

Cardiopulmonary exercise tests of adolescent elite sport climbers—a comparison of the German junior national team in sport climbing and nordic skiing

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Original Research Article

Keywords: Cardiopulmonary exercise testing, adolescent athlete, VO₂peak, cardiopulmonary capacity in climbing

Posted Date: May 11th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-26996/v1>

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Version of Record: A version of this preprint was published at Health Promotion & Physical Activity on February 25th, 2021. See the published version at <https://doi.org/10.5604/01.3001.0014.7755>.

Abstract

Background: All the research investigating the cardiopulmonary capacity in climbers focused on predictors for climbing performance. The effects of climbing on the cardiovascular system in adolescents climbing at an elite level (national team) have not been evaluated.

A retrospective analysis of the cardiopulmonary exercise test (CPET) performed on a cycle ergometer during the yearly medical examination of the entire German Junior National climbing team on one occasion and for a selected subgroup on two occasions spaced two years apart was undertaken. The data from the subgroup was compared to an age- and gender-matched control of nordic skiers from the German Junior National nordic skiing team.

Results: 47 climbers (20 girls, 27 boys) were examined once. The peak oxygen consumption (\dot{V}_{O_2}) achieved by the athletes was $41.3 \text{ mL kg}^{-1} \text{ min}^{-1}$ (boys) and $39.8 \text{ mL kg}^{-1} \text{ min}^{-1}$ (girls). 8 boys and 6 girls were tested twice over a time-frame of 27.5 months. The parameters of the exercise test measured on both occasions were significantly lower than those of the 14 nordic skiers. There was no change with respect to any variables over the examined time-frame.

Conclusions: The elite climbers investigated in this study showed comparable \dot{V}_{O_2} values to athletes from team and combat sports. The nordic skiers to which they were compared showed significantly higher values consistent with the fact that this is an endurance sport. Even though the cardiopulmonary measurements of the nordic skiers still improved after two years of training, no adaptations could be observed in the elite climbers.

Key Points

Climbers are able to achieve \dot{V}_{O_2} values comparable to athletes in team and combat sports but inferior to endurance athletes. Climbing therefore classifies as an intermediate between endurance and power sports. No cardiac pathologies were found in the German Junior National Team during the yearly medical examinations using CPET in the covered time frame.

Background

Over the past decade sport climbing has evolved into a highly professional sporting discipline and will debut at the 2020 Summer Olympic Games in Tokyo. The International Olympic Committee advocates that medical teams should protect and promote athlete health during training and competition. This requires the routine monitoring and surveillance of individuals and a specific understanding of the physiologic adaptations inherent within the sport.

There is little doubt about the positive effects of physical activity (PA) on reducing the risk of cardiovascular disease [1-3]. Sixty min. of exercise at moderate intensity per day with short bouts of anaerobic intensities per week are recommended [4]. However, elite athletes (in this article defined as

being in the National Team) train between 10 and 20 h per week with intensities exceeding the WHO recommendations [5]. Endurance activities (long distance running, swimming) reduce the systolic blood pressure by reducing the peripheral vascular resistance, and increase the cardiac stroke volume and output which in turn reduces myocardial oxygen consumption. Strength training on the other hand increases myocardial oxygen consumption, heart rate, blood pressure, and stroke volume, but to a lesser extent [6]. The consequence of performing PA on the elite level could be the occurrence of maladaptation of the cardiovascular system with sudden cardiac death as its most severe one [7, 8]. Some myocardial adaptations to intensive exercise such as bradycardia, early repolarization, atrial dilatation and ventricular hypertrophy have also been observed in young athletes [9] and are therefore not limited to adult athletes. After one cases of syncope during climbing due to cardiac disease (unknown long-QT-syndrome) known to us, and a first case of sudden cardiac death (SCD) during a climbing competition in Canada in the fall of 2019 (cause still unknown), we consider it as extremely important to understand possible pathophysiological changes in the myocardium as early as possible.

In this context, more understanding is needed about the nature of climbing with respect to its endurance characteristics. Climbing is about sustained and intermittent isometric forearm muscle contractions [10]. During climbing the athletes can achieve up to 89% of their maximal heart rate in cycling and treadmill tests [10, 11]. This comparably high heart rate is disproportional to the rise in oxygen consumption ($\dot{V}O_2$) [11]. The explanation for this disassociation has been assigned to the so called metaboreflex. As a consequence of metabolites accumulating within working tissue and stimulating feedback to the central nervous system a powerful sympathetically mediated pressor response consisting of increased heart rate, ventricular performance, central blood volume mobilization, vasoconstriction in renal and inactive skeletal muscle, and increased systemic arterial pressure is evoked [12]. This mechanism has been observed with isometric handgrip exercises and has been suggested to explain the dissociation between heart rate and $\dot{V}O_2$ in climbing [11, 13]. Another hypothesis is that peak oxygen uptake is lower during arm work than during leg or whole body work [14]. As the upper body is the main contributor to the work performed during climbing, arm-specific $\dot{V}O_{2max}$ could be reached while climbing [10, 13]. This hypothesis is strengthened by the short duration, climbers are able to maintain their exercise. At oxygen consumption of 40 – 50% of the peak oxygen consumption ($\dot{V}O_{2max}$) which is below the lactate threshold, the climbers should be able to maintain their exercise for periods up to one hour which is not the case [10]. Thus, arm-specific $\dot{V}O_{2max}$ is probably reached and the lactate accumulating in the working muscles contributes to the fatigue forcing the athletes to stop their exercise [10, 15]. Should climbing therefore be considered an aerobic exercise, or is the fact that the duration of the activity is so short and the fact that the metaboreflex elicits a disproportionate rise in blood pressure and heart rate the main characteristic?

