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Original Article

Optimal exercise intensities for fat metabolism in handbike cycling and cycling

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Study design: Energy expenditure (EE) and fat oxidation in handbike cycling compared to cycling in order to determine the intensity that elicits maximal fat oxidation in handbike cycling.
Objective: To establish the exercise intensity with the highest fat oxidation rate in handbike cycling compared with cycling (control group) in order to give training recommendations for spinal cord-injured (SCI) athletes performing handbike cycling.
Setting: Institute of Sports Medicine, Swiss Paraplegic Centre, Nottwil, Switzerland.
Methods: Eight endurance-trained handbike cyclists (VO_2 $peak_{handbike\ cycling}$ 37.5±7.8 ml/kg/min) and eight endurance trained cyclists (VO_2 $peak_{cycling}$ 62.5±4.5 ml/kg/min) performed three 20-min exercise blocks at 55, 65 and 75% VO_2 peak in handbike cycling on a treadmill or in cycling on a cycling ergometer, respectively, in order to find the intensity with the absolutely highest fat oxidation.
Results: The contribution of fat to total EE was highest (39.1±16.3% EE) at 55% VO_2 peak in handbike cycling compared to cycling, where highest contribution of fat to EE (50.8±13.8%) was found at 75% VO_2 peak. In handbike cycling, the highest absolute fat oxidation (0.28±0.10 g/min) was found at 55% VO_2 peak compared to cycling, where highest fat oxidation (0.67±0.20 g/min) was found at 75% VO_2 peak.
Conclusion: Well-trained handbike cyclists have their highest fat oxidation at 55% VO_2 $peak_{handbike\ cycling}$ compared to well-trained cyclists at 75% VO_2 $peak_{cycling}$. Handbike cyclists should perform endurance exercise training at 55% VO_2 $peak_{handbike\ cycling}$, whereas well-trained cyclists should be able to exercise at 75% VO_2 $peak_{cycling}$. For training recommendations, the heart rate at 55% VO_2 $peak_{handbike\ cycling}$ lies at 135±6 bpm in handbike cycling in SCI compared to 147±14 bpm at 75% VO_2 $peak_{cycling}$ in well-trained cyclists. We presume that the reduced muscle mass involved in exercise during handbike cycling is the most important factor for impaired fat oxidation compared to cycling. But also other factors as fitness level and haemodynamic differences should be considered. Our results are only applicable to well-trained handbike cyclists with SCI and not for the general SCI population.
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Keywords: paraplegia; tetraplegia; exercise type; energy expenditure

Introduction

Immobility due to a lesion of the spinal cord may lead to obesity. Therefore, spinal cord-injured (SCI) people have a higher risk for atherosclerosis due to obesity compared to able-bodied persons. The etiology of the accelerated atherogenesis seems to be multifactorial. Metabolic, hemostatic and autonomic reasons are considered.[1] It is known that increased physical activity with a consecutive reduction of adipose subcutaneous tissue reduces significantly the morbidity and mortality from cardiovascular diseases in SCI people.[2] In order to burn subcutaneous fat, it is generally recommended to perform endurance exercise at low to moderate intensities. In recent years, different intensities for the highest oxidation rate of fat have been found in studies with well trained able-bodied athletes. In 1993, Romijn *et al*[3] found the highest rate of fat oxidation at 65% VO_2 max (maximal oxygen uptake) in men on a cycling ergometer. In 2000, the same group confirmed these results also for women.[4] These results have been confirmed in 2002 with men on a cycling ergometer by another group.[5] In contrast to these results, Astorino[6]

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showed the highest oxidation rate of fat at 75% VO_2 peak in women on a treadmill. VO_2 max of 65 and 75% seem to be too high to burn fat because Van Loon *et al*[7] found in a further study the highest fat oxidation rate in cycling in well-trained men to be at lower intensities. In their study, the highest rate of fat oxidation was at 55% W_{max}, corresponding to 57 ± 1% VO_2 max. At the intensity of 75% W_{max} corresponding to 72 ± 2% VO_2 max, fat oxidation was inhibited. Reasons for these equivocal results may be differences in gender, type of exercise or fitness level of the subjects.

