Original Article

A new test to improve the training quality of wheelchair racing athletes

G Müller^{*,1}, P Odermatt² and C Perret³

¹Institute for Sports Medicine, Swiss Paraplegic Centre, Nottwil, Switzerland; ²Swiss Paralympic Association, Swiss Paraplegic Centre, Nottwil, Switzerland; ³Institute for Clinical Research, Swiss Paraplegic Centre, Nottwil, Switzerland

Study design: Validation of a new wheelchair racing test.

Objective: To assess the reproducibility of test parameters at different, subjectively chosen, intensity levels in wheelchair racing athletes.

Setting: Swiss Paraplegic Centre, Nottwil, Switzerland.

Subjects: We tested 11 (eight male, three female) young competitive wheelchair racing athletes. Their age was 20.5 ± 6.4 years, height 164.7 ± 16.3 cm and weight 54.1 ± 9.2 kg. Average weekly training time was 6.8 ± 2.7 h. All had been engaged in regular training for over 3.9 ± 2.8 years.

Methods: Within a period of 3 ± 1 days, every athlete completed two identical tests in their own racing chair on a training roller. The tests consisted of five 1500 m bouts at routine training intensities of 1 (warm-up) up to 5 (race speed), with a rest of 2 min between each bout. The athletes were blinded to all the collected data during the whole of the test, except for indications of the 500, 1000 and 1500 m markers. We measured the overall time (for 1500 m), average speed, stroke frequency, heart rate, rate of perceived exertion (RPE) and the concentration of lactic acid for all five intensity bouts. In order to get a measure on how reproducible these intensity levels were, we compared the two tests of each athlete with each other, and calculated the root-mean-squared coefficients of variation (CV) for all measured parameters during every bout.

Results: CVs of the measured data show that the most reproducible values were found for bout 5 (2.6–7.9%); except for the lactic acid parameter. The heart rate (CV: 3.1–6.4%) and stroke frequency (CV: 6.5–7.9%) parameters reached rather constant values throughout all five bouts. Lactic acid concentrations showed very high CVs (16.8–29.7%).

Conclusion: We conclude that this test is, with the exception of the lactic acid measurements, well reproducible, and particularly suitable for young wheelchair athletes. We find it to be a helpful tool for improving awareness for the individual training intensities, and for pursuing the development of the training process, as particularly the high-intensity bouts are well reproducible.

Spinal Cord (2004) 42, 585–590. doi:10.1038/sj.sc.3101611; Published online 27 April 2004

Keywords: wheelchair racing; test validation; RPE; coefficient of variation; exercise testing

Introduction

Exercise testing can be a helpful instrument to prescribe and control training. Indeed, in order to obtain reliable test results, sport-specific testing methods are needed,¹ especially for athletes with physical disabilities. Furthermore, in order to assess training progress, high test–retest reliability is essential. This reliability seems to be most pregnant at racing speed over racing distance.² Nevertheless, an increased sensitivity of awareness, also at lower intensity levels, is fundamental for competitive athletes in their daily training routine. This allows an improved guidance of the athlete's training by the coach, because the athlete can differentiate better

between intensities. Several studies showed that exercise testing based on rate of perceived exertion (RPE), is valid and useful for exercise prescription and regulation of exercise intensity,^{3,4} especially for moderate levels⁵ and adolescents.⁶ Schabert *et al*⁷ obtained more reliable results for tests with self-chosen intensities in regard to tests performed at fixed workloads. Trustworthy results have also been found for set distances performed in the shortest time possible.⁷ Goosey *et al*⁸ reported that self-chosen stroke frequencies are the most economical. All these facts show that a precise awareness of the different intensity levels is important in competition and training in order to economize the motor function and thereby increase the performance level. We are aware of the fact that for scientific publications, it is much easier to

*Correspondence: G Müller, Institute for Sports Medicine, Swiss Paraplegic Centre, CH-6207 Nottwil, Switzerland

calculate the reproducibility of clearly defined and measurable data. On the other hand, for practical use, other factors, such as a precise awareness, are equally important and have to be considered as well.

In our opinion, the ability to choose a certain training intensity level consciously is one of the most important skills needed in order to become a top class athlete. In this way training quality can be improved, allowing performance to increase. Additionally, we believe that a well-developed coenaesthesia helps the athlete to prevent injury. A reduced injury rate results in less training drop-outs, leading in its way to an improved training quality. The objective of the current study was to design a new test, based on the awareness of usual training intensities, which has in its way a high relevance to daily training practice. Therefore, a new test for wheelchair racing athletes was designed, at which the reproducibility of different test parameters at habitual, but subjectively chosen intensity bouts was tested.

