

Carceller, A

Differences in cardiorespiratory responses in winter mountaineering according to the pathway snow conditions

Anna Carceller, Casimiro Javierre, Jordi Corominas, Ginés Viscor

Anna Carceller: Secció de Fisiologia, Departament de Biologia Cel·lular, Fisiologia i Immunologia, Facultat de Biologia, Universitat de Barcelona, Barcelona, Spain. Medical Commission of the International Federation for Climbing and Mountaineering (UIAA MedCom). Email: acarcema7@alumnes.ub.edu Tel: +34608014963

Casimiro Javierre: Departament de Ciències Fisiològiques, Facultat de Medicina, Universitat de Barcelona, Barcelona, Spain. Email: cjavierre@ub.edu Tel: +34934024517

Jordi Corominas: International Federation of Mountain Guides Associations (UIAGM/IFMGA). Email: info@jordicorominas.es Tel: +34630750327

Ginés Viscor: Secció de Fisiologia, Departament de Biologia Cel·lular, Fisiologia i Immunologia, Facultat de Biologia, Universitat de Barcelona, Barcelona, Spain. Email: gviscor@ub.edu Tel: +34934021531.

Correspondence: Anna Carceller, Secció de Fisiologia, Departament de Biologia Cel·lular, Fisiologia i Immunologia. Facultat de Biologia. Universitat de Barcelona. Av. Diagonal, 643, 08028 Barcelona. Email: acarcema7@alumnes.ub.edu Tel: +34608014963

Running title: Locomotion in snowy terrain

Keywords: cardiopulmonary function, exercise, maximal oxygen uptake, work capacity, perception of effort

Carceller, A

Introduction

Winter mountaineering is a challenging sport that has gained popularity in recent years at the recreational, competitive and commercial levels (Ainslie et al., 2005). Even though the most popular mountains usually have an established ascent route, it is not uncommon for technical mountaineers to climb on virgin snow. In addition to this, within certain mountaineering styles and philosophies, first ascents are considered meritorious, and by definition they have to take place via routes that have not previously been trodden (International Climbing and Mountaineering Federation, 2002). Locomotion in ascent requires a higher energy expenditure than over flat terrain (Billat et al., 2010), and the most efficient mountain path gradient is 25% if there are no performance limitations impeding the subject from reaching maximal power (Minetti, 1995). Efficiency in locomotion decreases in snowy terrain, especially in individuals with little experience (Billat et al., 2010), presumably because of changes in biomechanical patterns of walking (Ramaswamy et al., 1966). Considering this, fitness is described as an additional strategy to increase mountain safety (Burtscher et al., 2015), especially if ascents are performed at altitude or in adverse meteorological conditions, but little is known of its influence on technical mountaineering performance and additional energy demands. Our working hypothesis was that walking on fresh snow is more expensive in terms of the need for power and energy expenditure, as ascents along non-traced routes usually appear to be slower and more fatiguing. Moreover, among professional mountain guides it is well known that being the first climber in a group is usually more exhausting than not leading the climb. However, to the best of our knowledge, there are no controlled intra-subject comparisons that confirm this statement or elucidate the metabolic reason for this widespread subjective feeling; neither have specific repercussions on training programs been assessed.

Carceller, A

Therefore, the main objective of this study was to evaluate differences in cardiorespiratory responses and the energetic cost of locomotion between an exercise performed in snowy terrain that had been previously compacted and walking on fresh snow. Our findings may contribute to decision making, not only when planning an ascent, but also during training for this specific mode of sport and when facing unexpected events on a mountain.

Material and methods

Subjects

The subjects recruited for this study were 15 healthy and physically active volunteers (13 male, 2 female), who were 35.4 ± 5.3 years old. All were highly experienced in winter mountain activities at a competitive level and followed a training regime of up to 10 hours per week. The anthropometric characteristics of the subjects were: height 1.72 ± 0.07 m, weight 67.1 ± 8.5 kg, body mass index 22.8 ± 2.6 kg·m⁻². Their maximal peak oxygen consumption was 66.4 ± 7.7 mL·kg⁻¹·min⁻¹. After approval by the local ethics committee, all of them were informed of the objective of the study, and signed an informed consent form to accept participation in the study. The protocol was conducted according to the principles of the Declaration of Helsinki.

