Combined arm-leg ergometry in persons with a lower limb amputation

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Repeatability and validity of the combined arm-leg (Cruiser) ergometer

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Abstract

The measurement of physical fitness of lower limb amputees is difficult, as the commonly used ergometer tests have limitations. A combined arm-leg (Cruiser) ergometer might be valuable. The aim of this study was to establish the repeatability and validity of the combined arm-leg (Cruiser) ergometer. Thirty healthy volunteers carried out three incremental exercise tests, once on the bicycle ergometer and twice on the Cruiser ergometer. The repeatability of the Cruiser ergometer was assessed by studying the mean values of the test–retest and the validity by studying the mean values of the bicycle and the two Cruiser ergometer tests. The intraclass correlation coefficient for repeated measurements on the Cruiser ergometer was 0.84 for the maximal oxygen consumption (VO_2max), and 0.71 for the maximal heart rate (HRmax). The intraclass correlation coefficient for the measurements on the bicycle ergometer and the Cruiser ergometer was 0.86 for the VO_2max and 0.73 for HRmax. Bland and Altman plots for VO_2max and HRmax showed a bias close to zero and a great accuracy. The conclusion of this study is that the Cruiser ergometer provides a repeatable and valid measurement of physical fitness in healthy volunteers. Its value in clinical practice for lower limb amputees needs to be further established.

Keywords: combined arm-leg (Cruiser) ergometer, exercise test, physical fitness, repeatability, validity

Introduction

Patients with a lower limb amputation experience a decline in physical fitness. Walking with a prosthesis expends more energy than walking with two sound legs[1]. To be able to learn to walk with a prosthesis at a practical level of activity, it is very important that the amputee is able to meet the inherent high energy-expenditure demands[2]. Nowadays, the most important element in the rehabilitation of patients with a lower limb amputation is training in walking with a prosthesis. Evidence from Chin et al.[3] suggests that when prosthetic rehabilitation only covers walking training with a prosthesis, maximal aerobic capacity of amputees does not improve to the level of able-bodied persons. Therefore, training in prosthetic walking should be accompanied by some kind of endurance exercise training with the aim of improving the fitness of amputees. Aerobic exercise training comes with some difficulties for lower limb amputees. First, lower limb amputees already have cardiovascular disease or are at risk of developing it[4]. Before commencing aerobic training, an appropriate maximal exercise test is necessary to detect underlying cardiovascular disease, such as ischaemia or heart rhythm problems[5]. Second, the intensity level of exercise training needs to be determined, usually through maximal oxygen uptake (VO_2max) measurement. Many amputees with peripheral vascular disease have altered blood pressure and heart rate (HR) responses to exercise, and most of them take medication such as β-blockers. The consequence of this is that VO_2max cannot be reliably estimated from submaximal oxygen uptake and HR data, and therefore has to be measured during a symptom-limited graded exercise test.

At present, different types of ergometers are available for exercise testing and training: treadmills, bicycle ergometers, arm-ergometers, rowing ergometers, and combined arm-leg ergometers. For a reliable measurement of aerobic capacity and safety, it is best to choose an ergometer on which the patient uses a large muscle mass while exercising, thus reaching higher VO_2max and HRmax[4]. Exercise testing through arm crank ergometry can provide useful data to generate a safe upper extremity exercise program[6]. However, arm ergometry does not stress the cardiovascular and respiratory systems as much as leg cycling or treadmill exercise. During arm ergometry, peak oxygen uptake will approximate 50–70% of that for leg cycling [7,8,9,10]. A combined arm-leg ergometer

might be of value in this respect. In a pilot study, Vestering et al.[11] developed a maximal exercise testing protocol for lower limb amputees using a combined arm-leg ergometer.
Vestering et al.[11] concluded that the Cruiser ergometer can indeed be used in limb amputees for the determination of maximal aerobic capacity, and in fact elicited a higher oxygen uptake and HR than that of arm ergometry.
Currently, no data are present on the repeatability and validity of the combined arm-leg (Cruiser) ergometer. The aim of this study is to establish the repeatability and validity of the Cruiser ergometer.

Methods

Volunteers

Healthy volunteers between 18 and 70 years of age were asked to participate in this study through an advertisement in a newsletter and on the website of the Center for Rehabilitation of the University Medical Center Groningen in the Netherlands. Exclusion criteria for participating in this study were age less than 18 years, a body mass index of more than 30, evidence or serious suspicion of cardiovascular diseases, stress or exercise-related pain in the chest, pulmonary diseases, a resting blood pressure greater than 140/90, viral or bacterial infection for less than 10 days, use of medication for cardiopulmonary diseases, balance disorders, and wounds on the legs and joint diseases. The study was approved by the Ethics Committee of the University Medical Center Groningen, and all volunteers gave written informed consent before testing.

