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Case Study

Performance diagnostics in handbiking during competition

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Study design: Case study in handbiking under competition conditions.
Objective: To investigate exercise-induced, metabolic, pulmonary, cardiovascular and energetic reactions of a paraplegic athlete during a city marathon.
Setting: City marathon Cologne, Germany.
Subject: We tested a 27-year-old male athlete from the German national team. The handicap of the athlete was a complete traumatic spinal cord injury ASIA/IMSOP Grade A at the level of the fourth thoratic vertebra (Th_4).
Method: In the competition, the athlete used his own race handbike whose crank system had been exchanged for a power measurement system with registering option. For measuring ventilatory gas parameters during exercise, a portable spirometric system was used. The athlete managed to finish the marathon race in 1:48:54 h.
Results: The mean oxygen uptake ($\dot{V}O_2$) during the marathon was 1580 ml/min, with a maximum value of 2535 ml/min. The mean heart frequency was 137 bpm with a maximum of 157 bpm. During the race the mean energy consumption was 463 kcal/h with a maximum of 758 kcal/h. Prior to the race, the blood lactate value was 2.9 mmol/l; after 10 km 4.4 mmol/l; after 20 km 2.9 mmol/l, and after 30 km 2.9 mmol/l.
Conclusion: Competition-oriented handbikers should concentrate on exercise units of long duration at low intensities – like marathon runners or cyclists – in order to improve their aerobic performance capacity. However, it has to be pointed out that paraplegic athletes develop relatively high metabolic intensities in competition and that the variability of their physiological parameters is considerably high.
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Keywords: spinal cord injury; wheelchair sports; marathon; gross mechanical efficiency

> "I want this sport to take off; I want people to ride with and compete against! So please if you are interested, give me a call and come over for a ride…, and may the wind always be at your back![1]"

Introduction

At the end of the 1980s the first modern handbikes for persons with spinal cord injuries were developed in the United States. These wheelchairs are driven by means of an arm crank system as it is known in cycling in contrast to wheelchairs in which propulsion is effective using pushrims at the rear wheels. In the initial phase, only models were constructed in which a fifth wheel was connected to the regular everyday wheelchair. The front wheels of the wheelchair were previously jacked up and the result was a three-wheel 'handbike'. The particular advantage of such a modified handbike – compared to everyday wheelchairs – is the increased mechanical efficiency from about 10 (race wheelchair)[2] to 11–15% for asynchronous arm crank ergometry,[3] which leads to a remarkably enlarged mobility radius. Furthermore, from the point of view of sports medicine, handbiking is highly recommended to maintain the level of physical fitness and to prevent arteriosclerotic diseases as it is characterized by a relatively high energy consumption at moderate training intensities.[4] In addition to the just-described modified bikes, more and more handbikes are being developed for the purpose of being used in sports.

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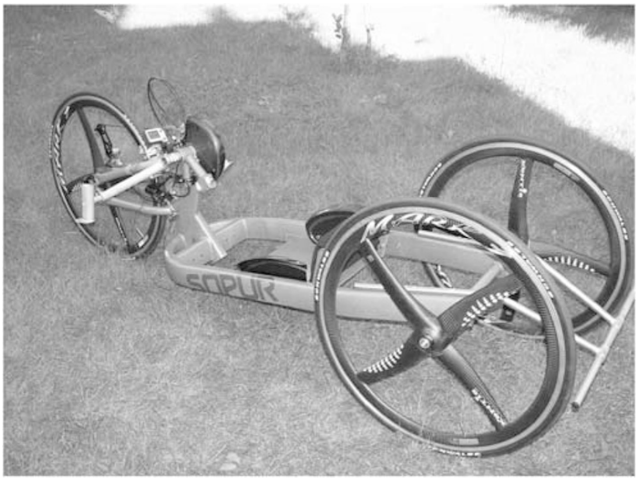

Figure 1 Race bike

Special frames and a low center of gravity contribute to improved driving properties, thus allowing a higher speed (Figure 1).