A group of 15 subjects shows statistical power higher than 80%. The sample size calculated to evaluate the differences in performance in a maximal test, with α error = 0.05, β error = 0.20 and an expected drop out of 15%, was of 11.

Laboratory test

Carceller, A

The laboratory test was performed in the exercise laboratory of the Physiological Sciences Department of the *Universitat de Barcelona*, at an ambient temperature of 22°C-24°C and relative humidity between 55% and 66%. Each test took place in the morning, after a light breakfast.

Participants performed the laboratory test on a pre-calibrated treadmill (Quasar, HP Cosmos Sports & Medical GmbH, Nussdorf-Traunstein, Germany), at a constant speed of 9 km·h⁻¹, starting at 0% slope which increased 1% every minute until exhaustion. Oxygen consumption and CO₂ production were recorded by means of an automatic gas analyzer (Metasys TR-plus, Brainware SA, La Valette, France), equipped with a pneumotachograph using a double way mask (Hans Rudolph, Kansas, USA). Before each test, calibration was performed including volume and gas composition, according to the manufacturer's recommendations. Heart rate was continuously monitored during the test (CardioScan v.4.0, DM Software, Stateline, Nevada, USA).

Field test

The field test took place on a northeastern slope, from a starting altitude of 2,043 m to a final altitude of 2,104 m, resulting in a positive ascent of 61 m. The total distance covered was 211 lineal meters. The ascent profile exhibited an initial gradient of 15% with a progressive increase in inclination, reaching a maximum gradient of 59%

The snowpack was homogenous, of approximately 60 cm depth. With altitude gain, the stiffness and cohesion of the surface crust varied, becoming weaker, thus allowing a deeper descent of the footstep, varying from 1-3 cm to 10-12 cm depth.

Experimental design

Carceller, A

A crossover study was designed in order to compare the different variables, with subjects being their own control.

Before the start of the field test, a homogenous pathway 50 cm wide was traced, which permitted comfortable locomotion. The depth of the pathway varied depending on the characteristics of the snow pack previously described. The test took place between 1200h and 1600h.

For each subject, four ascents were performed: locomotion inside the pathway (FP) at 100% (FP100) and 70% (FP70) of individual maximal capacity; and locomotion outside the pathway (FS) at 100% (FS100) and 70% (FS70) of individual maximal capacity. Assignment of the sequence of the ascents was random among the participants. The ascents in virgin snow (FS) took place in parallel to the pathway (FP), without modifying the ascent conditions.

Every participant was equipped with a GPS watch including a heart-rate monitor (Sunnto Ambit3 Peak, Vantaa, Finland). Only the ascending phase was considered for data collection. The participants wore rigid mountaineering footwear and dressed with the innermost of the three layers of clothing that are considered the gold standard in mountaineering apparel. The participants were allowed to cover up with warmer layers between ascents, but all ascents had to be performed with the same clothing. At each ascent finish, monitoring was interrupted and a Borg test (rate of perceived exertion scale) (6-20) was performed (Borg et al., 2006). The variables reported by the GPS watch were: heart rate, respiratory rate, oxygen consumption (calculated from heart rate) and time elapsed. Participants were allowed to descend slowly and recovery was at the base of the slope.

Carceller, A

Resting time between ascents was 12 to 15 minutes, checking that subjects had reached their basal heart rate.

Atmospheric conditions

On the day of test, the average temperature at a local meteorological station was -6.7°C , with a maximum temperature of 0.8°C , which minimized the risk of snow transformation. Relative humidity was 73%, with moderate winds and no precipitation.

Statistical analysis

The Kolmogorov–Smirnov test was used to establish the normal distribution of the different samples. Student's t-test was used to evaluate differences between the outdoor ascent trials. The correlations between the different cardiorespiratory responses and performance indicators during the outdoor tests were analyzed using Pearson's bivariate correlation test. Statistical significance was set at $p < 0.05$ for all the analyses, which were performed using SPSS v.15 (SPSS Inc., Chicago, USA).