Experimental design

Before testing, the age, height, weight and sex of the volunteers were noted, and spirometry was performed. The protocol consisted of carrying out three incremental exercise tests. The first test was carried out on a bicycle ergometer and the two other tests were carried out on the Cruiser ergometer, a combined arm-leg ergometer. The sequence of the tests was similar for each volunteer. Because the electrocardiogram (ECG) recordings on the Cruiser ergometer were not reliable for every person, the test on the bicycle ergometer was carried out first for safety reasons. The measurements were made at about the same time of day for each individual, with intervals of 1–2 weeks. All participants were asked to refrain from stimulants (caffeine, drugs, cigarettes, etc.), exercise and alcohol for 12h before testing. Each person was asked to have a light breakfast/ lunch at least 2h before the exercise test, and normal hydration was requested.

Equipment

The Jaeger ER 900L bicycle ergometer was used. On this ergometer, the patient sits in the semirecumbent position and uses both legs to overcome the resistance provided by the ergometer. The accuracy of the power is ±3%. The Cruiser ergometer (Enraf-Nonius, Delft, The Netherlands) is a combined arm-leg ergometer, and is equipped with a comfortable seat. The feet are placed against a nonmoving footrest, which can be adjusted to the patient's height. The footrest is used to push off to make the seat move backwards. The patient can move the seat forward again by pulling the handlebars with the arms. In this way, the arms and legs are used alternatively to overcome the resistance provided by the ergometer. The accuracy of the power of the Cruiser ergometer is ±10%.

Outcome parameters

During testing, the following parameters were measured: maximal load (Wmax) HR, VO_2, carbon dioxide output (VCO_2) and maximal ventilation (VE). VO_2, VCO_2 and VE were recorded by using an Oxycon Delta (Jaeger, Bunnik, The Netherlands). Heart rate was measured with a 12-lead ECG.

The anaerobic threshold (AT) was determined by the V-slope method using VO_2 and VCO_2. Blood pressure was measured every 2 min by an automatic blood pressure meter during the test on the bicycle ergometer. Blood pressure was measured before and after the test with a manual blood pressure meter during the test on the Cruiser ergometer, because it was technically not possible to measure the blood pressure during the test.

When the volunteers were at rest, after the warming-up period and at the point of *W*max ,the Borg 10-point category scale with ratio properties was used to rate the perceived exertion[12] . Dyspnoea, leg muscle fatigue (bicycle and cruiser ergometer) and arm muscle fatigue (Cruiser ergometer) were measured by using the Borg score.

Test protocol

The testing protocol was similar for the three tests. The test started with 3 min of quietly sitting on the ergometer with the ECG recording and the oxygen mouthpiece to asses baseline measurements. After these 3 min, a warm-up was

carried out at 50W for 5 min. After the warm-up, the workload was increased by 20 or 30W every minute upon exhaustion. For men, the workload was increased by 30W every minute and for women by 20W every minute. After the exercise test was terminated, a cooling down of 3min was performed at 20W.
Reasons for terminating the test were inability to maintain a revolution speed of 60 rotations/min on the bicycle ergometer or 50 rotations/min on the Cruiser ergometer, pain in the arms or legs, a painful feeling in the chest, a feeling of dizziness or faintness, severe dyspnoea, paleness, cyanosis, or a cold and clammy feeling of the skin. The test was also stopped by the researcher when there were ECG abnormalities, high systolic (>250mmHg) or high diastolic (>115mmHg) blood pressure or a drop of the systolic blood pressure of more than 10mmHg with an increase in working load in comparison with the systolic blood pressure at rest. After the test, the reason for termination of the exercise test was noted. After performing the three exercise tests, the volunteers were asked to state the test they preferred.

Statistical analysis

Data analysis was performed on SPSS version 14.0 for Windows (SPSS, Chicago, Illinois, USA)[13]. Descriptive statistics were generated for all variables. The repeatability of the Cruiser ergometer was assessed by studying the mean values of the test–retest and the validity by studying the mean values of the bicycle ergometer test and the two Cruiser ergometer tests. For analyses, paired (Students) *t*-tests, the one-way random, single measure intraclass correlation coefficient [ICC] and Bland and Altman plots were used[14]. The differences in Borg scores between the tests were assessed by the Wilcoxon signed rank test. Significance level was determined at a P value less than 0.05.

Results

Volunteers

Thirty volunteers participated in this study: 16 men and 14 women, ranging in age from 20 to 61 years. Values of patients' mean (±SD) age, height, weight and forced expiratory volume in 1s (FEV_1) (% of predicted) are presented in Table 1.