In the field of sports for the disabled, these top-end race handbikes are becoming more and more popular as very attractive high-performance sports equipment. Another reason for the growing interest is that handbikes allow common training sessions for both handicapped and able-bodied persons. Various kinds of sports like handbiking, cycling and inline skating can be performed together perfectly, provided that the sportsmen have similar physical fitness levels. In the field of competition in handbiking in Europe, mainly city marathon events and the European Handbike Circuit have been established. However, there are also ultra long-distance races like the race around the lake of Geneva (Tour du Lac Lemand) in Switzerland with a distance of 174 km as well as sprint races with a distance of 10 km. During the Paralympic Games in Athens in 2004, handbiking for the first time became an inherent element of the canon of disciplines. Considerably great differences in performance abilities can therefore be found between sedentary- and wheelchair-trained athletes.[5]

In this context, we can state the growing interest of athletes who ask for systematic performance control. Unfortunately, the existing pool of knowledge in the field of sports science and sports medicine does not by far meet the requirements. The prerequisite for an adequate performance control is the analysis of the demand profile. For this reason, the present study investigated exercise-induced, metabolic, pulmonary, cardiovascular and energetic reactions of a paraplegic athlete on the occasion of the fifth Cologne Ford Marathon.

Methods

A 27-year-old male athlete took part in this study after being informed about details and risks of the investigation and after signing written consent for participation. The handicap of the athlete was a complete traumatic spinal cord injury (AISA/EMSOP Grade A) at the level of the fourth thoracic vertebra (Th_4). A basal metabolism evaluation was made 1 week before the marathon after a one-night abrosia under standardized conditions[6] for half-an-hour using the Deltatrac II MBM-200 Metabolic Monitor (Datex-Engström, Achim, Germany). In addition, a stage test on the treadmill (initial speed 12 km/h, increase 2 km/h every 3 min) until exhaustion was performed 1 week before the race to elevate the physiological responses at maximum load. In the competition, the athlete used his own race handbike, the crank system of which had been exchanged for a power measurement system with registering option (Schoberer Rad Messtechnik SRM, Jülich, Germany). This technical device made it possible to continuously register speed, load, crank frequency, physical energy consumption and heart frequency during the whole race distance. For measuring ventilatory gas parameters during exercise, a portable spirometric system was used which offered the opportunity of breath-by-breath analysis (Cosmed K_4b^2, Rome, Italy). During spirometry the following parameters were measured, or calculated after measurement: respiratory frequency (Rf), ventilation in liters per minute ($\dot{V}_E$), tidal volume in milliliters per minute ($\dot{V}_T$), oxygen uptake in milliliters per minute ($\dot{V}O_2$), carbon dioxide production in milliliters per minute ($\dot{V}CO_2$), respiratory quotient as ratio of $\dot{V}O_2$-uptake and $\dot{V}CO_2$-production (RQ), as well as energy consumption by means of indirect calorimetry (kcal/h). The energy consumption was calculated according to the following equation:[7]

$$EE_{hour} = \dot{V}O_2 \times (3.9 + 1.1 \times RQ) \times 60$$

Gross and net mechanical efficiency (GME, NME) was calculated according to the following equation:[8]

$$GME = (A \times 100)/E$$

$$NME = (A \times 100)/(E - e)$$

With:

A = performed work measured at the SRM system in kcal;

E = energy expenditure measured via indirect calorimetry in kcal;

e = resting energy expenditure measured via indirect calorimetry in kcal.

Figure 2 shows the athlete with the spirometry mask during a pretest on a treadmill. Blood samples to determine the lactate concentration were taken in the course of the marathon at kilometres 10, 20, and 30. Owing to his spinal cord injury, the athlete is not able to sweat below his level of his lesions. According to this reduced thermoregulation, the rectal temperature of the athlete was continuously registered using a temperature measuring probe (constructed by Dipl. Ing. K. Wasser, Institute of Cardiology and Sports Medicine, Cologne, Germany), to gain information about the risks of hyperthermia. Before the race (3 weeks), the volunteer performed an incremental spirometric exercise test with his own handbike for determination of his level of fitness prior to the marathon.

