Do Anthropometric and Aerobic Parameters Predict a Professional Career for Adolescent Skiers?

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ABSTRACT

The aim of this study was to evaluate whether spiroergometry performance in adolescent alpine ski racers can predict later advancement to a professional career. Over 10 consecutive years, adolescent skiers of the regional Austrian Youth Skier Squad (local level) underwent annual medical examinations, including exhaustive bicycle spiroergometry. The performance was determined at fixed (2 and 4 mmol/l serum lactate) and individual (individual anaerobic threshold (IAT) and lactate equivalent (LAE)) thresholds. Data from the last available test were compared between skiers who later advanced to the professional level (Austrian national ski team) and those who did not. Ninety-seven alpine skiers (n = 51 male; n = 46 female); mean age 16.6 years (range 15–18) were included. Of these, 18 adolescents (n = 10 male; n = 8 female) entered a professional career. No significant differences were found for maximum oxygen uptake (VO_{2max}). Athletes advancing to the professional level had significantly higher performance and VO_2 at LAE. Additionally, male professionals had significantly higher performances at fixed thresholds and the IAT. The performance and VO_2 at the LAE, and thus the ability to produce power at a particular metabolic threshold, was the most relevant spiroergometric parameter to predict a later professional career.

Introduction

Professional skiing associations and the Austrian Government invest a considerable amount of money in the training of adolescent skiers, hoping to develop the professional skiers of tomorrow. As such it would be important to identify athletes with the potential of a professional career as early as possible. However, alpine skiing is a complex winter sport requiring a high level of motoric skills, strength and an effective energy management from professional athletes. All of these factors seem to be important for performance enhancement, injury prevention, talent identification and training prescription [19]. Regarding spiroergometry, however, no useful single parameter predicting the success of an alpine ski racer has been identified yet.

A good basic endurance allows for stable performance in training and competition. In adults, the maximum oxygen uptake (VO_{2max}) is acknowledged as one of the most important parameters characterizing aerobic capacity and thus basic endurance [4, 13, 23]. Athletes with higher aerobic capacities have a greater ability to tolerate lactate at higher altitudes [12]. In addition to the maximum oxygen uptake, the performances at the aerobic and anaerobic threshold also represent significant parameters of the aerobic performance [4, 13].

With durations ranging between 45 and 150 s, alpine ski races are associated with a high strain over a short period of time. Depending on the sub-discipline about 30–50 % of the energy is provided by aerobic metabolism [15, 20]. However, the impact of VO_{2max} on success in professional alpine skiers is still a matter of debate. While some studies have found no influence [16, 21], examinations of the Austrian national ski team have shown that the maximum oxygen uptake (VO_{2max}/kg) strongly correlated with international success [14]. Nevertheless, neither the predictive value of VO_{2max} nor the performances at the aerobic and anaerobic threshold have been examined in adolescent alpine ski racers.

Additionally, complex investigations of a variety of other physiological systems in different sports such as tests of muscular strength and flexibility, anaerobic power tests and the influence of muscle fiber type yielded conflicting findings [5, 11, 14]. Alpine ski racing appears to involve a complex integration of many different physiological systems, none of which may be more important than the other to overall performance [19]. However, the above-mentioned reports are predominantly based on adult athletes and partly use elaborate and expensive sports science examinations.

The purpose of this study was to retrospectively evaluate the differences in combined (both genders) and gender-specific anthropometric data and bicycle spiroergometry performance at adolescence between future professional (national ski level) and non-professional alpine skiers.

Materials and Methods

From 2004 until 2013, a total of 97 athletes (51 male; 46 female) with a mean age of 16.6 years (range 15–18) were included. Of these 97 athletes, 18 (10 male, 19.6 % of male skiers and 8 females, 17.4 % of female skiers) advanced from the local to the national Austrian (professional) level. All athletes trained for a mean of 12.2 ± 4.8 h per week (consisting of an average of 8 h endurance training and 4.2 h of strength training); there was no significant difference between the 2 groups (local level 12.1 ± 5.0 vs. national level 12.4 ± 3.6; $p = 0.557$). All of these athletes are required to undergo an annual clinical examination determining anthropometric data and performance diagnostics consisting of exhausting spiroergometry and lactate determination to be approved for training and competition. These examinations are performed before the start of the competition period.