For SCI subjects, it is necessary to know the intensity of the highest fat oxidation in order to recommend intensity for endurance exercise. As far as we are aware, only two studies have been performed to determine the intensity of the highest fat oxidation rate at upper body exercise in SCI persons. In one investigation, wheelchair racing[8] and in the other arm cranking at a stationary ergometer[9] have been under examination. Handbike cycling is very commonly used in SCI for endurance training in order to improve physical fitness and reduce adipose subcutaneous tissue. The aim of our study was to define the intensity of the highest fat oxidation rate in handbike cycling in order to provide training recommendations. Owing to the fact that all recent studies to determine the intensity of the highest fat oxidation rate were performed with highly trained able-bodied cyclists on a stationary ergometer, we included a control group of highly trained cyclists in order to compare our results of SCI individuals. We are aware that our results will exclusively be applicable to well-trained wheelchair athletes and cannot be generalized to less active persons with an SCI.

Subjects and methods

Subjects

Eight endurance-trained handbike cyclists participated in the study. Eight well-trained cyclists were included as control (Table 1). The handbike cyclists consisted of six paraplegic athletes and two athletes with amputations of the lower limbs. All athletes completed regular training in their disciplines. Handbike cyclists and cyclists were competing at either national or international level. In both groups, athletes of international top level were included. The study was approved by the local ethics committee and all subjects gave their written informed consent prior to testing.

Determination of VO_2 peak$_{handbike\ cycling}$

The athletes came to the laboratory for a VO_2 peak test on a treadmill in their own handbikes, 1 day to 2 weeks prior to the endurance tests. The results of the VO_2 peak$_{handbike\ cycling}$ for handbike cyclists are presented in Table 2. The handbikes were fixed to the treadmill (Saturn HP Cosmos, München, Germany) with a mobile lever arm. Exercise protocol started at a speed of 10 km/h and an inclination of 2.1%. Every 3 min, speed increased 2 km/h and inclination remained until RER $>$ 1.1 was reached.[10] At the end of every step, capillary blood was taken from the earlobe to measure concentration of lactic acid by an enzymatic method (Super GL ambulance, Ruhrtal Labor Technik, Möhnesee, Germany). Before each measurement of lactic acid, the analyser was calibrated with a 10 mmol/l lactate standard solution. During the whole test, oxygen

Table 1 Anthropometric data of handbike cyclists with handicap specifications and able-bodied athletes

	Age (years)	*Weight (kg)*	*Height (cm)*	*Classification according ASIA*	*Level or kind of lesion*
Handbike cyclists					
1	49	85	190	A	T11
2	35	70	185	A	T5
3	39	55	170	B	L1
4	37	70	172		Amputation upper leg right
5	45	70	180	A	T12
6	39	76	178	B	T12
7	32	71	162		Amputation lower leg right
8	33	74	184	A	T5
Mean ± SD	38.5 ± 5.4	70.5 ± 8.1	176.0 ± 9.8		
Cyclists					
1	38	70	172	—	—
2	32	70	180	—	—
3	38	62	174	—	—
4	39	74	182	—	—
5	38	67	172	—	—
6	38	78	180	—	—
7	28	74	177	—	—
8	37	75	180	—	—
Mean ± SD	36.0 ± 3.9	71.3 ± 5.2	177.1 ± 4.0	—	—

ASIA = American Spinal Injury Association

Table 2 Results of the VO_2 peak tests of handbike cyclists and able-bodied athletes