Figure 2 Laboratory settings

Results

The athlete managed to finish the marathon race in 1:48:54 h despite the fact that he wore the spirometry mask and had to make several breaks for blood sampling. This total time exceeded his best marathon result at that time by 20 minutes (1:27:20 h, Heidelberg, 2001). In Figures 3 and 4, the spirometric data of the athlete in the course of the marathon are shown, the values representing means of 30 s intervals. Invalid values or artifacts which occurred, that is, during the drinking or blood sampling phases, have been eliminated. Figure 3 gives an overview of the oxygen uptake and carbon dioxide production in ml/min, and Figure 4 of the respiratory exchange ratio and the energy consumption in kcal/h.

The mean oxygen uptake ($\dot{V}O_2$) during the marathon was 1580 ml/min (66.38% of the $\dot{V}O_{2peak}$ of the previous stage test), with a maximum value of 2535 ml/min (106.51% of previous test). The mean heart frequency was 137 bpm (81.07% of the maximal heart rate of the previous stage test), with a maximum of 157 bpm (92.90% of previous test). During the race, the mean energy consumption was 463 kcal/h, with a maximum of 758 kcal/h. Thus, the energy consumption during the total marathon period (1:48:54 h) amounted to 838 kcal. On average, the respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$) was 0.88 (89.80 of the maximal respiratory exchange ratio of the previous stage test), which indicates that the portion of fatty acid oxidation was approx. 40% of the total energy production (proteins are not considered). The mean respiratory frequency of the athlete was 53.2/min, with a maximum of 79.7/min and the mean

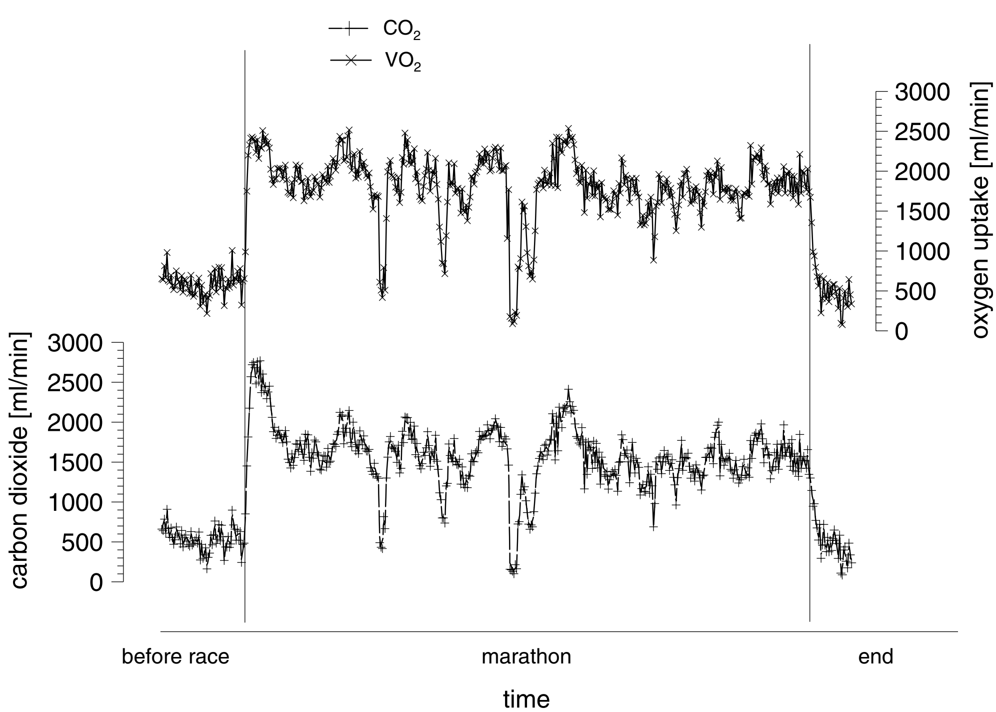

Figure 3 Carbon dioxide production (low curve) and oxygen uptake (upper curve) before, during, and after the race