The clinical examination included investigation of the following anthropometric data: height, body weight (BW) and body mass index (BMI). The body fat in % was determined by the caliper method using a 4-site skin fold procedure: the skin folds were determined on the right-side triceps muscle (vertical fold on the posterior midline halfway between the acromion and the olecranon), the biceps muscle (vertical fold on the anterior midline above the belly of the biceps muscle), subscapular (the diagonal fold 1–2 cm caudal to the inferior angle of the scapula) and supra-iliacal (diagonal fold 1 cm cranial of the anterior superior iliac crest). The sum of all skin folds was used to estimate the body fat according to a standardized table as previously published [7]. The body fat was then used to determine the lean body weight (LBW; BW without body fat). Additionally, blood pressure and a 12-lead-ECG in rest were obtained from all patients. The non-invasive blood pressure (NIBP) was determined with the cuff attached to the right upper arm. NIBP measurements were conducted in supine position before spiroergometry and then in a sitting position after each step of the spiroergometry and after the recovery phase.

The clinical examination was followed by a bicycle spiroergometry test (Excalibur Sport®, Lode B.V., Groningen, The Netherlands and Spirometer Oxycon Pro®, Carl Reiner GmbH, Vienna, Austria) with a sex and body weight dependent protocol (▶ **Table 1**) [22]. Heart rate was monitored throughout spiroergometry. The spiroergometry was continued to exhaustion of the athlete and followed by a 3-min recovery phase during which the athlete pedaled at a frequency of 60–70 rpm. The respiratory parameters included tidal volume, respiratory rate, minute volume (MV) and inspiratory (FiO_2) and expiratory (FeO_2) fraction of oxygen. The accuracy for FiO_2 and FeO_2 is given with ± 0.01 vol % by the manufacturer. Using these values and the minute volume, the oxygen uptake was calculated ($VO_2 = (FiO_2 - FeO_2) * MV$). The maximum oxygen uptake (VO_{2max}) was documented for each athlete.

Lactate levels were obtained by earlobe sampling (20 µl of blood per measurement were sampled to heparinized capillaries per test) before the test, at the end of each step (▶ **Table 1**) and after the recovery phase (enzymatically amperometric measurement with a Biosen C_line®, EKF Diagnostics for life, Cardiff, UK). To gain information about the aerobic capacity of the athletes the performance in Watt and Watt/kg and the oxygen uptake VO_2 at aerobic and anaerobic thresholds were recorded. Fixed thresholds (2 mmol/l and 4 mmol/l lactate level) and individual thresholds (minimal lactate equivalent and individual anaerobic threshold) were used. All parameters were derived as described in the literature previously [6]. A regression curve using an exponential function approach was plotted from the lactate levels; the performance and VO_2/kg were determined where the lactate line crossed 2 and 4 mmol/l levels.

The data of the examinations of athletes who advanced to the national level (member of the Europe Cup or World Cup team of the Austrian Skiing Association, "Österreichischer Skiverband") was compared to those who did not. For athletes who have been examined for several years, the 3 most recent examinations were evaluated before they either ended their career or entered the national (professional) level. Additionally, gender specific differences were evaluated.

This study confirms the ethical standards of the International Journal of Sports Medicine [10]. Informed written consent was obtained from all athletes and/or their legal guardians. The investigation conforms to the Code of Ethics of the World Medical Association (Declaration of Helsinki). The study was approved by the institutional review board (EK 30–030 ex 17/18).

▶ **Table 1** Protocol for bicycle spiroergometry testing.

Body weight [kg]	**Minimum performance (start) [Watt]**	**Step (increase) [Watt]**	**Duration of step [min]**	**Performance at 3 min recovery [Watt]**
41–45	30	30	3	30
46–50	35	35	3	35
51–55	40	35	3	40
56–60	45	40	3	40
> 60 (male)	50	50	3	50
> 60 (female)	50	40	3	40

▶ **Table 2** Anthropometry and results of spiroergometry at the last available according to success in alpine skiing.