	VO_2 peak (ml/min)	*VO_2 peak (ml/min/kg)*	*Maximal concentration of lactate (mmol/l)*	*Lactate threshold (% VO_2 peak)*	*Maximal heart rate (bpm)*
Handbike cyclists					
1	3290	38.7	13.6	53.4	165
2	2207	31.5	8.5	59.7	196
3	2870	53.7	12.1	48.5	191
4	2496	38.4	13.8	55.3	188
5	2292	32.7	7.9	57.5	190
6	2665	35.0	12.5	40.2	200
7	2743	38.6	10.4	51.6	183
8	2316	31.3	9.2	56.5	190
Mean±SD	2609±253	37.5±7.8	11.0±2.2	52.8±6.6	187.8±5.5
Cyclists					
1	3953	56.4	5.2	70.9	159
2	4355	62.2	10.7	60.7	208
3	4146	66.0	10.4	42.7	169
4	4272	57.7	8.3	61.3	185
5	4508	67.3	7.5	63.1	164
6	4578	58.3	9.6	76.6	174
7	5022	67.9	6.4	69.9	180
8	4791	63.9	6.7	60.4	187
Mean±SD	4453±347	62.5±4.5	8.1±2.0	63.2±10.1	178.3±15.5

uptake (VO_2) and carbon dioxide production (VCO_2) were measured continuously (Oxycon α, Jaeger, Würzburg, Germany). Gas analysers were calibrated prior to each test. Heart rate was measured continuously with a portable heart rate monitor (Polar M52, Kempele, Finland) and reported at the end of each incremental step.

Determination of VO_2 peak$_{cycling}$

Cyclists visited the laboratory for a VO_2 peak$_{cycling}$ test. 1 day to 2 weeks prior to the endurance tests. The results of the VO_2 peak$_{cycling}$ tests for cyclists are summarized in Table 2. They performed a VO_2 peak$_{cycling}$ test on a stationary cycling ergometer (ergoline 900, ergoline, Bitz, Germany). Work rate started at 100 W and was increased every 3 min by 30 W until RER > 1.1 was reached.[10] Measurement of lactate and respiratory gases were performed as described in the VO_2 peak$_{handbike\ cycling}$ test.

Determination of lactate threshold

Lactate threshold was determined in the VO_2 peak test as the point at which the blood lactate concentration during the incremental exercise rose above the lactate concentration at rest for more than 0.5 mmol/l.[11]

Endurance tests

Between 1 and 14 days after the VO_2 peak tests, subjects returned for the endurance tests. The evening before the test all subjects were told to eat a carbohydrate-rich meal with 70 kJ carbohydrates per kg bodyweight without fat. After an overnight fast, they reported to the laboratory at 0800 hours. They completed an endurance test in their discipline. The endurance test consisted of three stages of 20 min at 55, 65 and 75% VO_2 peak. Between each intensity stage they had a rest of 15 min and were allowed to drink tap-water without restriction of the amount. Immediately before the beginning of each intensity stage and every 10 min during the test, heart rate and concentration of lactate were recorded. A 20 μl capillary of glass was filled with blood from the earlobe to assess the concentration of lactate. During the 20 min, oxygen uptake (VO_2) and carbon dioxide production (VCO_2) were measured continuously. During the endurance tests, speed on the treadmill and workload (in W) on the cycling ergometer were adjusted in the first 5 min in order to reach the preset percentage of VO_2 peak for the rest of the endurance test.

Indirect calorimetry and calculations

VO_2 and VCO_2 from the last 10 min of each stage were used to calculate the rate of the oxidized substrate. Oxidation rate of fat and carbohydrate were calculated using the stoichiometric equations of Frayn,[12] where oxidation of carbohydrates is $4.55VCO_2-3.21VO_2-2.87n$ (nitrogen excretion rate) and oxidation of fat $1.67VO_2-1.67VCO_2-1.92n$. According to the study of Romijn *et al*,[4] n was assumed to be 135 μg/kg/min. EE from fat and carbohydrate were converted to kcal/min by multiplying the oxidation rate of fat with 9

Table 3 VO_2, RER, heart rate and contribution of fat to EE in handbike cycling compared to cycling