Cardiopulmonary exercise testing (CPET) is usually employed for determining endurance performance and cardiopulmonary fitness in elite athletes. One of the best studied parameters of CPET is the $\dot{V}O_{2max}$ as it represents an important parameter for endurance performance. It is influenced by maximal cardiac output and the arterio-venous oxygen difference [16]. Power athletes have lower $\dot{V}O_{2max}$ values than team and endurance athletes [16, 17]. However, this difference could be attributed to a higher cardiac output as a consequence of a higher cardiac adaptation [18] as well as to a larger oxygen carrying capacity and/or

oxygen extraction by endurance athletes [17]. Still, evaluating the during a standard cardiopulmonary exercise test should allow a classification of climbing when performed by elite climbers, especially when compared to elite Nordic skiers, a sport classified as an endurance sport, when performing the same non-sport-specific test, namely a cycle test.

Furthermore, CPET is also an important instrument for assessing the risk of sudden cardiac death in athletes [19] especially when employed in combination with an ECG. It allows for the differentiation between physiologic left ventricular hypertrophy and hypertrophic cardiomyopathy [20], one of the main reasons for SCD in young competitive athletes [21].

There is little data concerning the cardiopulmonary adaptations to climbing at an elite level, especially in young athletes. Every team member of the German Junior National Climbing Team (GJNTC) undergoes a yearly medical check-up in our hospital which includes CPET on a stationary bicycle. In order to evaluate the cardiopulmonary capacity of these elite climbers we analyzed the data from the cardiopulmonary exercise test. As some of the athletes remain on the team we also investigated the changes in CPET after a time frame of at least 24 months when possible as a longitudinal approach. Two years of regular physical training are believed to lead to characteristics of the athlete's heart [22]. As we work closely with the German Junior National Team in nordic skiing (GJNTN) we were able to compare the longitudinal data from the climber with age- and gender-matched controls from this classical endurance sport as their yearly examination mirrors ours and the same CPET with the same equipment is performed.

Material And Methods

All participants as well as their respective legal guardians gave written, informed consent. The ethics committee of the University of Erlangen-Nürnberg has approved the study.

Data were assembled over a 5-year timeframe. Every athlete of the German National Junior Climbing Team is required to undergo a medical examination in order to be allowed to participate in International competitions. As this is a convenience sample, no blinding was involved. Some athletes were screened multiple times as they were selected for the team several years in a row. In these cases only the most recent examination was reported for the cross-sectional approach, because we expected the greatest cardiovascular adaptations after climbing longer. Those athletes who remained on the team for a minimum duration of 2 years the datasets of two medical examinations were compared in order to determine the cardiovascular adaptations of climbing at an elite level over that timeframe. We compared the longitudinal data from those athletes with an age-matched control group of nordic skiers from the German Junior National Team, a typical endurance sport. As both teams (skiing and climbing) are comparable in size and with respect to age and gender no blinding or further matching could be achieved.

Anthropometric data included: height, weight and Body Mass Index (BMI). The anthropometric values were transferred into z-scores (number of standard deviations below or above the reference mean) using data by Kromeyer et al. [23]. Body fat was estimated using the Jackson-Pollock method [24], this method

is validated for use in children and adolescents and has been used in other studies investigating body fat in climbers [25, 26].

In order to assess the history of their sports career, we recorded the age they commenced climbing, and the time spent training for climbing per week in the last year. Cardiopulmonary training, if any was also taken into account.

Each athlete underwent a standard cardiopulmonary exercise test on an electronically braked cycle ergometer (E-bike Comfort, GE Medical Systems, Chicago, USA) in form of an incremental step test. A step time of three minutes with a starting load of 80 Watts in boys and 75 Watts in girls was used, with an increase of 40 Watts for every step in boys and 25 Watts for every step in girls until physical exhaustion was achieved. The athletes pedaled at a self-chosen cadence with a minimum allowable pedaling cadence of 60 rpm. This test protocol represents our standard incremental step test protocol used for testing elite athletes [27]. We used a cycle test as it represents the standard CPET used in Europe and also represented a sport-unspecific testing method for the climbers as well as the skiers.