	All Athletes	Local Level	National Level	p-value	Effect size (d)
	n = 97	n = 79	n = 18		
Age [a]	16.6 ± 1.2	16.7 ± 1.2	16.4 ± 1.1	0.329	0.26
Anthropometry					
Height [m]	1.73 ± 0.09	1.7 ± 0.1	1.8 ± 0.1	0.403	1.0
BW [kg]	69.8 ± 10.6	68.7 ± 10.1	74.3 ± 11.9	0.062	0.51
BMI	23.2 ± 2.2	23.0 ± 2.1	24.1 ± 2.2	**0.032**	0.52
Body fat [%]	18.5 ± 6.3	18.4 ± 6.5	18.7 ± 5.2	0.663	0.05
LBW [kg]	57.1 ± 10.9	56.2 ± 10.5	60.8 ± 12.1	0.140	1.0
Spiroergometry					
P_{max} [W]	294.3 ± 60.6	289.9 ± 58.8	313.3 ± 66.3	0.167	0.38
P_{max}/kg BW [W/kg]	4.2 ± 0.5	4.2 ± 0.6	4.2 ± 0.5	0.978	0
VO_{2max} [ml/min]	3730 ± 709	3687 ± 690	3917 ± 783	0.258	0.31
VO_{2max}/kg BW [ml/(min * kg)]	53.5 ± 6.3	53.7 ± 6.6	52.6 ± 5.3	0.571	0.19
VO_{2max}/kg LBW [ml/(min * kg)]	65.5 ± 5.1	65.7 ± 5.1	64.7 ± 5.1	0.452	0.20
P_{AT} [W]	157.4 ± 46.5	155.0 ± 43.9	168.0 ± 56.6	0.280	0.26
P_{AT}/kg BW [W/kg]	2.2 ± 0.5	2.2 ± 0.5	2.2 ± 0.6	0.856	0
VO_{2AT}/VO_{2max} [%]	57.8 ± 7.2	57.4 ± 6.3	59.9 ± 10.2	0.224	0.31
P_{LAE} [W]	139.4 ± 35.2	135.1 ± 33.1	158.4 ± 38.6	**0.020**	0.65
P_{LAE}/kg BW [W/kg]	2.0 ± 0.4	2.0 ± 0.4	2.1 ± 0.4	**0.038**	0.25
VO_{2LAE}/VO_{2max} [%]	52.6 ± 5.7	51.7 ± 5.5	56.7 ± 4.9	**0.001**	0.96
P_{ANT} [W]	213.6 ± 48.2	209.8 ± 46.2	230.7 ± 54.2	0.141	0.42
P_{ANT}/kg BW [W/kg]	3.1 ± 0.5	3.0 ± 0.5	3.1 ± 0.4	0.686	0.22
VO_{2ANT}/VO_{2max} [%]	74.6 ± 6.2	74.3 ± 5.8	76.2 ± 7.8	0.429	0.29
P_{IAT} [W]	217.7 ± 50.5	213.6 ± 49.1	235.4 ± 53.9	0.127	0.42
P_{IAT}/kg BW [W/kg]	3.1 ± 0.5	3.1 ± 0.5	3.2 ± 0.4	0.516	0.22
VO_{2IAT}/VO_{2max} [%]	75.5 ± 6.8	75.0 ± 6.7	77.4 ± 6.8	0.153	0.36

BW = body weight; BMI = body mass index; LBW = lean body weight; Pmax = maximal performance; VO2max = maximal oxygen uptake; PIAT = performance at the individual anaerobic threshold; PLAE = performance at the minimal lactate equivalent; PAT = performance at aerobic threshold (serum lactate = 2 mmol/l); PANT = performance at the anaerobic threshold (serum lactate = 4 mmol/l).