	VO_2 (ml/min)	*RER*	*Heart rate (bpm)*	*Energy expenditure (EE) (kcal/min)*	*Contribution of fat to EE (%)*
Handbike cyclists					
55% VO_2 peak	1348±105	0.83±0.04	135.3±6.4	6.8±0.8	39±16
65% VO_2 peak	1609±160	0.89±0.02	146.3±6.8	8.5±1.2	22±10
75% VO_2 peak	1947±207	0.93±0.01	160.7±7.2	10.1±1.1	22±10
Cyclists					
55% VO_2 peak	2519±209	0.87±0.03	116.6±9.3	11.7±0.9	35±14
65% VO_2 peak	2977±247	0.87±0.05	130.0±12.4	14.5±1.0	35±15
75% VO_2 peak	3435±285	0.87±0.03	147.5±14.6	16.6±1.3	50±13

and the oxidation rate of carbohydrate with 4 using the Atwater[13] general conversion factor. VO_2 and VCO_2 from the last 10 min of each stage were used to calculate RER. Also, the values of RER and heart rate measured during the last 10 min of exercise were used to calculate an average.

Statistical analysis

Two-way ANOVA with repeated measures were performed with Systat 10 (Systat Software, Inc., USA) to detect statistically significant differences between intensities for EE, fat oxidation, carbohydrate oxidation, concentration of lactate, RER and heart rate within and between the two groups. Bonferroni *post hoc* tests were performed for significant ANOVA. An unpaired *t*-test was performed to detect statistically significant differences between VO_2 $peak_{handbike\ cycling}$ and VO_2 $peak_{cycling}$ as well as for lactate threshold in handbike cyclists and cyclists. Probability level for a statistical significant difference was set at $P<0.05$.

Results

Subjects, VO_2 peak tests and lactate thresholds

Handbike cyclists and cyclists showed no difference in age, weight and height (Table 1). VO_2 peak ($P<0.001$) and lactate threshold ($P=0.027$) were significantly higher in cyclists compared to handbike cyclists (Table 2). Maximal heart rate and maximal concentration of lactate were not different between the two groups (Table 2).

Total EE and contribution of fat to EE

Handbike cyclists and cyclists showed highest EE at 75% VO_2 peak compared to 65% VO_2 peak ($P=0.027$ versus 0.003) and 55% VO_2 peak ($P<0.001$) (Table 3). Handbike cyclists expended significantly less energy than cyclists at 55% VO_2 peak ($P<0.001$), at 65% VO_2 peak ($P<0.001$) and at 75% VO_2 peak ($P<0.001$). Contribution of fat to EE was highest at 55% VO_2 peak in handbike cyclists compared to cyclists with the highest contribution of fat at 75% VO_2 peak.

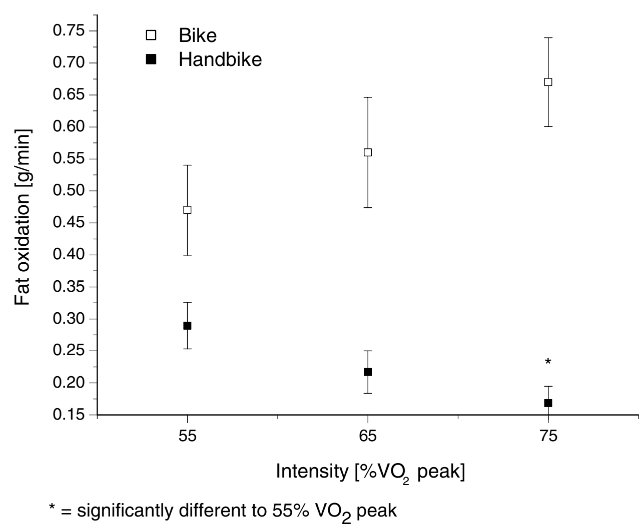

Figure 1 Fat oxidation. Mean±SE of absolute fat oxidation (g/min) at the three different intensities of 55, 65 and 75% VO_2 peak

Fat oxidation

Handbike cyclists had a significantly lower fat oxidation than cyclists at 55% VO_2 peak ($P=0.045$) compared to 65 and 75% VO_2 peak (Figure 1). In contrast to handbike cyclists, cyclists showed the highest fat oxidation rate at 75% VO_2 peak compared to 65 and 55% VO_2 peak. Handbike cyclists had a significantly lower fat oxidation than cyclists at 55% VO_2 peak ($P=0.036$), at 65% VO_2 peak ($P=0.002$) and at 75% VO_2 peak ($P<0.001$).