Capillary blood lactate (BL) (ear lobe) was collected prior to, during, and at the termination of the test and post-test (two and five minutes). BL was analyzed using the Lactate Scout \boxtimes (EKF, Cardiff – United Kingdom). Cardiopulmonary capacity was measured using a ZAN600 \boxtimes spiroergometer (ZAN \boxtimes , Oberthulba, Germany). A standard 12-lead exercise ECG was recorded over the entire duration of the test protocol. At the end of the test the subjective reasons for termination as well as any changes in the ECG were recorded. The standards of general performance diagnosis and stress tests were fulfilled (temperature 18-24°, relative humidity 30-60%) and all participants had a minimum rest period of >48 h to sport or energy demanding activity.

Statistical analysis was performed using Microsoft Excel 2000 $\text{\textcircled{R}}$ for data collection and SPSS 12.0 $\text{\textcircled{R}}$ (SPSS Inc., Chicago, IL). All measured values are reported as means and standard deviations. The Kolmogorov-Smirnov test was used to check for normal distribution. Homogeneity of variance was investigated using Levine's F-test. For normally distributed variables differences between the two tests with a timeframe of at least 2 years in between were assessed with paired t-tests, otherwise the Wilcoxon or the Whitney-Mann-U-tests were used. For normally distributed variables, differences between the climbers and the cross-nordic skiers were assessed with unpaired t-tests, otherwise the Wilcoxon or the Whitney-Mann-U-tests were used. All tests were 2-tailed, a 5% probability level was considered significant (*).

Results

A total of forty-seven adolescent climbers were examined in the time frame of the study, 27 were male and 20 were female. The z-scores are negative for all age groups except for the group of girls at the age of 12 – 13 years which was made up of only one girl. There were no z-scores below -2.5, the lowest was a z-score of -2.27 for a girl of 17 years with a height of 153.5 cm, and for a boy of 17 years of age with a weight of 49 kg (height 164 cm).

14 climbers were reevaluated after a mean timeframe of 27.5 months and compared to their previous data. These 8 boys and 6 girls were compared to an age- and gender-matched control group of 8 boys and 6 girls from the GJNTN who were also evaluated twice within 28.7 months' time. Both groups were comparable with respect to age, height, weight and BMI (s. table 2). Even though the 14 climbers were already a mean of 16 years at the moment of the first examination, all the adolescents still showed a significant increase in height, weight, and BMI after two years. The same was true for the nordic skiers, so that the groups did not differ with respect to the gain in height, weight or BMI.

Both boys and girls had been climbing for an average of 8 years ($SD \pm 2.9$), the boys were training for 13 hours ($SD \pm 2.9$) and the girls for 11.5 hours ($SD \pm 4$) per week in average. Alternative sports for recreation or for improving cardiopulmonary fitness were undertaken by 19 of the athletes and consisted of a mean of 2 hours per week of running (14 athletes), biking (3 athletes), soccer (1 athlete) and Zumba (1 athlete), performed either randomly or twice a week. Fourteen had previously competed in other sports, mainly soccer (6 athletes), and track and field (4 athletes), but also swimming (1 athlete), rowing (1 athlete), gymnastics (1 athlete), tennis (1 athlete).

The values recorded for the cardiopulmonary exercise testing are recorded in table 1. There is only one previous study which investigated the cardiopulmonary capacity of climbers with an incremental cycling test and we have included the available measurements for comparison in table 1. Self-reported muscular fatigue was the most common cause of termination in 90% (43 out of 47) of the subjects. Out of these 43 athletes 11 stated that they had felt a shortness of breath as well as a muscular fatigue at the end amounting to 23 % of all subjects. This was a purely subjective feeling when the participants were asked about their reason for stopping the exercise. None of the subjects terminated the test because of shortness of breath before the onset of muscular fatigue. The athletes who performed endurance sport in addition to climbing did not achieve better results in the cardiopulmonary exercise test. Four athletes were only tested sub-maximally as they had suffered from a viral infection in the 3 weeks preceding the test.

Fourteen climbers undertook the same cardiopulmonary exercise test twice within a mean of 27.8 months. Those were the only team members who remained on the team for more than two years. The other athletes did not make the team again over this time frame and were thus not evaluated a second time in the setting of the yearly team examination. Of these 14 athletes 6 stated training running and/or cycling regularly for about 2 hours a week. This did not change over the timeframe of two years. Even though their endurance training did not change, the time spent training for climbing increased significantly from 12 to 18 hours per week. The of these 14 athletes did not significantly change during the 27.8 months they were on the team and neither did the values measured for the skiers (s. fig. 1). Actually, there were no significant differences with respect to any of the measured variables between the two tests in the climbing group (s. table 2). At both occasions was significantly lower for the climbers than for the nordic skiers (s. fig 2 and fig. 3). The climbers had significantly lower CPET measurements than the skiers except for respiratory exchange ratio (RER) and peak lactate which were comparable at both test occasions (s. table 2).