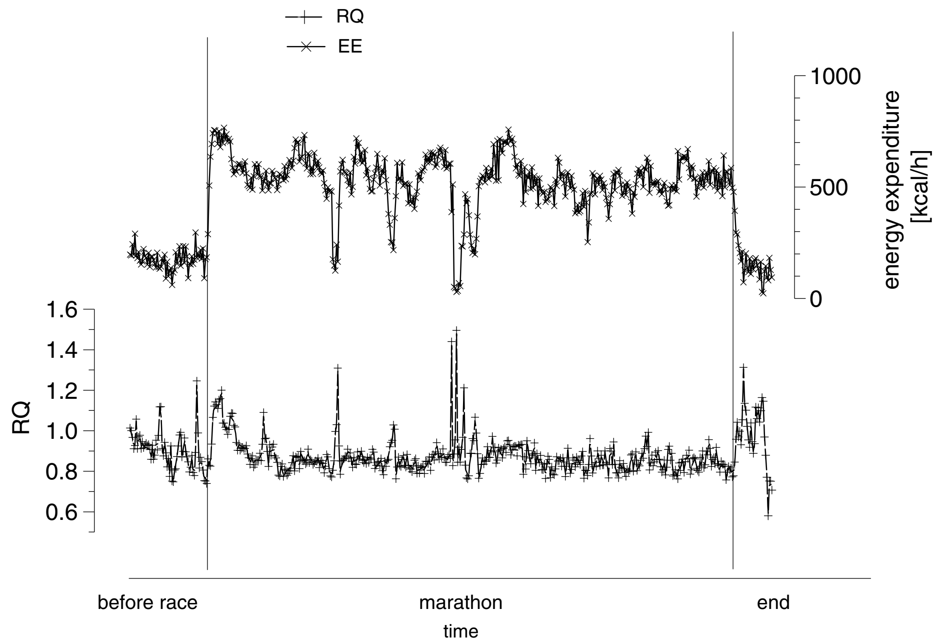

Figure 4 Respiratory exchange ration (lower curve) and energy expenditure (upper curve) before, during and after the race

ventilatory minute volume was 62.0 l/min, with a maximum of 97.3 l/min. In the basal metabolism evaluation, which was made before the race, the resting energy expenditure was 50.04 kcal/h. The gross mechanical efficiency during the whole race was 15.25%, and the net mechanical efficiency 17.09%.

Prior to the race, the blood lactate value was 2.9 mmol/l; after 10 km 4.4 mmol/l; after 20 km 2.9 mmol/l; and after 30 km 2.9 mmol/l. The average value during exercise was 3.4 mmol/l (55.74 % of the maximal lactate concentration of the previous stage test). Figure 5 reflects the results of the SRM system. The left side depicts the phase before the start and the right side the load during the marathon. The mean load was 84.1 W, with a maximum of 211 W, and the average speed was 24.4 km/h, with a maximum of 31.5 km/h. The athlete completed the race at an average crank frequency of 78.6 U/min, with a maximum of 105 U/min. The energy balance, measured at the SRM-crank during the whole marathon distance, amounted to 524.1 kJ (127.8 kcal) within 1:48:54 h.

Figure 6 shows the behavior of the rectal temperature during the race. A maximum rectal temperature of 40.4°C was observed, whereas the temperature at rest was 36.8°C.