Statistical analysis

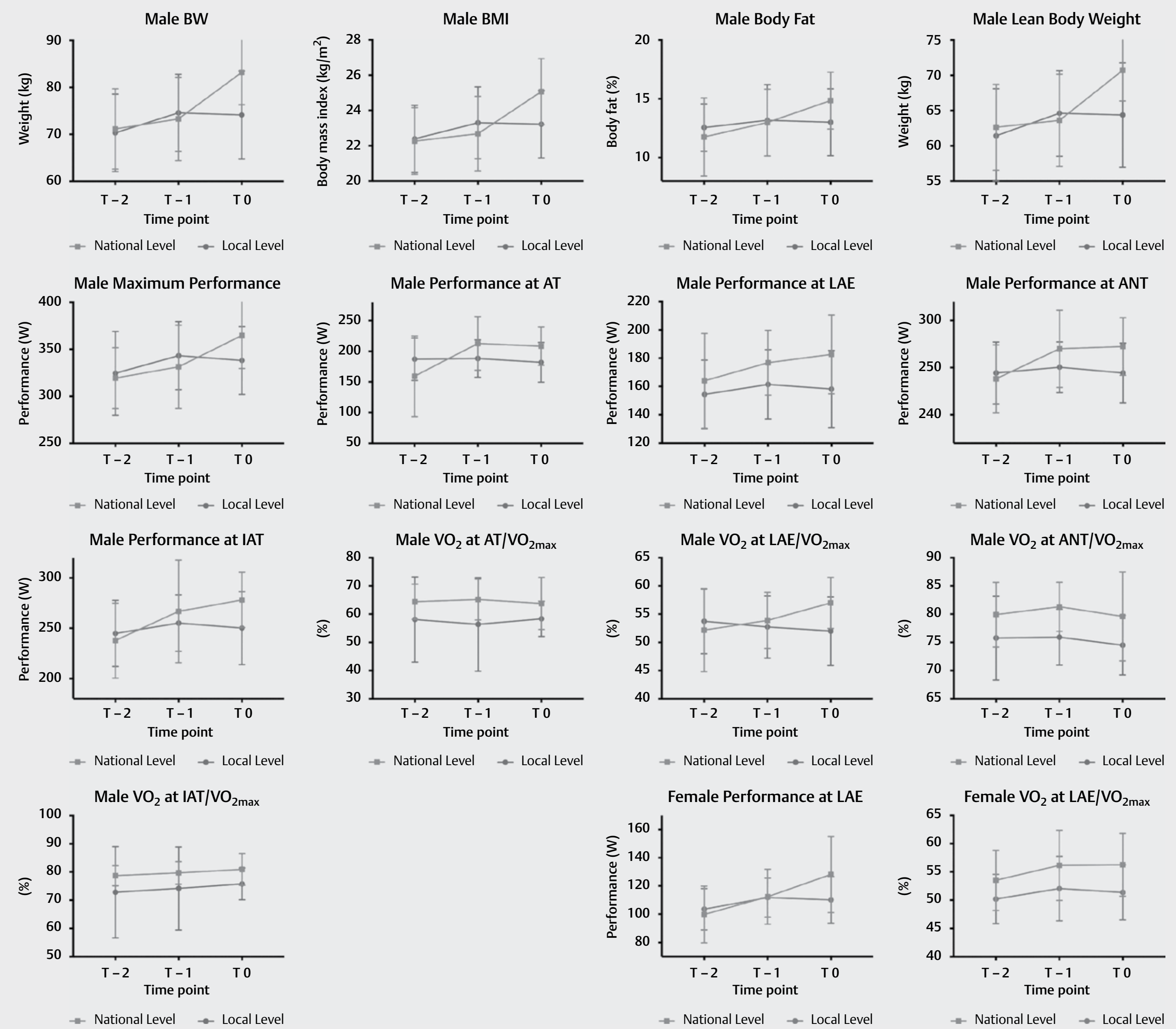
All data were entered into a Microsoft Excel 2011® spreadsheet. The statistical evaluation was performed with SPSS 22.0®. Nominal and ordinal data are displayed as numbers and percent; metric data as means ± standard deviation (minimum – maximum).

Due to the group size, an independent non-parametric Mann-Whitney-U-Test was used for comparisons of independent samples. P-values < 0.05 were regarded as statistically significant. G * Power® was used to determine posthoc effect size (d). An effect size < 0.5 was interpreted as minor, a d between 0.5 and 0.8 as moderate and a d > 0.8 as major effect.