Table 1. Characteristics of the 16 men and 14 women

Variable	Mean (±SD)	Range
Age (years)	37.0 (10.0)	20 - 61
Height (m)	1.78 (0.1)	1.6 – 2.0
Weight (kg)	79.0 (13.7)	55 - 109
BMI (kg/m2)	24.7 (2.5)	19.3 - 29.3
FEV_1 (% of predicted)	110.3 (12.23)	81.8 – 136.6

FEV_1, forced expiratory volume in 1 s.

Repeatability of the Cruiser ergometer test

The results of the two tests on the Cruiser ergometer did not show significant differences for the VO_2, VCO_2, HR and AT. A significant difference was found for the *V*E at 50W and for the Wmax. The Wmax reached at the second test on the Cruiser ergometer was higher than at the first test (Table 2).

The ICC for repeated measurements on the Cruiser ergometer was 0.84 (VO_2max) and 0.71 (HRmax) (Table 3).

In the Bland and Altman plots the bias ±1.96SD of the VO_2max is 0.016 ± 0.74 l/min (Fig. 1) and of the HRmax 2.83 ± 19.85 beats/min (Fig. 2). Both plots show a bias close to zero and high accuracy

Table 2. Comparison of the three exercise tests

	Bicycle	Cruiser first test	Cruiser second test
mean (SD) n=30			
VO_2 50 W (l/min)	1.00 (0.09)	1.10 (0.15)[a]	1.05 (0.15)
VCO_2 50W (l/min)	0.83 (0.09)[b]	1.00 (0.16)[a]	0.93 (0.13)
VE 50 W (l/min)	25.25 (2.79)[b]	32.08 (4.61)[a]	30.47 (4.26)[c]
HR 50W (beats/min)	101.87 (13.88)	103.73 (12.97)	103.04 (15.30)
VO_2max(l/min)	2.70 (0.60)	2.62 (0.63)	2.64 (0.67)
VCO_2max (l/min)	3.06 (0.68)	2.84 (0.69)[a]	3.00 (0.90)
VEmax (l/min)	91.62 (21.14)	89.89 (22.18)	98.21 (33.11)
HRmax (beats/min)	167.50 (13.94)	164.77 (14.88)	167.60 (12.19)
Maximal load (Wmax)	240.00 (54.20)[b]	196.00 (42.31)[a]	208.67 (48.00)[c]
ATmax	1.70 (0.37)	1.81 (0.42)	1.80 (0.47)

ATmax, anaerobic threshold at maximum load; HRmax, maximum heart rate; HR 50W, heart rate at 50 W; *V*CO_2max, maximum carbon dioxide output; *V*$CO_2$50W, carbon dioxide output at 50W; *V*Emax, maximum ventilation; *V*E 50W, maximum ventilation at 50W; *V*O_2max, maximum oxygen consumption; *V*O_2 50W, oxygen consumption at 50W.

[a]Significant difference between test on the bicycle ergometer and first test on the Cruiser ergometer.

[b]Significant difference between test on the bicycle ergometer and second test on the Cruiser ergometer.

[c]Significant difference between the tests on the Cruiser ergometer.

Table 3. ICC of the two Cruiser ergometer tests

	ICC (single measures)	95% CI
VO_2 50 W	0.69	0.45-0.84
HR 50 W	0.70	0.46-0.85
VE 50 W	0.63	0.35-0.80
VO_2max	0.84	0.69-0.92
HR max	0.71	0.48-0.85
VE max	0.59	0.29-0.78

CI, confidence interval; HRmax, maximum heart rate; HR 50W, heart rate at 50 W; ICC, intraclass correlation coefficient; *V*Emax, maximum ventilation; *V*E 50W, maximum ventilation at 50W; *V*O_2max, maximum oxygen consumption; *V*O_2 50W, oxygen consumption at 50W.

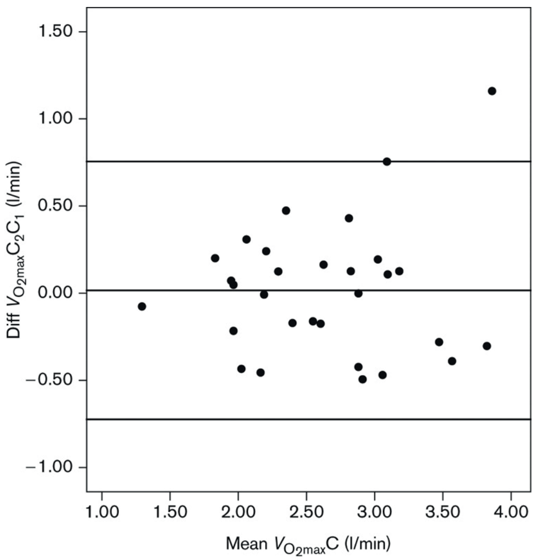

Figure 1. Bland and Altman plot for maximal oxygen consumption (VO_2max) measured on the Cruiser ergometer. Diff $VO_2maxC_2C_1$, difference between the VO_2max in l/min between the first and the second tests on the Cruiser ergometer; Mean VO_2maxC, mean VO_2max in l/min of the two tests on the Cruiser ergometer.