Discussion

The athlete completed this marathon race in a total time that exceeded his personal best time at the date of the marathon by 20 min. This is most likely due to the necessary breaks for blood sampling and the wearing of a portable spirometry system. Although the athlete had a lesion-induced neuronally and hormonally inhibited positive chronotropic impact on the sympathetic neuronal system, his average heart frequency of 136 bpm was relatively high (the origin of sympathetic innervation of the heart is located between Th_1 und Th_4).[9] In this case, the average heart frequency is an important indicator of a rather high work load. As the lactate accumulation is limited due to the lesion level and the reduced effective muscle mass,[5] mean lactate values of 3.4 mmol/l, recorded at three points of time, speak for an intensive work load, too. (Maximum lactate concentration on a previous stage test was 6.1 mmol/l). The average oxygen uptake of 1584 ml/min revealed a lower value compared to persons with a low- and mid-lesion level spinal cord injury (Th_{5-12} according to the classification by Schmid (1998)[10]), but this result can also be attributed to the reduced positive impact of the sympathicus.[9] In handbiking, the extent of energy consumption, which is a very important factor from the point of view of preventive medicine, is highly encouraging.[4,11,12] The American College of Sports Medicine (ACSM), for example, recommends an additional energy consumption by endurance sport on 3 days/week with a moderate intensity to prevent arteriosclerotic diseases.[13] According to the examinations by Paffenbarger *et al* (1986)[14] a clearly higher additional weekly energy expenditure of 2000–2500 kcal or an additional daily energy expenditure of approx. 300–350 kcal leads to the greatest possible reduction of the risk of myocardial infarction. The current values show that these values might be easily achieved when handbike training is performed daily. Other studies show that a duration of approx. 1 h at a moderate intensity is recommendable.[4] The measured mechanical efficiency shows values comparable to the findings of