Results

Anthropometric data and the results of spiroergometry are listed in ▶ **Table 2**. Skiers who reached the national level (at the latest one year after the spiroergometry test) had a 5 % greater BMI and insignificantly greater (8 %) body weight compared to adolescents who did not. Height and lean body weight had a major effect, while BMI and body weight had a moderate effect. In spiroergometry testing, professionals (national level) had significantly greater VO_{2LAE}/VO_{2max} than those at the local level (9 %, major effect). Additionally, the maximum performance (17 %, moderate effect) and maximum performance per kg (5 %, minor effect) at the minimal lactate equivalent (▶ **Table 2**) of professional athletes was significantly higher. There were no statistically significant differences for the other parameters investigated.

Male ski racers advancing to the professional level had a significantly greater body weight (12 %, major effect), BMI (8 %, major effect), body fat (15 %, moderate effect) and lean body weight (10 %, major effect) compared to those who remained at the local level. While BMI body weight, body fat and lean body weight showed an obvious increase in athletes at the national level these parameters remained rather stationary in those at the local level (▶ **Fig. 1** and Supplement **Fig 1S**). In spiroergometry testing, they showed significantly greater maximum performance (8 %, moderate effect), performance at the individual anaerobic threshold (11 %, major effect), performance at the minimal lactate equivalent (15 %, major effect) and performance at the 2 (14 %, major effect) and 4 mmol/l (11 %, major effect) thresholds. Additionally, professional athletes had significantly higher oxygen uptakes at the LAE (9 %, major effect) and IAT (6 %, major effect) (in % of the maximum uptake) than those at the local level. Other than the oxygen uptake per kilogram BW and LBW, all parameters improved in professional athletes while they remained stationary or decreased in skiers at the local level (▶ **Fig. 1** and Supplement **Fig 1S**).



▶ **Fig. 1** Change of parameters during the course of time in male and female athletes. Only parameters with significant differences between local and national level at the last available examination (T 0) are displayed; for all parameters Supplement **Fig 1S and 2S**. T-1: Examination 1 year before T 0; T-2: Examination 2 years before T 0; BW = body weight; BMI = body mass index; LBW = lean body weight; VO_{2max} = maximal oxygen uptake; IAT = individual anaerobic threshold; LAE = minimal lactate equivalent; AT = aerobic threshold (serum lactate = 2 mmol/l); ANT = anaerobic threshold (serum lactate = 4 mmol/l).

Comparing local and future national level female athletes, no significant differences could be observed for either the anthropometric data (minor effects for all parameters; ▶ **Table 3**) or the results of spiroergometry.

However, there was insignificantly greater performance at the minimal lactate equivalent (16 %, major effect) and the oxygen uptake at the LAE (in % of the maximum oxygen uptake) in female skiers who advanced to the professional level (9 %, major effect; ▶ **Table 4**). During the course of time maximum performance, performance at IAT, LAE and the 4 mmol/l threshold, as well as the VO_{2max} increased in professional female skiers while it remained stationary or decreased in those at the local level (▶ **Fig. 1** and Supplement **Fig 2S**). The performance at the 2 mmol/l threshold and the VO_2/kg decreased in both groups.