Subjects and methods

Subjects

We tested 11 competitive wheelchair racing athletes. Detailed information of their anthropometrical data, impairment and training volume is given in Table 1. The local ethics committee approved the study. All 11 participants, as well as their parents (in case subjects were under 18 years of age before the start of the study), were informed about the procedures and gave written consent before participation.

Methods

Within a period of 3 ± 1 days, every athlete completed two identical tests in their own racing chair on a nearly frictionless training roller (Spinner, New Hall's Wheels,

Cambridge, USA). The tests consisted of five 1500 m bouts, at subjectively chosen, habitual training intensities, with a rest of 2 min between each bout. These training intensities were defined as 1 = warm up/cool down, 2 = extensive aerobic training, 3 = intensive aerobic training, 4 = training in the area of the anaerobic threshold, 5 = race intensity. As in every sports discipline, athletes and coaches use a certain scale and description for their different intensity levels. Even if these levels were somehow defined by words, they are not necessarily the same for everyone. Our goal was to assess the reproducibility of these intensity levels, in order to get a measure on how exactly these athletes were able to implement training guidelines. They were told to maintain subjectively a constant velocity during every bout, after which they were asked for RPE by means of a Borg-Scale ranging from 6 to 20.⁹ The athletes were blinded to any of the collected data during the whole test, since we wanted them to perform only in reference to their own awareness. The only information they got throughout the test were verbal indications of the 500 and 1000 m markers and the end of each bout. Verbal encouragement was only given during the last 200 m of bout 5, because it has been proven that frequent encouragement leads to a significantly higher maximum effort.¹⁰ We measured the time to complete the 1500 m (in min) using a stopwatch. Average speed (km/h) was measured by a speedometer (CicloMaster, Hochschorner GmbH, Krailling, Deutschland), which was calibrated and mounted on the training roller. Stroke frequency (min^{-1}) was measured by a hand counter, on which each single stroke of the whole test (on each bout) was registered. Mean stroke frequency was calculated afterwards. Heart rate (HR) (bpm) was registered every 5 s during the whole test time by means of an HR monitor (Polar Vantage NV, Polar Electro, Kempele, Finland). Mean HR values of the last minute

Table 1 Anthropometric data, impairment and training information

Sex	Age (years)	Height (cm)	Weight (kg)	Lesion level	ASIA/ impairment	Impairment since (years)	Training volume (h/week)	Training since (years)
M	26	153	52	L 3	C	26	7	10
M	21	176	60	Th 5	A	3	6	2
M	17	172	58	Th 12	Spina bifida	17	12	5
M	15	140	50	L3	A	15	5	3
W	13	138	38	Unknown	Spina bifida	13	6	3
W	18	170	46	L1	B	3	9	1
M	23	170	69	L1	Spina bifida	23	8	8
M	17	180	60	—	Cerebral paresis	17	3	2
W	36	162	47	—	Leg amputee (r)	17	10	3
M	22	191	65	Th12	A	3	5	2
M	17	160	50	L4	Spina bifida	17	4	4
Mean	20.5	164.7	54.1			14.0	6.8	3.9
SD	6.4	16.3	9.2			7.9	2.7	2.8

SD: standard deviation

of each bout were calculated. Capillary blood samples to measure lactic acid concentrations (mmol/l), were collected from the earlobe before the test, immediately at the end of each bout, as well as at 2, 4 and 6 min after the end of bout 5. Blood samples were analysed enzymatically by a lactate analyser (Super GL Ambulance, Ruhrtal Labor Technik, Möhnsee, Germany).

All athletes performed no or only low intensity exercise the day before each test and recorded sleep, food, beverages, supplements and medication during the 24 h before both tests. Participants were asked to replicate test preparations for the second test. Nutrition and training protocols were checked before both tests by a questionnaire. At the second test, preparation was compared with the 24 h before the first test. If test preparations were not strictly adhered to, the test was cancelled. Additionally, all athletes were told to refrain from caffeine intake on both test days, because caffeine intake may increase exercise performance.¹¹

Statistical analysis

In order to get a measure on how reproducible the subjectively chosen intensity levels (1–5) were, we calculated the root-mean-squared coefficients of variation (CV) of the overall time (for 1500 m), average speed, stroke frequency, heart rate, RPE and the concentration of lactic acid on every bout, according to the duplicate measurement method described by Glüer *et al*.¹²

Results

Mean CVs (%) of the overall time (for 1500 m), average speed, stroke frequency, HR, RPE and concentration of lactic acid of bouts 1–5 are shown in Table 2. CVs were smallest for the HR and stroke frequency parameters and values of bout 5. This newly designed wheelchair test resulted in CVs $\leq 9.5\%$ for nearly all parameters. Exceptions were the lactic acid parameters on all bouts, the average speed together with the RPE on the two lowest intensity bouts and the time of bout 2.