Carbohydrate oxidation

In contrast to fat oxidation, carbohydrate oxidation in handbike cyclists was significantly higher at 75% VO_2 peak than 65% VO_2 peak ($P=0.013$). and 55% VO_2 peak ($P=0.004$) (Figure 2).

Also in cyclists, carbohydrate oxidation was significantly higher in 75% VO_2 peak ($P=0.018$) compared to 65% VO_2 peak and 55% VO_2 peak. Handbike cyclists had a significantly lower carbohydrate oxidation than cyclists at 55% VO_2 peak ($P=0.001$), at 65% VO_2 peak ($P=0.014$) and at 75% VO_2 peak ($P=0.021$).

Concentration of lactate

In handbike cyclists ($P=0.027$) and cyclists ($P<0.001$), concentration of lactate was significantly higher at 75% VO_2 peak compared to 65% VO_2 peak and 55% VO_2 peak (Figure 3). Handbike cyclists had a significantly higher concentration of lactate than cyclists at 55% VO_2 peak ($P=0.001$), at 65% VO_2 peak ($P=0.001$) and at 75% VO_2 peak ($P<0.001$).

RER

In handbike cyclists, RER at 55% VO_2 peak was significantly lower than at 65% VO_2 peak ($P=0.003$) and at 75% VO_2 peak ($P=0.000$) (Figure 4). Also at 65% VO_2 peak, RER was significantly lower than at 75% VO_2 peak ($P=0.043$). In cyclists, no difference in RER between the intensities was found.

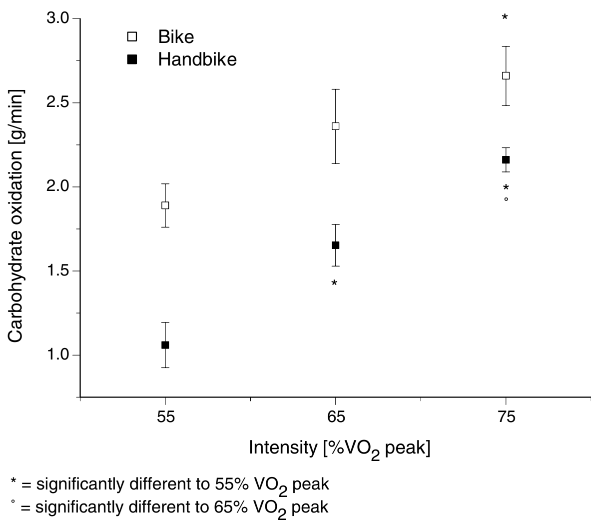

Figure 2 Carbohydrate oxidation. Mean ± SE of absolute carbohydrate oxidation (g/min) at the three different intensities of 55, 65 and 75% VO_2 peak

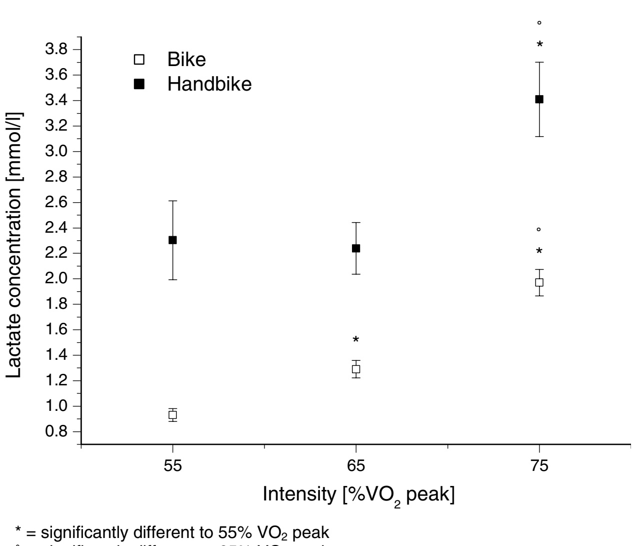

Figure 3 Concentration of lactate. Mean ± SE of lactate concentrations (mmol/l) at the three different intensities of 55, 65 and 75% VO_2 peak

Heart rate

In handbike cyclists, heart rate was at 55% VO_2 peak ($P=0.000$) and 65% VO_2 peak ($P=0.030$) significantly lower than at 75% VO_2 peak (Figure 5). In cyclists, heart rate was significantly lower in 55% VO_2 peak compared to 65% VO_2 peak ($P=0.013$) and 75% VO_2 peak ($P=0.000$) and in 65% VO_2 peak compared to 75% VO_2 peak ($P=0.001$).