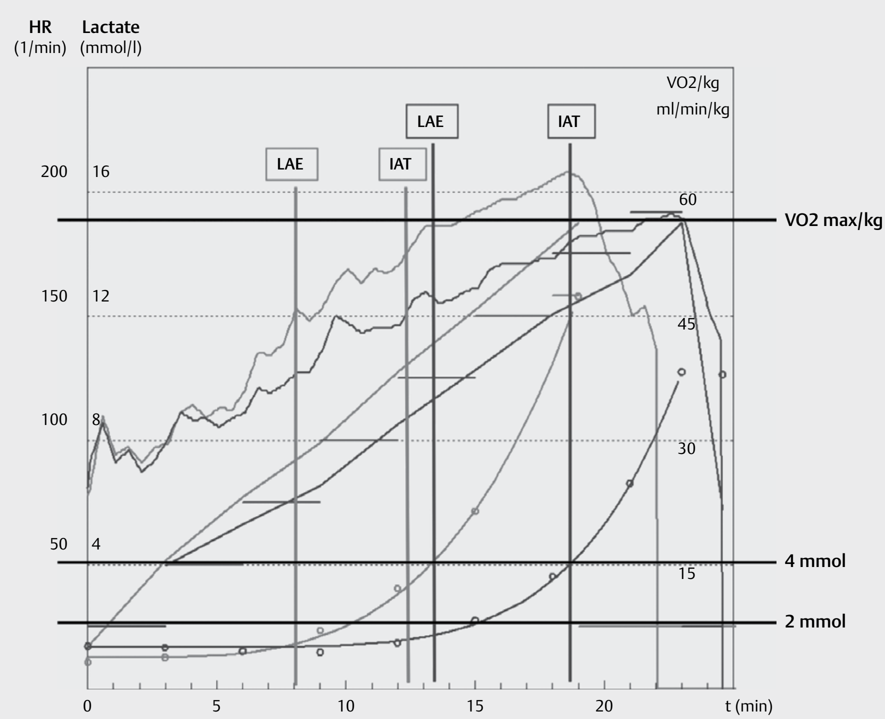
Discussion

In our study, all athletes (at both national and local levels) had a high VO_{2max}, with values comparable to other reports in the literature [1, 14, 16]. In contrast to these studies, which have shown higher VO_{2max} in professional skiers, our data showed no significant differences of this parameter between skiers at the national (professional) and local levels. Interestingly, the performance and the oxygen uptake (in % of the VO_{2max}) at the LAE, as a measure for muscle metabolism, was significantly higher in adolescent skiers who entered a professional career (national level). This became especially evident when following the athletes over time. While (especially male, but also female) professional athletes (national level) showed increases of this parameter, it remained stationary in athletes at the local level. Additionally, male but not female athletes

▶ **Table 3** General data and anthropometry at the last available examination according to gender.

	Male			
	Local	**National**	**p-value**	**Effect size (d)**
	n = 41	**n = 10**		
Age [a]	16.8 ± 1.2	16.9 ± 1.2	0.891	0.08
Training [h/week]	13.3 ± 5.5	12.8 ± 3.1	0.949	0.12
Anthropometry				
Height [m]	1.8 ± 0.1 (1.60–1.94)	1.8 ± 0.1 (1.74–1.93)	0.160	0
BW [kg]	74.1 ± 9.4 (59–99)	83.2 ± 6.9 (75–93)	**0.005**	1.12
BMI	23.2 ± 1.9 (19.7–27.8)	25.1 ± 1.9 (22.2–28.4)	**0.012**	1.0
Body fat [%]	13.0 ± 2.8 (8.3–22.3)	14.9 ± 2.4 (10.4–19.0)	**0.023**	0.73
LBW [kg]	64.4 ± 7.4 (51.4–85.8)	70.7 ± 4.4 (63.5–77.2)	**0.009**	1.11
	Female			
	Local	**National**	**p-value**	**Effect size (d)**
	n = 38	**n = 8**		
Age [a]	16.6 ± 1.2	15.7 ± 0.8	0.096	0.91
Training [h/week]	10.8 ± 4.1	11.9 ± 4.5	0.595	0.26
Anthropometry				
Height [m]	1.7 ± 0.1 (1.56–1.81)	1.7 ± 0.0 (1.57–1.70)	0.921	0
BW [kg]	62.9 ± 7.2 (46–80)	63.3 ± 5.5 (54–69)	0.809	0.06
BMI	22.7 ± 2.3 (18.6–32.2)	23.0 ± 2.2 (19.8–26.3)	0.680	0.13
Body fat [%]	24.3 ± 3.6 (16.4–32.2)	23.5 ± 3.1 (19.6–29.1)	0.503	0.24
LBW [kg]	47.5 ± 4.5 (37.4–55.9)	48.3 ± 3.6 (42.1–54.0)	0.570	0.20

BW = body weight; BMI = body mass index; LBW = lean body weight



▶ **Fig. 2** Performance, lactate levels, thresholds, heart rate and VO_{2max} comparing 2 athletes. The blue curve depicts an athlete who later advanced to the professional level; the red curve shows a skier who stayed at the local level. Both athletes had comparable VO_{2max} but had clear differences regarding the performance and VO_2 at the metabolic thresholds. HR = heart rate.

▶ **Table 4** Results of spiroergometry at the last available examination according to gender.