Results

Field test

Maximal exercise

As can be observed in Table 1, the maximal calculated oxygen consumption showed a moderate but statistically significant increase (2.6% CI95%: 0.9%-4.5%, $t=3.22$, $p=0.005$) when the subjects followed the previously traced pathway (FP) compared to the virgin snow (FS). The time necessary to complete the FS100 route was clearly longer than for the FP100 pathway. Thus, compacted snow allowed locomotion speed to

Carceller, A

increase by $0.43 \pm 0.11 \text{ km} \cdot \text{h}^{-1}$ ($t=4.21$, $p=0.01$). Meanwhile, the respiratory rate was significantly higher during FS100 ascent conditions (an increase of $2.3 \pm 2.4 \text{ b} \cdot \text{min}^{-1}$, $t=4.00$, $p=0.001$) than for FP100. No statistically significant differences were found between FS100 and FP100 when considering the Borg scores for declared perception of effort, heart rate or oxygen consumption (Table 1).

Submaximal exercise

Similarly to the maximal test, more time was necessary to complete FS70 than FP70 (Table 2), with this difference ($36 \pm 25 \text{ s}$) being statistically significant ($t=6.33$, $p<0.001$). The calculated mean oxygen consumption during the FS70 test was higher than for FP70 and this difference also reached statistical significance ($1.2 \pm 2.3 \text{ mL} \cdot \text{kg} \cdot \text{min}^{-1}$, $p=0.048$). In line with this, the respiratory rate was faster during FS70 by $2.9 \pm 4.4 \text{ b} \cdot \text{min}^{-1}$ ($p=0.02$). We also detected statistical differences in the subjective perception of effort, according to the Borg scale: it was higher for FS70 than for FP70 (FS70: 14.6 ± 0.7 ; FP70: 14.0 ± 0.2 ; $p=0.04$). Remarkably, the average score was around 14, which corresponds to a moderate effort equivalent to 70% of maximal individual capacity. As in the maximal test, average heart rate did not show a statistically significant difference between FS70 and FP70 (Table 2).

Laboratory test

Maximal exercise

In the laboratory test, we observed that the maximal respiratory parameters (oxygen consumption and respiratory rate) as well as the maximum heart rate were higher than

Carceller, A

those observed in the maximal field test (Table 3). When comparing the maximal performance observed in the field test with the maximal parameters obtained in the laboratory, we observed a correlation between the individual maximal O_2 consumption and the time elapsed during the maximal test inside the pathway (FP100) ($r=0.763$, $p=0.002$). When studying the values observed at the aerobic threshold (A_{Th1}) of the laboratory test, we observed correlations between time for the field test inside the pathway (FP70) and: oxygen consumption (VO_2) in the laboratory ($r=0.539$, $p=0.047$), fraction of O_2 in expired air (FeO_2) ($r= -0.634$, $p=0.002$), fraction of CO_2 in expired air ($FeCO_2$) ($r=0.604$, $p=0.029$), oxygen uptake per heart beat (O_2 pulse) ($r=0.626$, $p=0.022$) and end-tidal PCO_2 ($PETCO_2$) ($r= 0.622$, $p=0.023$). Conversely, there was no relationship between submaximal virgin snow performance (FS70) and the cardiorespiratory data observed in the laboratory conditions at A_{Th1}, except for heart rate. When correlating the values observed at the anaerobic threshold (A_{nTh2}) of the laboratory test with the data for the submaximal effort field test, we observed a relationship between performance in the field test of FP70 and tidal volume (V_T) ($r= -0.736$, $p=0.004$). When considering performance in FS70 and laboratory cardiorespiratory data, we also observed a positive relationship with: fraction of O_2 in expired air (FeO_2) ($r=0.579$, $p=0.038$), respiratory equivalent for O_2 (ERO_2) ($r=0.585$, $p=0.036$), respiratory equivalent for CO_2 ($ERCO_2$) ($r=0.566$, $p=0.044$), end-tidal PO_2 ($PETO_2$) ($r=0.596$, $p=0.031$) and end-tidal PCO_2 ($PETCO_2$) ($r= - 0.575$, $p=0.04$).