Discussion

The athletes of the GJNTC were smaller, slimmer and had a lower BMI than age matched population distributions as reflected by the negative z-scores. Watts et al. [25] recorded comparable values for height in a cohort of 13 year old male climbers (mean 162.5 cm) to our sample but higher values for weight, BMI, and body fat. Therefore, our data supports the assumption that elite climbers tend to be of a smaller stature with low body fat, BMI and body weight [28] but there were no signs of pathological eating habits.

The finding that junior athletes had been climbing for an average of 8 years was unexpected as it meant that a large proportion of the athletes had commenced their climbing career aged 3 – 5 years. Less than half of the participants reported engaging in general endurance training to improve their cardiopulmonary exercise capacity.

When evaluating the CPET data from the 47 athletes who were seen on one occasion, the values of the boys ($41.3 \text{ mL kg}^{-1} \text{ min}^{-1}$) and girls ($39.8 \text{ mL kg}^{-1} \text{ min}^{-1}$) were comparable to a previous study which studied adult climbers on a cycle ergometer ($45.5 \text{ mL kg}^{-1} \text{ min}^{-1}$) [11]. The highest values of \dot{V}_{O_2} are achieved by young elite (national team members) endurance athletes ($60 \text{ mL kg}^{-1} \text{ min}^{-1}$) [29]. Adolescent sprint- and power-related athletes range between $46 \text{ mL kg}^{-1} \text{ min}^{-1}$ for girls and $52 \text{ mL kg}^{-1} \text{ min}^{-1}$ for boys [29]. Aerobic capacity has been estimated to be one of the most important predictors for good results in combat disciplines and they range between $55 \text{ mL kg}^{-1} \text{ min}^{-1}$ for male and $46 \text{ mL kg}^{-1} \text{ min}^{-1}$ for female adolescents [29] and even higher in elite junior judo athletes and boxers who achieved values as high as $53 - 66 \text{ mL kg}^{-1} \text{ min}^{-1}$ [30]. Team sports achieve values ranging between $47 \text{ mL kg}^{-1} \text{ min}^{-1}$ [31] and $59 \text{ mL kg}^{-1} \text{ min}^{-1}$ [32]. All these values were achieved during treadmill testing during which higher \dot{V}_{O_2} values can be achieved than when the testing is performed on a cycle ergometer. Considering this, the climbers probably compare to sprint- and power-related athletes and those in combat or team sports. It is unclear whether a higher \dot{V}_{O_2} could improve their climbing as observed in combat sports because this has not been studied yet. However, if climbers reach arm-specific \dot{V}_{O_2} during hard climbs, as suggested previously [10], improving their maximum oxygen uptake could possibly imply an improvement in the difficulty of climbing.

The adaptation of a particular aspect of the cardiopulmonary system, like an increase of the \dot{V}_{O_2} pulse, suggesting a higher cardiac output, or an improved minute ventilation could not be observed in the group of elite climbers studied during the cross-sectional approach.

Interestingly, although the climbers stated muscular fatigue as the reason for terminating the CPET, a mean RER of 1.1 and a peak lactate of 8.1 in girls and 9.0 in boys as well as a mean heart rate of over $180 \text{ beats min}^{-1}$ point towards maximal exertion. Even though the climbers in our study climbed at a comparably high level and were of comparable age they also achieved poorer maximum workloads during the cycle test with 3.2 W kg^{-1} (boys) and 2.7 W kg^{-1} (girls) in comparison to 4.2 W kg^{-1} [11] and a poorer mean RER (1.1 in comparison to 1.24). One explanation could be that the climbers in our study did not push themselves enough and could have gone higher. Another explanation is the different exercise

protocol for cycle ergometry. Whereas we used an incremental step test, a ramp test was used in the other study [11].

The longitudinal approach of 14 athletes of whom two exercise tests spaced 2 years apart could be compared the nordic skiers achieved significantly higher CPET parameters except for peak blood lactate. The values of \dot{V}_{O_2} were comparable to the data from previous studies for endurance athletes [29] and taking into consideration the fact that they were obtained during a cycle ergometry and not on a treadmill, even higher. This finding reflects the very high endurance level of elite nordic skiers. It also allows for the clear differentiation between the nature of climbing and nordic skiing. Interestingly no significant changes occurred over the time frame of two years in both groups. For the nordic skiers this could be a consequence of their already highly trained status at the moment of the first examination, which could not further be improved in the timeframe of two years. Although the climbers increased their climbing training significantly, the time spent on classical endurance training like running or cycling did not change. The fact that there was no change in \dot{V}_{O_2} after two years of climbing on the GJNTC even though the time spent training for climbing increased significantly, suggests that climbing probably does not elicit cardiopulmonary changes seen in endurance sports. A surprising finding was the relatively low heart rate of the 14 male climbers on both occasions especially in comparison with their nordic skiing counterparts. As the RER was higher in the group of climbers and peak lactate values were comparable between both groups, it cannot be suspected that the nordic skiers just pushed themselves harder than the climbers. However, the high standard deviation of the peak heart rate, not observed in the group of nordic skiers suggests a big interindividual variability and indeed varied for the climbers between 153 and 200 beats min^{-1} .