The absolute values of the different subjects showed large variations to one another due to a large range of age and training practice of the tested athletes. However, this does not affect the calculation of the CVs, since all of the subjects' values were only compared to

themselves. Means $\pm$ SD of test 1 and test 2 of bouts 1–5 are shown for the overall time (for 1500 m) (Figure 1), RPE (Figure 2), HR (Figure 3) and stroke frequency (Figure 4).

Discussion

According to Devillard *et al*,¹³ exercise tests with wheelchair ergometers that deliver parameters with CVs $< 9.5\%$, are suitable for practical use. As shown in Table 2, our results comply with this recommendation, in particular the high reproducibility of the upper intensity bouts. Measurement of lactic acid concentrations showed a too low reproducibility to be of any practical use.

Levels of suitable CVs for a test validation depend on many different factors. We therefore recommend considering sports discipline, level, age and number of

Figure 1 Mean $\pm$ SD for the time to complete 1500 m at five different exercise intensities on two separate test days

Figure 2 Mean $\pm$ SD for the rate of perceived exertion at five different exercise intensities on two separate test days

Table 2 Coefficients of variation (%)

	Bout 1	Bout 2	Bout 3	Bout 4	Bout 5
Time for 1500 m	9.4	10.7	9.5	9.5	2.8
Average speed	12	10.9	8.5	7.8	2.6
RPE	14.4	10.7	6.9	6	3.5
Heart rate	6.4	6.4	6.3	6.1	3.1
Lactic acid	20.6	16.8	25.2	29.7	23.2
Stroke frequency	6.7	7.7	7.2	6.5	7.9

RPE: rate of perceived exertion

Figure 3 Mean $\pm$ SD for the heart rate (HR) at five different exercise intensities on two separate test days

Figure 4 Mean $\pm$ SD for the average stroke frequency at five different exercise intensities on two separate test days

subjects before assessing CV values. Even though we only had 11 subjects of rather different proficiency levels, most CVs are in the above-mentioned range. If the test parameters above are used for monitoring training progress and to improve awareness of exercise intensity (which cannot be measured or defined exactly), the reproducibility of our tested parameters is quite high. We therefore conclude that our test is valid for wheelchair racing athletes, in particular for inexperienced athletes. In this last group, potential training progress is still bigger than in elite athletes. At the same time, this progress is large enough to be detected by our testing procedure.

We realize that standardizing and testing of a certain sensation is rather difficult and also depends on a lot of individual factors. It has been reported that the psychological factors may also play an important role

during testing.^{14,15} There are no conclusive data available on the physiological and psychological contribution to variability in athletic performance.¹⁶ We therefore recommend the best possible standardized conditions before and during testing. This is one of the most important requirements in order to get reliable performance test results, even if the tested intensities are based on personal feelings. In this study, we standardized test conditions, nutrition and test preparations as described under Methods.

It should furthermore be noted that even in trained athletes,¹⁴ learning effects have been observed in many exercise tests, especially between the first and the second trial.¹⁷ In order to measure the training progress and not learning effects, we recommend performing an initial 'learning trial' test. In this way, one can learn in which amount the intensity has to be increased between the different bouts and one can get familiarized with the testing conditions. The second test will then deliver a more realistic basic level, which can later be compared with further tests, in order to detect a training progress. As shown in Table 2, a rather high reproducibility resulted from our tests, even without a learning trial. Nevertheless, in order to achieve an even better reproducibility, a learning trial would be an additional benefit, even more so for young athletes. For a meaningful training control, we consequently recommend a learning trial before using this test in practice.

Eston and Williams¹⁸ reported that RPE ratings are a useful tool with high reproducibility for high intensity exercise, and only a small amount of practice with the scale is needed for low intensity levels. This finding confirms our CVs found for RPE ratings, which range from 14.4% on bout 1 to 3.5% on bout 5 (Table 2). Furthermore, it has been reported that RPE ratings are also related to goal orientation, especially in young athletes between 11 and 15 years.¹⁹ Since we tested two subjects of this particular age group, this could also have extended our range of CVs for RPE, even more so at the low-intensity bouts.

In young subjects, a close relationship of RPE, HR and relative exercise intensity has been noted.²⁰ HR seems to be a reliable test parameter, even when athletes choose their own intensity, blinded to time, HR, velocity and stroke frequency. Our CVs of HR are nearly constant around 6% from bout 1 to 4 and with 3.1% during bout 5, even lower. Similar results were also shown by other groups^{21,22} who reported increased HR reliability with increased power output. Concerning HR, one has to pay special attention to athletes with lesion levels above Th6, if activity of the sympathetic system is partly suppressed. As we had only one athlete (Th5) with a lesion above Th6 among our subjects, this factor should not play an important role in the outcome of our study, since the HR is not influenced a lot in this particular case.