Discussion

In this study, we show the differences between training and performing a real ascent on a fresh snow surface (FS) or a previously trodden route (FP), which have different repercussions for energy expenditure and imply the use of different metabolic

Carceller, A

substrates. This can have significant technical, biomechanical and tactical (in competition) repercussions. The applicability of our results includes the fields of competition and sports events; as well as mountain safety strategies affecting the workload that can be assumed by mountain rescue teams, mountain border patrols and other emergency service operatives in snowy terrain. Moreover, there is the possibility of applying field CT100 tests to obtain an estimated maximal oxygen consumption value for athletes.

The time to complete the same route was higher in virgin snow (FS): 12% at maximal intensity and 11% in submaximal efforts. The power developed, considering time spent for moving the same weight, was higher when following the route inside an established pathway (FP) in both series. Given that alpinism is a sport where intensities are usually mild or moderate but sustained for a long period of time (Burtscher et al., 2015), our data suggest that when planning activities in snowy terrain not previously traced out, slower ascents can be expected. This is common knowledge among experienced mountaineers, but our study allows for a more accurate quantification of this extra effort to be developed.

The lack of significant differences in the values of heart rate for the different routes in the field test reflects similar intensity during the ascents and consequently our FP and FS data are comparable, in either maximal or submaximal efforts.

It is known that, for an equal load, walking on snow implies a higher maximal oxygen consumption than on a treadmill at the same intensity along flat terrain (Smolander et al., 1989); and that the increase in energy expenditure is proportional to the depth of the footprint in the snow (Heinonen et al., 1959). The value of the maximal oxygen consumption observed in the maximal ascents in this study was a 2.6% higher when

Carceller, A

locomotion was performed in FP than in FS, due to the higher capacity to develop speed and aerobic power. In the maximal effort outside the pathway (FS), there probably exists a greater anaerobic component, reflected in an increase of the respiratory rate of 2.3 cycles per minute in maximal effort and 2.9 in submaximal effort. This could be related to the additional biomechanical requirements for locomotion in virgin snow, due to the loss of the elastic rebound component of walking on a solid surface and the greater peripheral energy requirements of lower limb muscles (Minetti, 1995), as more effort is necessary to overcome the obstacle that the thickness of the snow represents (Ramaswamy et al., 1966); this leads to less efficient body postures and increased difficulties in maintaining balance (Pandolf et al., 1976). All of this could be modulated according to individual experience, as well as the acquisition of locomotor abilities through training (Billat et al., 2010; Burtsher et al., 2015).

The difference in respiratory data between field tests and laboratory tests is higher in submaximal efforts than in maximal efforts. This finding can be justified by considering that at maximal load, there is an intrinsic anaerobic component due to the high intensity, which could reduce the differences between respiratory cycles observed in FP and FS. In contrast, at submaximal load and when locomotion is performed at FP, this component is reduced due to the lower intensity; consequently, there is no need for such a degree of anaerobic metabolism to be involved.

Finally, speed was significantly greater in maximal efforts (13%) and in the submaximal series (16%) in FP, suggesting that even at low intensities and at the depth of snow footprint assessed in this study, alterations to normal walking gestures can be a limiting factor when it comes to maintaining an appropriate locomotion speed. This finding is not in agreement with previous reports that the maximum depth of footprint in snow suitable to maintain constant locomotion is 20 cm (Pandolf et al., 1976).

Carceller, A

When analyzing correlations among data in submaximal effort in the field test and in the laboratory test, we observed that respiratory parameters during effort intensity below the aerobic threshold in the laboratory are related to the performance results of the field test in the FP trials. Conversely, performance on fresh snow did not correlate with the data obtained at the aerobic threshold in the laboratory test. Thus, the hypothesis that the development of aerobic power is not limited in FP is reinforced.