Discussion

The main finding of this investigation was the fact that the absolutely and relatively highest fat oxidation rates

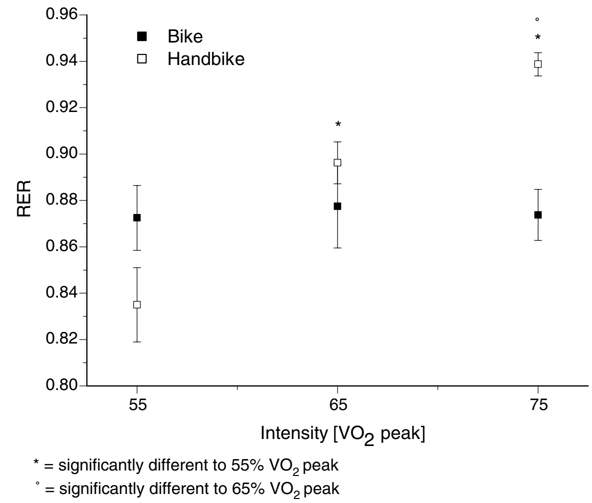

Figure 4 RER. Mean ± SE of RER at the three different intensities of 55, 65 and 75% VO_2 peak

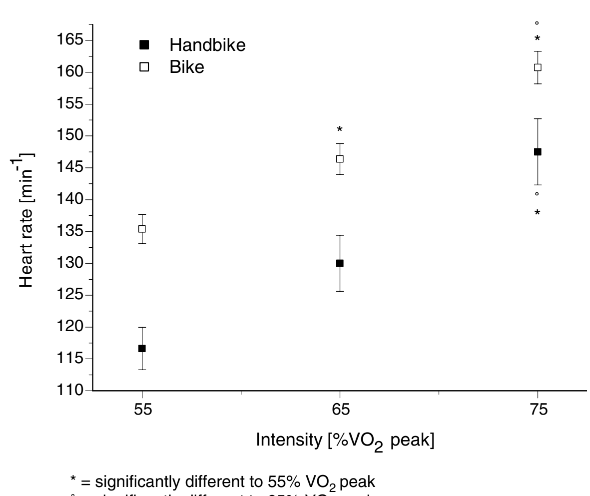

Figure 5 Heart rate. Mean ± SE of heart rate (bpm) at the three different intensities of 55, 65 and 75% VO_2 peak

were at 55% VO_2 peak in handbike cycling, whereas in cycling, absolutely and relatively highest fat oxidation was found 75% VO_2 peak. Possible reasons for these differences could be the muscle mass involved in exercise, the fitness level, the distribution of muscle fiber type and hemodynamic considerations.

Muscle mass involved in exercise

Oxygen is needed to oxidize carbohydrates and fat. VO_2 max is depending upon the muscle mass engaged in exercise[14] and seems to be limited in upper body exercise compared to lower body exercise. It has been shown in able-bodied persons that VO_2 max in two arm-cranking corresponds to 55% VO_2 max of two leg VO_2 max.[15] Individuals with SCI have a limitation in VO_2 peak compared to able-bodied persons, which is rather due to the small active muscle mass[16] than the limitation of the cardiovascular[17] or the cardiopulmonary system[18] depending upon the level of lesion.[19] The corresponding impaired work capacity of SCI individuals compared to able-bodied persons can be attributed to the smaller active muscle mass available for physical performance.[20]

It has been shown in SCI persons that the kind of sitting position[21] and the kind of upper body exercise[22] may influence muscle efficiency and force production during exercise. During handbike cycling, the athlete is sitting on a chair, the upper body is fixed on the bench and only the muscles of the shoulders and arms are mainly involved in exercise. The large muscle mass of the back and the front of the upper body remain fixed and are not especially moved during exercise.