Even though HR reliability is rather high in our newly designed test, we do not recommend daily training control based on HR, particularly not for young athletes, because they should first achieve a stable

awareness of their exercise intensity. Also, if attention is focused too much on HR, the main training goal will be delayed, because stress sensation is suppressed due to concentration on an external device (eg a heart rate monitor). In daily training practice, HR can also be greatly influenced by factors such as heat, wind, fluid intake and boosting in athletes with high lesion levels. These factors are standardized in most laboratory trials and are therefore more reliable than in daily training practice on the track.

Another important finding concerning training practice with young athletes is, that development of metabolic adaptation in adolescents is not yet completed.²³ In the same way, muscular differentiation in type I and type II fibres, as well as lactic acid metabolism, are still immature. Therefore, with young athletes, high intensity anaerobic exercise bouts should not be performed as often as with elite athletes. Aerobic training is recommended for adolescents, and more so for the spinal cord injured, because it enhances thermoregulatory capacity during exercise; something that is of high importance for this particular group.¹ Further studies reported other special conditions for adolescent athletes. Beneke *et al*²⁴ found that neuromuscular coordination has a higher influence on performance in young athletes than metabolic parameters. Williams *et al*²⁵ studied lactic acid metabolism in children. They found that they can exercise at intensities close to their peak oxygen uptake, without accumulating high levels of blood lactate. They therefore recommend not using the 4 mmol blood lactate level to assess and monitor exercise performance in children between 11 and 13 years. Additionally, in spinal cord injured athletes, accumulation of lactic acid also depends on the lesion level and is significantly higher for quadriplegics than for paraplegics.¹ All these factors, concerning lactic acid accumulation and degradation, could probably have influenced our values if six of our athletes would have been between 13 and 18 years of age. We hence conclude not to use lactic acid measurements in wheelchair athletes younger than 18 years.

In the same way, it is of no practical use to measure oxygen uptake (VO_2) in athletes younger than 17 years.²⁶ Peak VO_2 also has a weak relationship with the 1500 m running performance of 14–18 years old boys and girls,²⁷ of which exercise time and distance corresponds to our tests with 1500 m wheelchair racing bouts. In addition, CVs from VO_2 measurements are not as small as CVs from peak power output measurements.¹⁶ Considering the effort and discomfort of VO_2 measurements, combined with the above arguments, we do not recommend VO_2 measurement for testing adolescent athletes. This is the cause why we did not measure VO_2 in our study.

In an international study²⁸ on disabled athletes, it is reported that a third of all wheelchair racing athletes did not receive any coaching nor have any scientific knowledge in order to improve their training techniques. This shows potential for future support of these athletes in order to avoid the risk of overtraining, especially in the

area of disabled sports.²⁹ We are confident that this study can contribute further knowledge and help athletes and coaches to improve the training quality. We recommend the execution of the 5 × 1500 m test at regular intervals, especially for young wheelchair racing athletes. Since the implementation of this test is very easy and noninvasive (we recommend omission of lactic acid analysis), coaches are able to perform it with their athletes, without assistance of any medical or scientific staff.

For practical use, we recommend to carry out this test every 5–6 weeks, in the above-described way (see Methods), particularly during the winter months. Especially, in this time of year, there is no training control by means of competitions, but most athletes want to know 'where they stand'. To train awareness of training intensities, but also to report training progress by a simple but valid testing method, we advise to predominantly perform this test during the first 2 or 3 years of an athletes sporting career, even though further research is still needed to measure the improvement of the training quality exactly and to quantify it somehow.

Of course, it is not a very sensitive test to detect small progress in exercise performance and it is therefore not suitable for highly trained athletes. This is the reason why we principally recommend it for junior or inexperienced athletes, in order to educate awareness of the different training levels. Nevertheless, the higher the performance level of an athlete is, the better these values will be able to be reproduced and how easier it will be to detect small changes. But to really prove this assumption and to see the difference of CVs in, for example, highly trained athletes, further studies are needed.

Conclusion

We conclude that our newly designed test is, with exception of the lactic acid data, suitable for practical use. We recommend a learning trial, after which a periodical conduction of the test allows for a better monitoring of the training progress, in particular during the winter months. It additionally trains the awareness of the specific training intensities. Given that the implementation of this test is rather easy, coaches are able to perform it with their athletes without further assistance. We find it to be a helpful tool for improving awareness of the individual training intensities, and for pursuing the development of the training process, as particularly the high-intensity bouts are well reproducible.

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