Maximal values of heart rate and respiratory parameters in the laboratory test were higher to those obtained in the field test, challenging the equivalence of the data observed in a laboratory stress test and real performance in the field, in spite of using a laboratory stress test adapted to mountaineering requirements. Even so, it was possible to establish a relationship between time in the maximal test FP100 and maximal aerobic power registered in the laboratory. This opens up a possibility for a valid field test to estimate maximal oxygen consumption, based on time to complete FP100 ($VO_{2max} = 110.9 - 11.73 \cdot t$). The results of this correlate fairly well with those of the laboratory test (Figure 1). However, despite there being a correlation, maximal oxygen uptake results are lower in the field than in the maximal laboratory test. This, added to the lower tachycardization for the same workload when performing in the field, either at maximal or submaximal efforts, suggests that limitation of individual performance when walking uphill remains, even if there is a trodden pace, but the limiting factor does not seem to be the cardiorespiratory system. Peripheral muscular demands appear to be higher in the field, and even adapting the laboratory test by increasing the specificity for alpine needs, the results yield an acceptable data correlation but the test is not capable of faithfully reproducing the mountaineering requirements of other components of fatigue, such as muscular fatigue of the lower limbs. Differences in the intensity measurements between laboratory tests and field tests may also influence the different results.

Carceller, A

These observations lead us to consider that for the design of both a field and a laboratory test oriented to assessing the physical performance in a mountaineer whose sporting objective includes progression in snow, inclusion of the peripheral strength requirements when designing the treadmill protocol might be considered. This would potentially improve the specificity of the test in addition to the usual assessment of aerobic power and oxygen uptake capacity. Technical and lower limb strength training in order to achieve more efficient locomotion in snow seems to be an important element that would permit mountain athletes to develop their aerobic power in the field.

Limitations

Backpack weight and altitude effects were not considered during the field tests. The reduced number of participants did not permit us to have strong statistical power. Although mountaineering experience was one of the inclusion criteria of the study, individual ability to walk in snow is difficult to control for, as is the influence of footwear. We tried to solve these limitations by taking the subjects as their own control. Sex differences were not analyzed because of the small number of female participants included in the study.

Conclusions

Whether locomotion on snowy terrain is conducted on a previously trodden pathway or breaking a trail through virgin snow has demonstrable consequences. The latter requires more time and has an increased energy cost for a given route, either at maximal or submaximal intensities.

Carceller, A

During submaximal efforts, at an exercise intensity equivalent to that usually adopted in mountaineering climbing activity, locomotion on virgin snow involves a greater average oxygen consumption, an increase of the workload, a higher energy cost, with a higher anaerobic component, and higher subjective fatigue perception than following a previously trodden path. This limitation for locomotion due to the characteristics of the terrain impedes development of maximal aerobic power, especially on fresh snow, so peak oxygen consumption is higher when walking inside an established pathway. Consistent with this, respiratory data observed in the laboratory below the anaerobic threshold correlate with performance in the submaximal test on the terrain; and these laboratory data at the anaerobic threshold are fairly well related with field tests performed on virgin snow. Our results should be interesting for mountain safety, as they objectively describe limitations to ascents, depending on the pathway. This knowledge could lead to different strategies when climbing with a group in order to limit individual fatigue, such as changing the leader regularly, assuming longer ascent times along virgin snow routes and considering lower limb strength and specific training for snowy terrain as important requirements when confronting the ascent. These data may also be useful to design field tests for performance assessment in mountaineering and other snow sports which allow aerobic power to be an estimated.

In the same way, knowing if an ascent has been performed on a previously established pathway or on fresh snow can be a differential factor when comparing different activities, especially if time of ascent is assessed as a sports merit, or if ascents of the same mountain are performed via different routes under a range of snow conditions.

Carceller, A

Acknowledgments

The authors are grateful to the participants in this study for their enthusiasm and commitment. We would also like to thank the members of the ACNA (*Asociació pel Coneixement de la Neu i Allaus*) for their collaboration in obtaining the snow cuts reported in this paper. We also want to thank Dr. Christopher Evans at the SAL (*Servei d'Assessorament Lingüístic*) of the University of Barcelona for help editing the text.

Conflict of interest

No competing financial interests exist.