	Male				Female			
	Local	National	p-value	D	Local	National	p-value	d
	n=41	n=10			n=38	n=8		
P_{max} [W]	338.1±36.1	364.8±35.2	**0.049**	0.75	238.0±23.3	249.0±23.7	0.296	0.47
P_{max}/kg BW [W/kg]	4.6±0.4	4.4±0.4	0.209	0.5	3.8±0.4	4.0±0.5	0.324	0.44
VO_{2max} [ml/min]	4267±388	4514±461	0.158	0.58	3062±257	3170±264	0.310	0.42
VO_{2max}/kg BW [ml/(min * kg)]	57.9±4.5	54.4±5.0	0.061	0.74	49.1±5.2	50.4±5.1	0.485	0.25
VO_{2max}/kg LBW [ml/(min * kg)]	66.6±4.8	63.8±5.1	0.155	0.57	64.8±5.3	65.8±5.3	0.787	0.19
P_{AT} [W]	182.1±32.4	208.5±31.2	**0.022**	0.83	125.7±35.1	117.4±35.3	0.659	0.24
P_{AT}/kg BW [W/kg]	2.5±0.3	2.5±0.3	0.602	0	2.0±0.6	1.9±0.6	0.599	0.17
VO_{2AT}/VO_{2max} [%]	58.4±6.3	63.8±9.3	0.051	0.71	56.3±6.2	55.1±9.6	0.680	0.16
P_{LAE} [W]	158.2±27.3	182.7±27.9	**0.019**	0.89	110.1±16.5	128.1±27.0	0.065	0.85
P_{LAE}/kg BW [W/kg]	2.1±0.3	2.2±0.3	0.265	0.33	1.8±0.3	2.0±0.4	0.085	0.57
VO_{2LAE}/VO_{2max} [%]	52.0±6.1	57.0±4.5	**0.016**	0.96	51.4±4.9	56.3±5.5	0.061	0.94
P_{ANT} [W]	244.4±31.7	272.4±30.6	**0.021**	0.87	172.4±25.6	178.5±18.4	0.384	0.28
P_{ANT}/kg BW [W/kg]	3.3±0.3	3.3±0.3	0.981	0	2.8±0.4	2.8±0.4	0.744	0
VO_{2ANT}/VO_{2max} [%]	74.5±5.3	79.6±7.9	**0.046**	0.78	74.1±6.4	71.9±5.6	0.324	0.37
P_{IAT} [W]	250.1±36.3	278.2±27.4	**0.027**	0.89	174.2±24.4	182.0±15.0	0.324	0.41
P_{IAT}/kg BW [W/kg]	3.4±0.4	3.4±0.3	0.981	0	2.8±0.4	2.9±0.4	0.485	0.25
VO_{2IAT}/VO_{2max} [%]	75.8±5.6	80.9±5.6	**0.008**	0.92	74.2±7.8	73.1±5.8	0.450	0.16

d = Effect size; Pmax = maximal performance; VO2max = maximal oxygen uptake; PIAT = performance at the individual anaerobic threshold; PLAE = performance at the minimal lactate equivalent; PAT = performance at aerobic threshold (serum lactate = 2 mmol/l); PANT = performance at the anaerobic threshold (serum lactate = 4 mmol/l)

showed differences in the anthropometric profile between skiers who advanced to the professional level and those who did not.

In our investigation, a specific anthropometric profile characterized by a higher body mass, average body fat content and higher lean body weight was encountered in male athletes who later entered a professional career. These male skiers were heavier than those reported in an investigation of Swiss adolescent cadre skiers [9]. Likewise, another study of 13–18 year old skiers has shown lower anthropometric parameters (height, weight, % body fat) than our cohort [2]. In a previous report focusing solely on the professional level, a distribution of size and body fat similar to our data for professional skiers was found [14]. Similarly, associations of body weight and performance have been reported in male skiers by other authors [8, 9, 21]. The exact underlying reasons – especially for the gender differences – remain unclear, but associations with the physical requirements of professional skiing could be hypothesized.