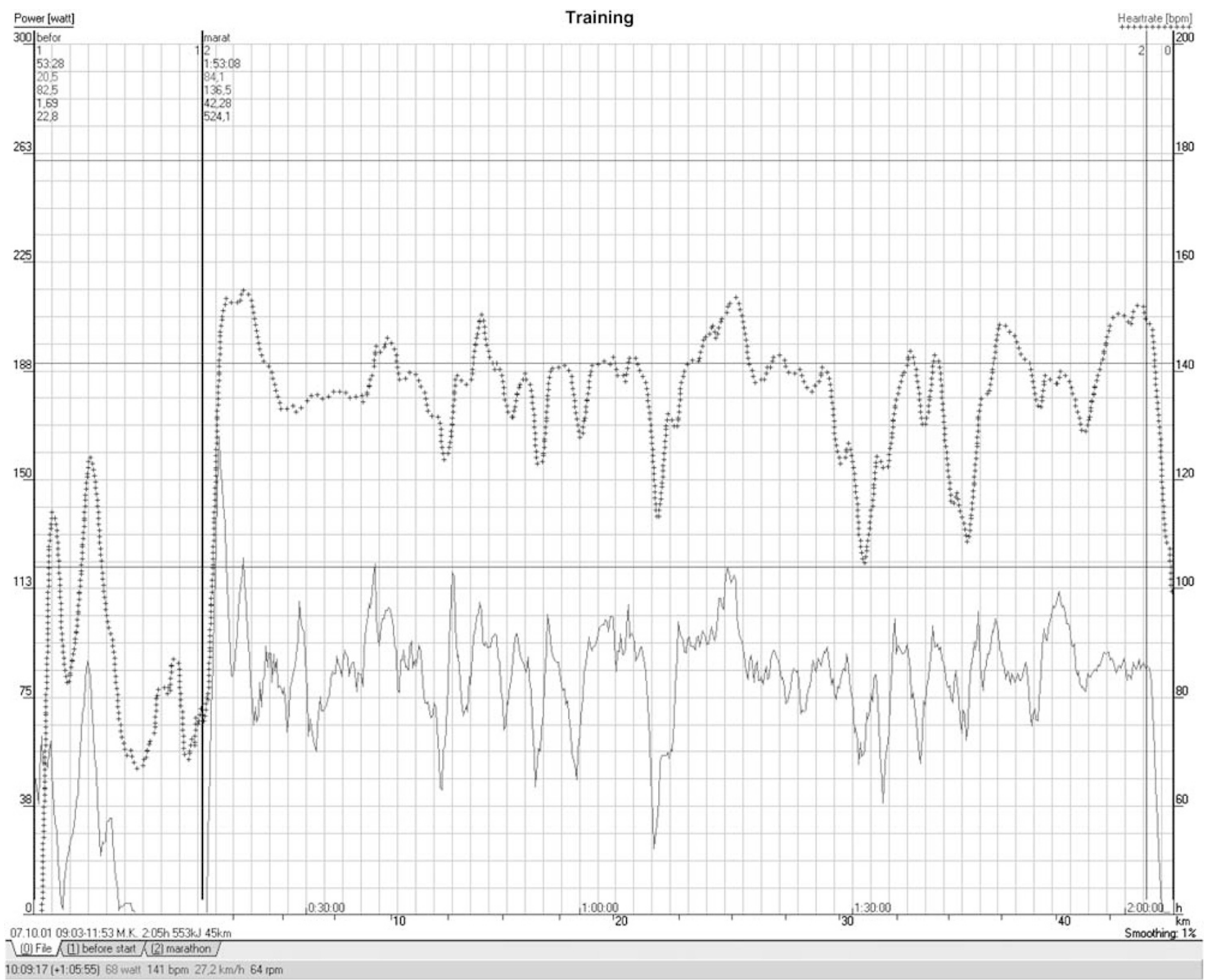

Figure 5 Work load (lower curve) and heart rate (upper curve) before, during, and after the race

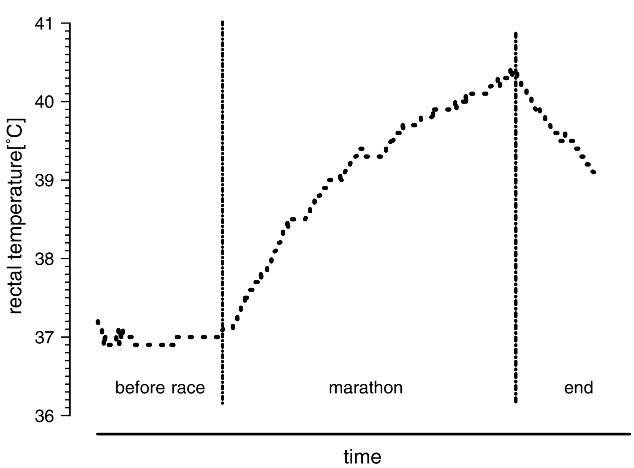

Figure 6 Rectal temperature before, during, and after the race

Hopman *et al* (1995)[3] in a laboratory setting. The higher mechanical efficiency in handbiking as compared to that in the race wheelchair shows the importance and benefits for wheelchair-dependent persons using a handbike in sport-specific circumstances but especially in all-day mobility.[3,4,11]

The measured temperature values with a maximum of 40.4°C were remarkably high at the end of the marathon. As the athlete is not able to sweat below the lesion level due to his paraplegia, disturbances of his thermoregulation with the risk of hyperthermia had to be seriously considered. When the race took place, the environmental temperature was not higher than 20–22°C. In the course of the marathon race the athlete's body temperature increased continuously during exercise, as is shown in Figure 6. At the end of the race, the temperature reached critical values. However, in marathon runners, significantly higher values have been observed.[15] For this reason, it could not be concluded with certainity that the athlete developed a pathologicaly relevant hyperthermia though he had poor regulation of temperature. Further studies are planned to investigate if longer load periods combined with higher environmental temperatures lead to a further increase of the rectal temperature.