References

- Ainslie PN, Campbell IT, Lambert JP, MacLaren DP, and Reilly T (2005). Physiological and metabolic aspects of very prolonged exercise with particular reference to hill walking. *Sports Medicine* (Auckland, N.Z.) 35 (7): 619–47.
- Billat VL, Dupre M, Karp JR, and Koralsztejn JP (2010). Mountaineering experience decreases the net oxygen cost of climbing Mont Blanc (4,808 M). *European Journal of Applied Physiology* 108 (6): 1209–16. <https://doi.org/10.1007/s00421-009-1334-9>.
- Borg E, and Kaijser L (2006). A comparison between three rating scales for perceived exertion and two different work tests. *Scandinavian Journal of Medicine & Science in Sports* 16 (1): 57–69. <https://doi.org/10.1111/j.1600-0838.2005.00448.x>.
- Burtscher M, Gatterer H, and Kleinsasser A (2015). Cardiorespiratory fitness of high altitude mountaineers: the underestimated prerequisite. *High Altitude Medicine & Biology* 16 (2): 169–70. <https://doi.org/10.1089/ham.2015.0021>.
- Heinonex A, Karvones MJ, Ruosteenoja R (1959). The energy expenditure of walking on snow at various depths. *Ergonomics* 2 (4): 389–94. <https://doi.org/10.1080/00140135908930455>.
- International Climbing and Mountaineering Federation (2002) The UIAA Tyrol Declaration- UIAA Mountain Code. Conference on the Future of Mountain Sports. Innsbruck. <http://www.theuiaa.org/tyrol-declaration.html>

Carceller, A

Minetti, AE (1995). Optimum gradient of mountain paths. *Journal of Applied Physiology* 79 (5): 1698–1703.

Pandolf KB, Haisman MF, Goldman RF (1976). Metabolic energy expenditure and terrain coefficients for walking on snow. *Ergonomics* 19 (6): 683–90. <https://doi.org/10.1080/00140137608931583>.

Ramaswamy SS, Dua GL, Raizada VK, Dimri GP, Viswanathan KR, Madhavia J, and Srivastava TN (1966). Effect of looseness of snow on energy expenditure in marching on snow-covered ground. *Journal of Applied Physiology* 21 (6): 1747–49.

Smolander J, Louhevaara V, Hakola T, Ahonen E, and Klen T (1989). Cardiorespiratory strain during walking in snow with boots of different weights. *Ergonomics* 32 (1): 3–13. <https://doi.org/10.1080/00140138908966063>.

.

Table 1.

Variables	FS100	FP100	<i>p value</i>
Time (<i>s</i>)	256 ± 30	225 ± 29	<0.001
Speed (<i>km · h⁻¹</i>)	3.14 ± 0.36	3.56 ± 0.52	0.001
Heart rate (<i>beats · min⁻¹</i>)	164.0 ± 9.6	163.6 ± 8.0	0.521
Respiratory rate (<i>breaths · min⁻¹</i>)	38.1 ± 5.5	35.8 ± 5.8	0.001
Calculated VO ₂ max (<i>ml · kg⁻¹ · min⁻¹</i>)	33.5 ± 4.4	34.4 ± 4.3	0.007
Calculated VO ₂ mean (<i>ml · kg⁻¹ · min⁻¹</i>)	29.9 ± 4.0	29.7 ± 3.9	0.631
Borg score	20 ± 0	20 ± 0	-

Carceller, A

Table 2.

Variables	FS70	FP70	<i>p value</i>
Time (<i>s</i>)	326 ± 30	290 ± 24	<0.001
Speed (<i>km · h⁻¹</i>)	3.1 ± 0.4	3.6 ± 0.5	0.001
Heart rate (<i>beats · min⁻¹</i>)	148.6 ± 11.5	144.3 ± 11.7	0.084
Respiratory rate (<i>breaths · min⁻¹</i>)	31.8 ± 5.8	28.9 ± 4.6	0.02
Calculated VO _{2 mean} (<i>ml · kg⁻¹ · min⁻¹</i>)	25.2 ± 3.3	24.0 ± 3.8	0.048
Borg score	14.6 ± 0.7	14.0 ± 0.2	0.004

Carceller, A

Table 3.