Whereas some adaptation to the endurance nature of nordic skiing could be seen in the increase of the cardiac output (\dot{V}_{O_2} pulse) as well as the minute ventilation (\dot{V}_E), though not significantly, such adaptations did not occur in the group of elite climbers. As both groups were comparable to age, size, and gender, the cardiopulmonary effects of climbing may not be important enough to elicit any adaptations. However, the question remains whether an endurance training targeted to increase \dot{V}_{O_2} could improve the overall climbing ability. Prospective studies are needed to evaluate this effect.

An important reason to perform cardiopulmonary exercise testing during the yearly medical examination of elite athletes is for preventing sudden cardiac death. The use of CPET in combination with an electrocardiogram allows for detection of channelopathies, dangerous arrhythmias, arrhythmogenic ventricular cardiomyopathy and for differentiation between athlete's heart and hypertrophic cardiomyopathy in which \dot{V}_{O_2} pulse and the ventilatory threshold are taken into consideration. There were no pathological findings in the team members of the GJNTC during the investigated time-frame. However, since the SCD of a young Canadian athlete in the fall of 2019, the need for regular cardiac check-ups and a clear understanding of the impact of the sport on the cardiac system is essential and more knowledge especially with regards to young elite athletes is needed for a better prevention of SCD.

Our study has several limitations. First of all, the design of the study is retrospective which is a limitation in and of itself. The collective is rather inhomogeneous and presents young athletes over a large age-span. This is based on the fact that the study entry is defined by acceptance to the German Junior National Team of Climbing which is solely based on their climbing ability. For the longitudinal design the number of athletes is comparably small. As we only wanted to include high-level climbers and compare them to high-level nordic skiers we limited our evaluation to the members of the German Junior National Team in both sports, thus the number we were able to follow for the required timeframe was comparably low. Also there was no age-matched control group of sedentary subjects which is why literature data and z-scores were used for comparison.

Conclusions

In conclusion it can be said, that the climbers were able to achieve $\dot{V}O_{2peak}$ values comparable to athletes in team and combat sports but inferior to endurance athletes. This was also apparent when compared to a group of age- and gender-matched elite nordic skiers. No cardiac pathologies were found during the yearly medical examinations using CPET. Further studies are needed for evaluating the effect of incorporating an endurance sport into the training regimen of elite climbers.

Declarations

Ethical Approval and Consent to participate

All participants as well as their respective legal guardians gave written, informed consent. The ethics committee of the University of Erlangen-Nürnberg has approved the study.

Consent for publication

All authors consent to the publication of this article in its current form.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

Competing interests

The authors declare that they have no competing interests

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author's Contribution

Isabelle Schöffl: Conception and design as well as analysis and interpretation of data; drafting the article; and final approval of the version to be published. She declares that she has no competing interests.

Jan Wüstenfeld: Conception and design as well as analysis and interpretation of data; revising the article critically for important intellectual content; and final approval of the version to be published. He declares that he has no competing interests.

Gareth Jones: Drafting and revising the article critically for important intellectual content; and final approval of the version to be published. He declares that he has no competing interests.

Sven Dittrich: Analysis and interpretation of data; revising the article critically for important intellectual content; and final approval of the version to be published. He declares that he has no competing interests.

Volker Schöffl: Conception and design as well as analysis and interpretation of data; revising the article critically for important intellectual content; and final approval of the version to be published. He declares that he has no competing interests.

Acknowledgements

N/A

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Tables

Table 1: Mean values (standard deviation in brackets) from cardiopulmonary exercise tests of 47 athletes who were seen on one occasion

	Boys	Girls
Work load (Watt kg ⁻¹)	3.2 (0.4)	2.7 (0.6)
Peak Heart rate (beats min ⁻¹)	181.4 (14.4)	183.8 (12.1)
Heart rate at VT ₁ (beats min ⁻¹)	156.5 (11.6)	157.8 (11.6)
Peak Borg	18.3 (1.5)	18 (1.7)
Peak Lactate (mmol L ⁻¹)	9 (3.3)	8.1 (3.1)
(ml kg ⁻¹ min ⁻¹)	41.3 (6.7)	39.8 (5.4)
at VT1 (% of VO _{2peak})	77.1 (9.8)	73.2 (11.1)
Peak Breath rate (breaths min ⁻¹)	39.1 (5.5)	37.3 (4.7)
Peak O ₂ -pulse (mL beat ⁻¹)	13.9 (2.6)	16.8 (21.9)
Peak (L min ⁻¹)	90.2 (26.6)	76.7 (13.2)
Peak RER	1.1 (0.1)	1.1 (0.1)