The relatively high concentrations of lactic acid at low to moderate intensities (Figure 3) and the increase of RER with increasing intensity (Figure 4) seem to reflect the high intensity of the small muscle mass involved in exercise.

The limited muscle mass during upper body exercise seems to have an influence on substrate utilization. In able-bodied persons, the smaller arm musculature becomes more dependent on carbohydrate utilization compared to the legs when substrate utilization during arm and leg exercise is compared.[23] As Figure 4 shows, RER increases at each intensity in SCI compared to cyclists, where RER remains stable at each intensity. For SCI, we could show in two recent studies that the intensity of the highest fat oxidation is lower in wheelchair racing[8] than in arm cranking.[9] This might be a consequence of the different muscle mass engaged in exercise.

Fitness level

The determination of VO_2 max is the most relevant factor for endurance fitness. VO_2 max is the classical variable in the field of exercise physiology to measure the cardiorespiratory fitness of athletes and depends upon training status, the muscles involved in exercise and constitutional conditions.[24] The higher VO_2 max, the better is the performance in an endurance event.[25] In handbike cyclists, only about 30–65% of the body muscle mass is involved during exercise.[26] This is reflected by a significantly smaller energy expenditure at the same percentage of VO_2 peak in handbike cyclists compared to cyclists (Table 3). For handbike cyclists, VO_2 $peak_{handbike\ cycling}$ values of 37.5 ± 7.8 ml/min/kg (Table 2) indicate that these athletes are highly trained and are comparable with our well-trained cyclists in the control group. Our results of VO_2 $peak_{handbike\ cycling}$ agree with results of other studies,[19,27,28] where highly trained wheelchair athletes reach a VO_2 max of 30–40 ml/min/kg.

Only very highly trained endurance wheelchair athletes can reach a VO_2 max of more than 50 ml/min/kg[29] as opposed to endurance-trained able-bodied athletes who reach VO_2 max values of 75–85 ml/min/kg due to the larger muscle mass actively involved in exercise.[30]

Influence of intensity and lactate

The increased concentration of lactate at higher intensities might have an influence on fat oxidation. At an intensity of 80% VO_2 max glycogen stores will be emptied in about 90–180 min[31] and at this intensity, 80% of the energy derives from carbohydrate oxidation[32] of the muscle glycogen, whereas the oxidation of intramuscular triglycerides is inhibited.[33] At even higher intensities, muscle glycogen is oxidized anaerobically and the concentration of lactate will rise to values around 5 mmol/l.[34] The reason for inhibition of fat oxidation at higher intensities is given by the inhibition of mobilization of long-chain fatty acids from subcutaneous adipose tissue,[35] the limited entry of long-chain fatty acids into the mitochondria for oxidation[36] and the inhibition of the oxidation of intramuscular triglycerides.[33]

With increasing intensity, carbohydrate oxidation is increased, whereas fat oxidation is reduced[37] and lactate fails to be completely eliminated.[38] The elimination of lactate in SCI could be reduced compared to able-bodied persons due to differences in muscle mass and muscle fibre distribution. Elimination of lactate in able-bodied persons depends mainly upon capillary density, muscle volume, whole body lactate concentration and muscle fibre distribution.[39] Also, for able-bodied individuals, blood lactate concentration is higher after arm cranking than after leg cycling,[40] but in trained able-bodied athletes, it has been shown that high concentrations of lactate do not inhibit subcutaneous lipolysis.[41]

The threshold of a lactate concentration of 2 mmol/l is set as aerobic threshold, reflecting the upper limit of exclusive aerobic metabolism.[42] The aerobic threshold corresponds to the point beyond which blood lactate increases systematically above resting values.[43] Lactate concentrations at the end of each stage were higher in handbikers than in cyclists at each stage and highest at 75% VO_2 peak (Figure 3). At 75% VO_2 $peak_{cycling}$, cyclists still had lactate concentrations below 2 mmol/l, whereas handbike cyclists showed concentrations of lactate above 2 mmol/l at 55–75% VO_2 peak$_{handbike\ cycling}$.

