ 5.7%). For both groups, the absolute values showed the largest variation among subjects (~8%).

Discussion

This study demonstrates differences in anthropometric and physiological capacities between sprint- and distance-specialized elite cross-country skiers. Absolute VO_{2peak} and anaerobic capacity were higher in the sprint skiers compared with the distance skiers, while the distance skiers showed a significantly higher VO_{2peak} relative to body mass. The sprint specialists were heavier and taller than the distance specialists.

In the current study, body mass, body height, and body-mass index in the sprint skiers were almost identical to those in the only study that has explicitly used international-level sprint skiers from the Norwegian national team.[4] Notably, Norwegian elite sprint skiers seem to be taller and heavier than sprint skiers from other countries. The 10 best sprint skiers from the overall World Cup standing 2011–12 (which included 2 Norwegians) had a body height and body mass of ~179 cm and 78 kg.[22] However, despite the same body height in the 10 best distance skiers, they were significantly lighter (~72 kg) than the sprint skiers, similar to the distance skiers in the current study.[22] Due to the gravitational work, lighter skiers with a high VO_{2peak} relative to body mass are favored in uphill parts of the course. However, sprint courses are shorter, have less total climb, and normally have shorter uphills.[1] Hence, in sprint skiing, a high absolute VO_{2peak} and a high anaerobic capacity may compensate for a lower VO_{2peak} relative to body mass.

The distance skiers showed a narrower range in VO_{2peak} relative to body mass than the sprint skiers. Hence, VO_{2peak} relative to body mass as a single determinant of performance is likely to be more important in distance skiing than in sprint skiing. The very high VO_{2peak} values reported in the distance skiers is similar to those in other studies on world-class skiers tested during running over the last 6 decades.[2,3,23–26] Bergh[23] stated that there was very little chance of male skiers winning gold medals in distance skiing in the Olympic games or world championship with a VO_{2peak} more than a few percent below ~350 $mL \cdot kg^{-2/3} \cdot min^{-1}$ or 85 $mL \cdot kg^{-1} \cdot min^{-1}$ during the 1970 and 1980s. Therefore, independent of the changes that have occurred in XC distance skiing in recent decades (eg, more mass starts), such values are probably still a prerequisite for international success in distance XC skiing.

An interesting finding was that Hb mass relative to body mass tended to be higher in the distance skiers. This is consistent with the higher VO_{2peak} relative to body mass.[27] Theoretically, this difference may be due

to individual variations in training, heritage, and/or use of altitude training. The only differences in training we could identify were that the sprint skiers had higher volumes of speed training (P = .02) and strength training (P = .08). The effect of strength training on Hb mass is not known, and it could be that strength training affects muscle mass, and therefore body mass, without affecting blood volume. There is no evidence that altitude training has a long-lasting effect on Hb mass. In addition, the use of altitude training was not different between the groups (data not shown). The most likely reason for the higher Hb mass is therefore genetics. It must be emphasized, however, that the sprint skiers had Hb mass in the range of well-trained endurance-trained athletes.[28]

The current study is the first, to our knowledge, to quantify anaerobic capacity in a group of international-level sprint and distance skiers. Anaerobic capacity is likely to be an important factor in sprint skiing, as the sprint skiers had a significantly higher $\sum O_2$ deficit both in absolute and relative values than the distance skiers. Previous studies have shown that $\sum O_2$ deficit is related to the muscle mass involved in the exercise.[13,14] Therefore, higher body mass and body-mass index in the sprint skiers may partially explain why the sprint skiers seem to have a higher $\sum O_2$ deficit than the distance skiers. Long-term heavy strength training will induce increases in muscle cross-sectional area and thus muscle mass in XC skiers.[18] The annual volume of strength and speed training in the sprint skiers was also higher than in the distance skiers (~65 vs 36 h, P = .007, ES = 1.55). Thus, it can be suggested that some of the differences in $\sum O_2$ deficit (and body mass) between skiers are related to differences in training focus with regard to maximal strength and speed training. However, inheritable factors obviously also play important roles related not only to anthropometry but possibly also to fiber-type distribution and other muscle characteristics.

Notably, in the current study we established the relation between external power and O_2 cost by increasing the incline and maintaining the speed constant, while during the 1000-m test, the incline was constant and the speed was changed. Although such methodical interpretation does not have a major impact for results in the current study since all subjects performed the same protocol, future studies should be aware of the methodical considerations previously discussed.[7]

Practical Applications

Knowledge of what capacities are required for a specific sport is important for both talent identification and training optimization. Over the last decades, there have been some changes in competition formats (eg, more mass starts), increasing the reliance on sprinting ability in the finishing phase. However, the aerobic power of distance skiers has not changed over the last 6 decades.[2,3,23–26] Hence, development of a high aerobic power, both in absolute values and relative to body mass, must still be a main focus in training. A high VO_{2peak} relative to body mass also seems important in sprint skiing, but optimal performance in such events also relies on a high absolute VO_{2peak} and a high anaerobic capacity. The sprint skiers also performed more strength and speed training than the distance skiers. However, sprint skiing is a relatively new discipline, and the scientific basis for the effect of speed and strength training on performance is currently lacking.

Conclusion

Elite male sprint skiers have both higher absolute anaerobic capacity and higher maximal aerobic power than elite distance skiers. However, distance skiers have higher maximal aerobic power relative to body mass.

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