Success in competition seems to be influenced especially by 2 factors: a high level of aerobic capacity to meet the large energy demands of a relatively short race time and by balanced muscle function and strength [14]. Regarding aerobic capacity, the maximum oxygen uptake (VO_{2max}) is a measure for the cardio-vascular fitness and is influenced by intensive and extensive endurance training [4]. Previous studies in adult professional skiers have focused on the VO_{2max} determined by bicycle spiroergometry. They report values of 53–56 ml/kg/min for female and 57–67 ml/kg/min for male athletes [1, 14, 16], which are comparable to the results of our tests and support the good cardiovascular fitness of athletes included in our study. Although a high VO_{2max} is essential in athletes and reflects the upper limit for performance in sports events, it is not the best measure for the athletic ability [3]. Consequently, VO_{2max} was already high in all athletes and showed no significant differences between the groups (local and national levels) in our cohort. Thus, VO_{2max} was not suited to predict a later professional career in our study.

While VO_{2max} reflects the cardio-vascular fitness, the performance at the metabolic thresholds gives an impression of the athletes' muscle metabolism [4]. Generally, the performance at these thresholds reflects the capability for aerobic muscle metabolism under exercise. On the one hand, part of the energy consumption can be covered by lipid beta-oxidation; on the other hand, aerobic glucose metabolism is more efficient and produces more adenosine-triphosphate than anaerobic glucose metabolism. Hence, glycogen stores are depleted less quickly, and carbohydrates are saved as an energy source for maximum performances needed during competitions. Regarding the investigation of performance parameters at metabolic thresholds, Neumayr et al. have described results similar to our findings at the 2 and 4 mmol/l lactate levels [14]. However, they did not investigate the performance at the LAE and the IAT. We are first to report a significantly better performance at the minimal LAE (as a measure of the lowest lactate production in relation to the athlete's performance) of athletes who later entered a professional career. In this regard, levels of > 2.3 Watt/kg for males and > 2.1 Watt/kg for females were associated with a 60 % chance for males and 63 % chance for females to later reach the professional level. Although this threshold is arbitrary, athletes with lower levels had lower chances (27 % for males and 11 % for females) to enter a professional career.

In our cohort, the performance and the VO_2 at the LAE had great impact on the career of male athletes. It seems that not the VO_{2max} as a measure for the cardio-vascular fitness, but the LAE (reflecting the aerobic muscle metabolism) is an important parameter associated with a later professional career in alpine skiers (▶ **Fig. 2**). If the oxygen uptake at the LAE is expressed as percentage of the VO_{2max}, athletes advancing to the professional level had significantly better results than those not advancing (▶ **Tables 3** and ▶ **4**). It can be hypothesized that later professional athletes had a higher capability for aerobic muscle metabolism (mainly lipid beta-oxidation but also aerobic glucose metabolism) at sub-maximal levels. We presume that this allows for better regeneration after training and thus takes influence on the general performance of the athletes. Although this was less pronounced in female skiers, they too exhibited a clear trend towards greater performance and VO_2 at the LAE in later professionals. Similar to the anthropometric data, the reason for this gender difference remains unclear. It can only be speculated that parameters other than those examined in this study also influence the performance of female professional skiers.

Study limitations

One possible limitation of this study is its retrospective design. However, this method has already previously been used with success in the identification of parameters characterizing athletes who have attained adult careers [17, 18]. Another possible limitation is the mode of testing by bicycle spiroergometry. This method is not specific for alpine skiers, but is required by the Austrian Skiing Association annually from all athletes. In this study, we were especially interested in differences characterizing the athletes´ endurance. At present, there is no specific endurance test in a laboratory setting for alpine skiers. Finally, we found several differences between parameters predicting a professional career between male and female athletes. The exact reason for these differences could not be determined and remains unclear at this time.

In conclusion, the performance and VO_2 at the metabolic thresholds seem to be an important factor associated with a later professional skiing career. In this context, performance and VO_2 at the LAE (reflecting the aerobic muscle metabolism) appear to be the most relevant parameters. While these findings were significant in male athletes, they were less pronounced in female skiers. Nevertheless, females showed a clear trend towards higher performance and VO_2 at the lactate equivalent in later professional athletes. Finally, it seems worthwhile to enforce endurance training in alpine skiers, in order to increase performance and VO_2 at the metabolic threshold, because this increases the chances of a later professional career. In this regard, specific recommendations for professional alpine skiing clubs based on the findings of our study are planned for the future.

Conflict of Interest

Authors declare that they have no conflict of interest.

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