Table 2: Mean values (standard deviation in brackets) from two cardiopulmonary exercise tests of 14 climbers who were seen a second time 2 years after their first visit in comparison to data from 14 nordic skiers who also received CPET on two separate occasions spaced two years apart

	First Visit				Second Visit			
	Male		Female		Male		Female	
	Climber	Nordic Skier	Climber	Nordic Skier	Climber	Nordic Skier	Climber	Nordic Skier
VO _{2peak} (mL kg ⁻¹ min ⁻¹)	37.7 (1.3)	66.5 (6.5)	38 (2.9)	52.1 (3.1)	34.8 (4.3)	66.2 (4.7)	35 (4.3)	56.7 (4.5)
Work load (Watt kg ⁻¹)	3 (0.2)	4 (0.1)	2.8 (0.1)	3.4 (0.0)	2.8 (0.4)	4.1 (0.4)	2.7 (0.4)	3.8 (0.6)
Peak Heart rate (beats min ⁻¹)	162 (16)	205 (3)	187 (4)	202 (3)	169 (10)	201 (7)	180 (11)	194 (7)
Peak Lactate (mmol L ⁻¹)	9.1 (1.4)	8.2 (0.6)	6.4 (0.8)	7.1 (1.0)	8.5 (0.8)	9.3 (1.9)	7.4 (1.2)	7.8 (2.4)
Peak Breath rate (breaths min ⁻¹)	41 (6)	60 (8)	37 (6.1)	62.3 (8.6)	34.8 (4.3)	66.1 (4.7)	33.5 (5.9)	68.4 (9.4)
Peak O ₂ -pulse (mL beat ⁻¹)	14.5 (2.6)	19.8 (6.1)	10.4 (1.7)	12.7 (1.6)	14.3 (1.3)	23.2 (1.8)	10.5 (1.2)	16.2 (1.0)
Peak (L min ⁻¹)	84.8 (38.3)	133.5 (26.9)	62.5 (9.4)	91.7 (9.1)	76.8 (21.4)	151.7 (24.9)	58 (10.4)	100 (9.1)
Peak RER	1.1 (0.1)	1.1 (0.1)	1.1 (0.1)	1.0 (0.1)	1.1 (0.1)	1.0 (0.0)	1.1 (0.0)	1.0 (0.1)