From the point of view of a systematic training control, the gained data represent a valuable demand profile, which finally offers the base for individual training recommendations. Contrary to the general assumptions of most athletes, handbike races over the marathon distance are performed with a relatively high portion of fatty acid oxidation within the process of energy production (average respiratory exchange ratio = 0.88). In conclusion, competition-oriented handbikers should concentrate on exercise units of long duration at low intensities – like marathon runners or cyclists – in order to improve their aerobic performance capacity. The aim is to achieve a very high portion of fatty acid oxidation within the process of energy delivery.[16] However, it has to be pointed out that paraplegic athletes develop relatively high metabolic intensities in competition and that the variability of their physiological parameters is considerably high.[4] Therefore, general recommendations aiming at the control of their training intensities can only be given if the respective individual prerequisites are taken into account and if the athletes undergo regular scientific investigations to verify their efficiency.

Acknowledgements

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References

1 Cornelsen D. The wonderful world of cycling. *Sports and Spokes* 1991; **4:** 11–12.
2 van der Woude LH, Veeger HE, Rozendal RH, Sargeant AJ. Optimum cycle frequencies in hand-rim wheelchair propulsion. Wheelchair propulsion technique. *Eur J Appl Physiol Occup Physiol* 1989; **58:** 625–632.
3 Hopman MT, van Teeffelen WM, Brouwer J, Houtman S, Binkhorst RA. Physiological responses to asynchronous and synchronous arm-cranking exercise. *Eur J Appl Physiol Occup Physiol* 1995; **72:** 111–114.
4 Abel T, Kroner M, Rojas Vega S, Peters C, Klose C, Platen P. Energy expenditure in wheelchair racing and handbiking – a basis for prevention of cardiovascular diseases in those with disabilities. *Eur J Cardiovascular Prevent Rehabili* 2003; **10:** 371–376.
5 Huonker M, Schmid A, Sorichter S, Schmidt-Trucksab A, Mrosek P, Keul J. Cardiovascular differences between sedentary and wheelchair-trained subjects with paraplegia. *Med Sci Sports Exerc* 1998; **30:** 609–613.
6 Montoye HJ. *Measuring Physical Activity and Energy Expenditure*. Human Kinetics: Illinois 1996.
7 Roche AF, Heymsfield SB, Lohman TG. *Human Body Composition*. Human Kinetics: Champaign 1996.
8 Hollmann W, Hettinger TH. *Sportmedizin Gundlagen für Arbeit, Training und Präventivmedizin*, Vol. 4, völlig neu bearb, Aufl. Edition. Schattauer: Stuttgart 2000.
9 Schmid A *et al*. Catecholamines response of high performance wheelchair athletes at rest and during exercise with autonomic dysreflexia. *Int J Sports Med* 2001; **22:** 2–7.
10 Schmid A *et al*. Free plasma catecholamines in spinal cord injured persons with different injury levels at rest and during exercise. *J Auton Nerv Syst* 1998; **68:** 96–100.
11 Schmid A, Huber G, Marschner J, Zimmer M. Medizinische Aspekte im Behindertensport. *Deutsches Ärzteblatt* 2004; **101:** 1819–1825.
12 Abel T, Rojas Vega S, Bleicher I, Platen P. Handbiking: physiological responses to synchronous and asynchronous crank montage. *Eur J Sport Sci* 2003; **3:** 1–8.
13 American College of Sports Medicine. Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* 1998; **30:** 975–991.
14 Paffenbarger Jr RS, Hyde RT, Wing AL, Hsieh CC. Physical activity, all-cause mortality, and longevity of college alumni. *N Engl J Med* 1986; **314:** 605–613.
15 Roth RN, Verdile VP, Grollman LJ, Stone DA. Agreement between rectal and tympanic membrane temperatures in marathon runners. *Ann Emerg Med* 1996; **28:** 414–417.
16 Mader A. Evaluation of the endurance performance of marathon runners and theoretical analysis of test results. *J Sports Med Phys Fitness* 1991; **31:** 1–19.