Astorino[6] rose the question whether the highest fat oxidation rate is at the ventilatory threshold. In his study, the ventilatory threshold lies at 76.0 ± 7.41% VO_2 peak and the lactate threshold at 62.0 ± 4.7% VO_2 peak. In cyclists, we found the highest absolute fat oxidation at 75% VO_2 peak$_{cycling}$, which is higher than the lactate threshold of 63.2% VO_2 peak$_{cycling}$ (Table 2). But the lactate threshold of 63.2% VO_2 peak$_{cycling}$ corresponds to the results of Astorino.[6] In contrast, handbike cyclists showed highest fat oxidation rate at 55% VO_2 peak$_{handbike\ cycling}$ and they have a significantly lower lactate threshold (Table 2) than cyclists.

Distribution of muscle fibres

The distribution of type of muscle fibre and the change of muscle fibre recruitment during endurance exercise may play a role in substrate metabolism.[44–46] Endurance-trained athletes have more type I than type II fibres.[47,48] Type I fibres are highly oxidative low glycolytic fibres with a higher fat oxidation and lower production of lactic acid than type II fibres.

The shoulder is the most important part of the body for propulsion of a handbike cyclist. The anterior part of the deltoid muscle consists of more type I fibres than type II fibres. The highest percentage of type I fibres are found in tetraplegic subjects with 74%, followed by paraplegics with 57% and able-bodied persons with 42%.[49] We would presume from these results that athletes using mainly their muscles of the shoulder for exercise should have a relatively high fat oxidation at each exercise intensity. But it has been shown that during arm cranking more type II fibres are recruited compared to leg cycling.[50,51] Another important factor in this context is the recruitment of muscle fibres at different exercise intensities. Generally, type II fibres are recruited at higher intensities[52] and this could also influence substrate utilization.

Haemodynamic considerations and blood flow

During handbike cycling with upper body exercise, central haemodynamics will be different from cycling with lower body exercise. It is well known that the cardiovascular system of SCI individuals is limited due to impaired sympathetic cardiac stimulation.[20] The reduced cardiac capacity of tetraplegic and high-lesion paraplegic individuals may be linked to their lower maximal exercise capacity and lower VO_2 compared to able-bodied persons.[19] In SCI, circulatory response to submaximal exercise is different from able-bodied persons.[53] This could influence availability of oxygen and therefore substrate utilization.

Localized blood flow and substrate utilization could also be influenced in SCI during upper body exercise even though it has been shown in able-bodied persons that during submaximal exercise cardiorespiratory responses of upper body exercise do not differ from lower body exercise at the same relative intensity.[54]

But there are haemodynamic differences between strict lower body exercise and strict upper body exercise in able-bodied persons[55] and venous return is facilitated and peripheral resistance decreased when lower body exercise is added to upper body exercise.[56]

In general, training recommendations for endurance exercise are prescribed on the basis of heart rates. Relying upon our results (Figure 5), the intensity with the highest fat oxidation in handbike cycling in SCI corresponds to a heart rate of 130–140 bpm.

Conclusion

Well-trained handbike cyclists have their highest fat oxidation at 55% VO_2 peak$_{handbike\ cycling}$ compared to well-trained cyclists at 75% VO_2 peak$_{cycling}$. Handbike cyclists should perform endurance exercise training at 55% VO_2 peak$_{handbike\ cycling}$, whereas well-trained cyclists should be able to exercise at 75% VO_2 peak$_{cycling}$. For training recommendations, the heart rate at 55% VO_2 peak$_{handbike\ cycling}$ lies at 135 ± 6 bpm in handbike cycling in SCI compared to 147 ± 14 bpm at 75% VO_2 peak$_{cycling}$ in well-trained cyclists. We presume that the reduced muscle mass involved in exercise during handbike cycling is the most important factor for impaired fat oxidation compared to cycling. But other factors such as fitness level and haemodynamic differences should also be considered. Our results are only applicable to well-trained handbike cyclists with SCI and not for the general SCI population.

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