Figures

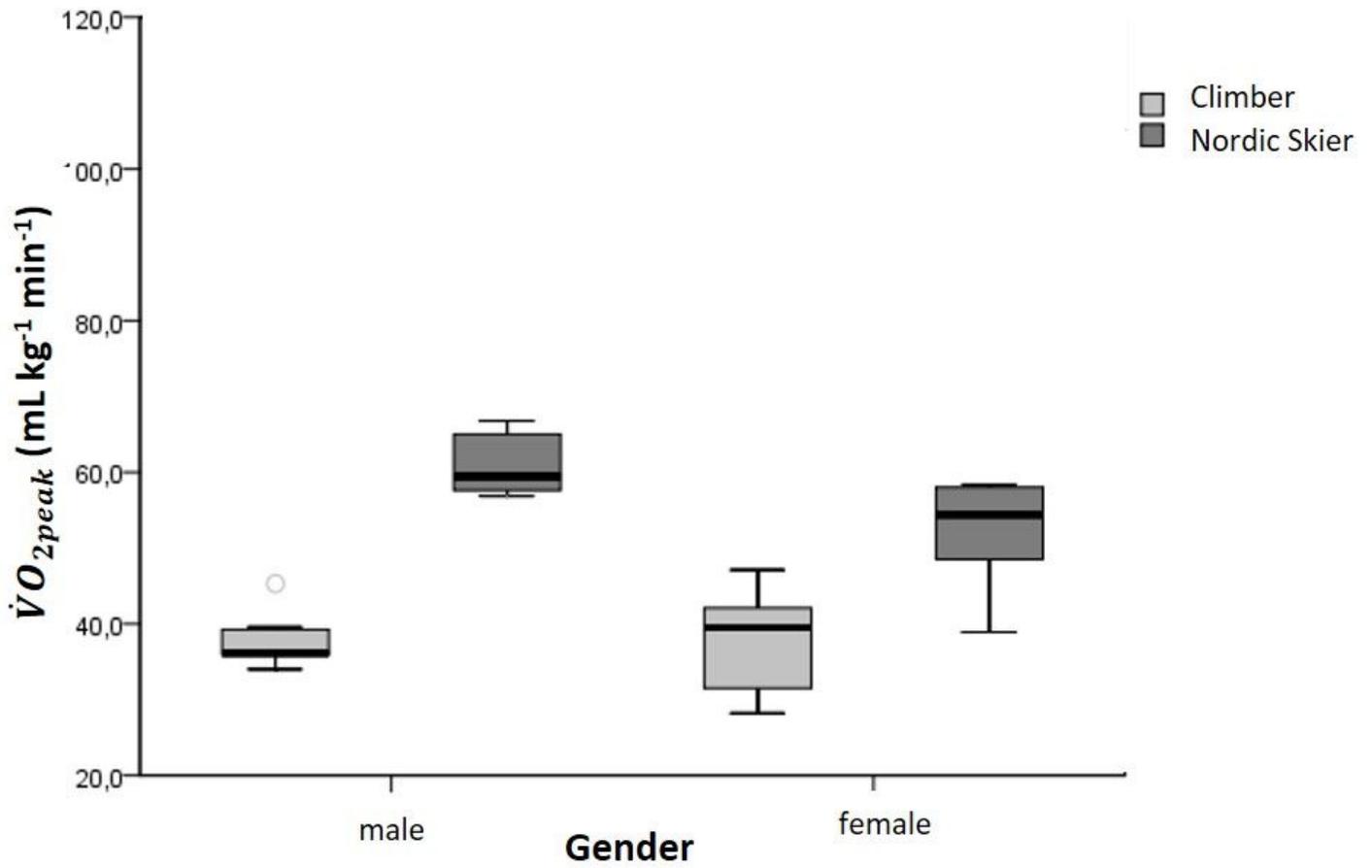


Figure 1

$\dot{V}O_{2peak}$ of 14 athletes from the GJNTC in comparison to 14 athletes from the GJNTN at the first examination