Variables	ATh1	AnTh2	Maximal
Respiratory rate (<i>breaths · min⁻¹</i>)	30.7 ± 5.7	41.6 ± 8.2	51.4 ± 9.0
V _E (<i>l · min⁻¹</i>)	67.8 ± 9.6	108.0 ± 19.2	135.7 ± 27.3
V _T (<i>l · min⁻¹</i>)	2.01 ± 0.33	2.38 ± 0.32	2.41 ± 0.38
VO ₂ (<i>ml · kg⁻¹ · min⁻¹</i>)	44.4 ± 12.6	58.1 ± 6.1	66.4 ± 7.7
VO ₂ (<i>l · min⁻¹</i>)	2.75 ± 0.56	3.88 ± 0.70	4.44 ± 0.84
VCO ₂ (<i>l · min⁻¹</i>)	2.40 ± 0.44	3.94 ± 0.70	4.90 ± 1.01
Heart rate (<i>beats · min⁻¹</i>)	141.7 ± 35.9	171.7 ± 10.3	178.2 ± 10.6
O ₂ pulse (<i>ml · beat⁻¹</i>)	17.2 ± 5.8	22.5 ± 3.7	24.8 ± 4.3

Figure 1

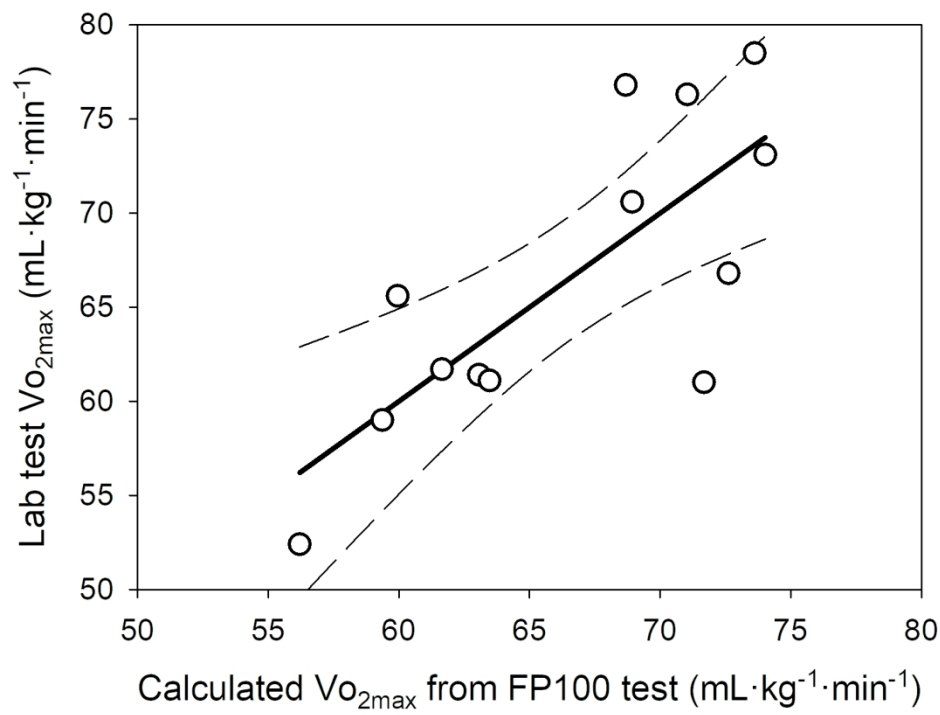


Figure 1

159x136mm (300 x 300 DPI)

Legends for Tables and Figure

Table 1. Data for outdoor tests performed at maximal individual capacity. Mean values \pm standard deviation.

(FS100: locomotion off the pathway at 100%; FP100: locomotion along the pathway at 100%)

Table 2. Data from submaximal outdoor tests. Mean values \pm standard deviation

Table 3. Performance-related parameters measured during maximal laboratory test. Mean values \pm standard deviation

(VE: ventilation; VT: tidal volume; $\text{VO}_2 \cdot \text{kg}^{-1}$: oxygen uptake relative to body weight; VO_2 : oxygen consumption; VCO_2 : CO_2 production; O₂ pulse: oxygen uptake per heart beat)

Figure 1. Relationship between real maximal oxygen consumption during lab test and estimated oxygen consumption during outdoor ascent at individual maximal capacity.