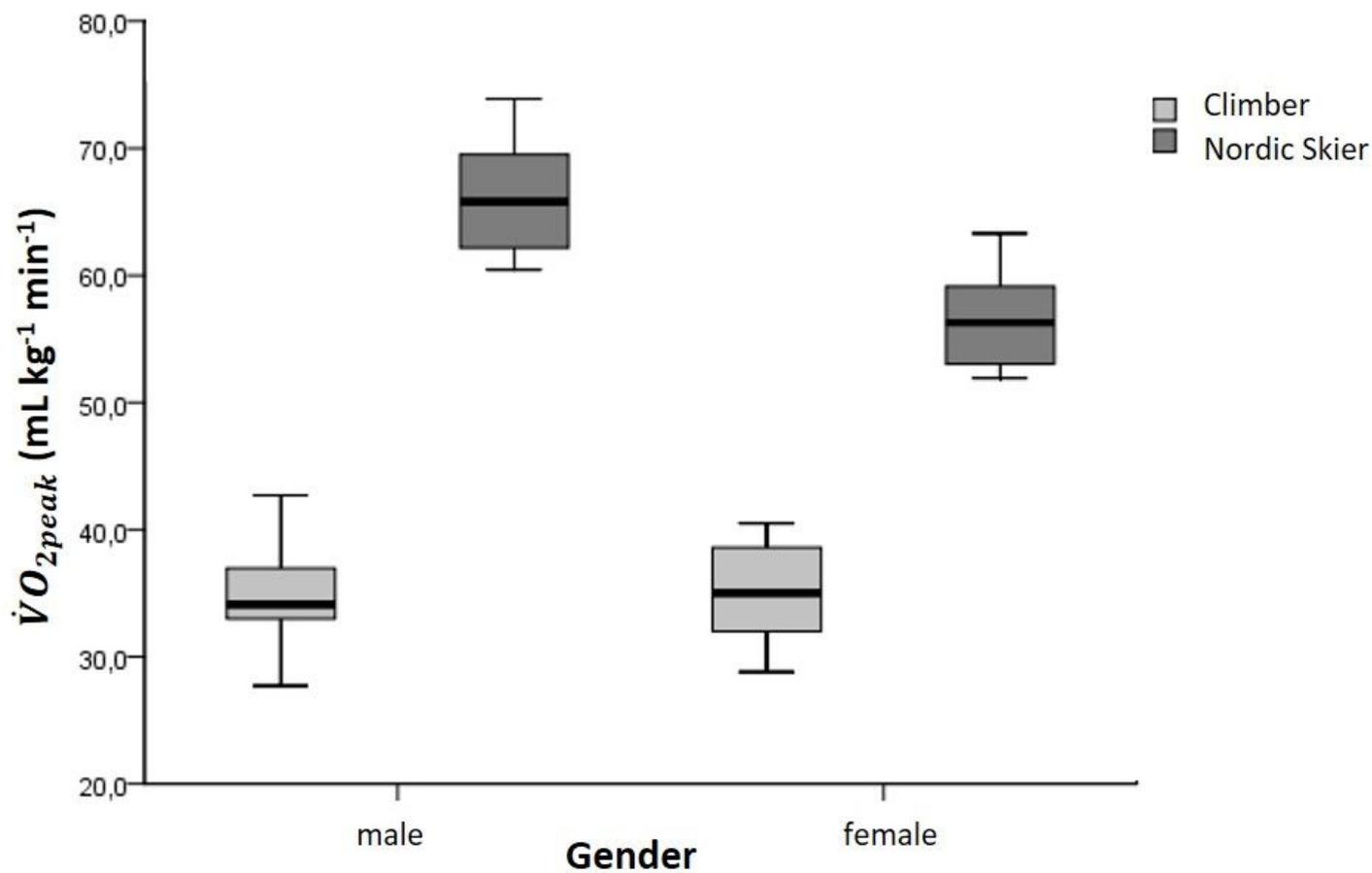


Figure 2

$\dot{V}O_{2peak}$ of 14 athletes from the GJNTC in comparison to 14 athletes from GJNTN at the second examination recorded 27.8 months after the first examination

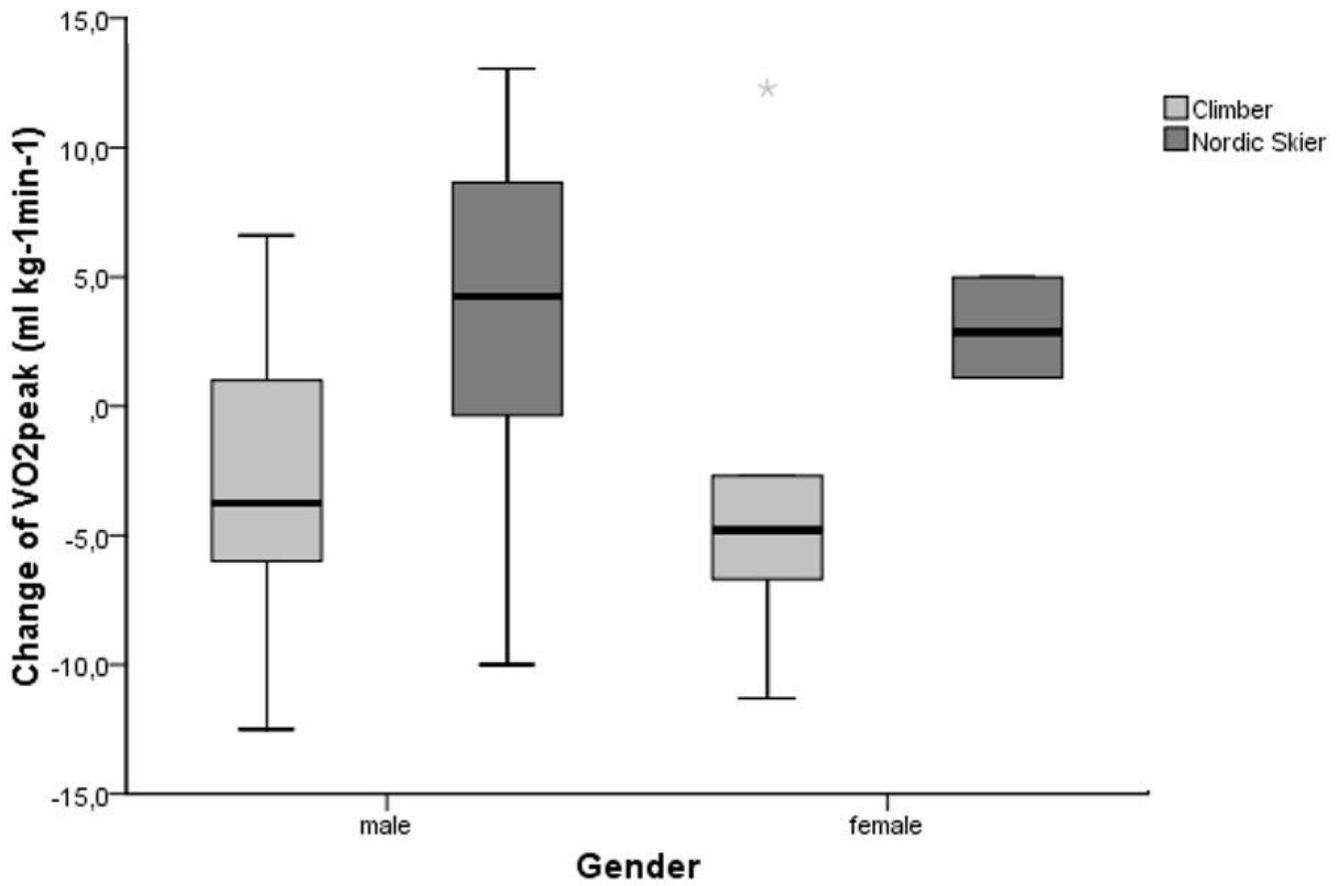


Figure 3

Changes in $\dot{V}O_{2peak}$ of 14 athletes from the GJNTC in comparison to 14 athletes from the GJNTN over the timeframe of 27.8 months