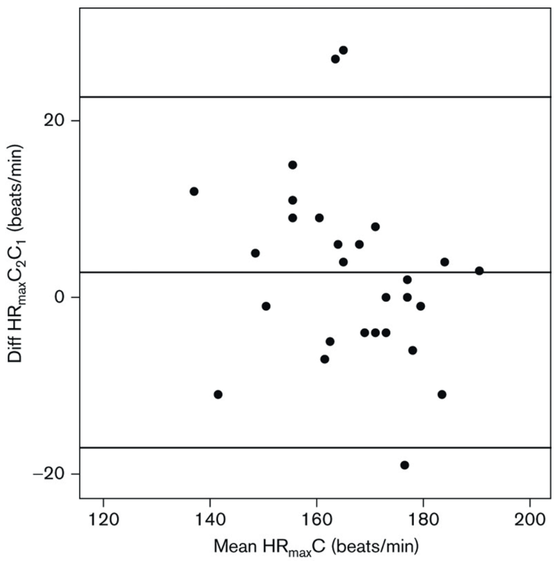

Figure 2 Bland and Altman plot for maximal heart rate (HRmax) measured on the Cruiser ergometer. Diff $HRmaxC_2C_1$, difference between the HRmax in beats/min between the first and the second tests on the Cruiser ergometer; Mean HRmaxC, mean HRmax in beats/min of the two tests on the Cruiser ergometer.

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Validity of the Cruiser ergometer test

The results from the two Cruiser tests compared with the bicycle test did not show significant differences for the $\dot{V}O_2$max , $\dot{V}E$max, HRmax and ATmax.
At 50W, significant differences were found between the first Cruiser test and the bicycle test for the $\dot{V}O_2$, $\dot{V}CO_2$ and $\dot{V}E$ and at Wmax for the $\dot{V}CO_2$. At 50W, the $\dot{V}CO_2$ and $\dot{V}E$ were significantly different between the second Cruiser test and the bicycle test (Table 2). The Wmax reached on the bicycle ergometer was higher than on the Cruiser ergometer, and this difference was significant in comparison with the first test ($P<0.001$) and with the second ($P<0.001$) on the Cruiser ergometer.
The ICC for the measurements on the bicycle ergometer and the second test on the Cruiser ergometer was 0.86 ($\dot{V}O_2$max) and 0.73 (HRmax) (Table 4).
In the Bland and Altman plots, the bias ±1.96SD of the $\dot{V}O_2$max is 0.06 ± 0.67 l/min (Fig. 3), and of the HRmax -1,0 ± 19.21 (Fig. 4). Both plots show a bias close to zero and high accuracy.

Table 4. ICC of the bicycle and Cruiser ergometer tests

	ICC (single measures)	**95% CI**
VO_2 50 W	0.28	-0.08-0.57
HR 50 W	0.74	0.53-0.87
VE 50 W	-0.09	-0.43-0.27
VO_2max	0.86	0.72-0.93
HRmax	0.73	0.51-0.86
VEmax	0.63	0.36-0.80

CI, confidence interval; HRmax, maximum heart rate; HR 50W, heart rate at 50 W; ICC, intraclass correlation coefficient; $\dot{V}E$max, maximum ventilation; $\dot{V}E$ 50W, maximum ventilation at 50W; $\dot{V}O_2$max, maximum oxygen consumption; $\dot{V}O_2$ 50W, oxygen consumption at 50W.

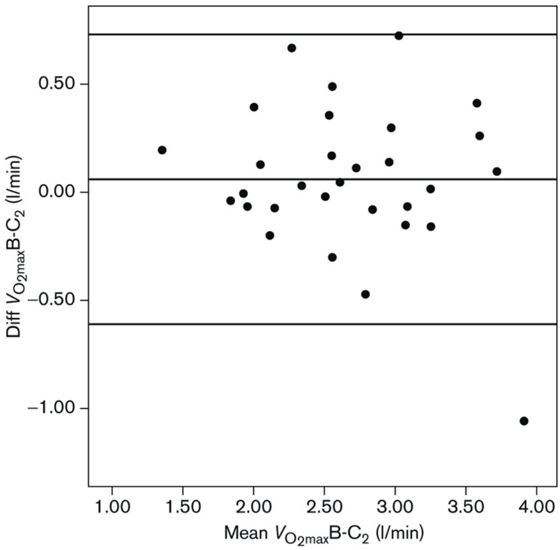

Figure 3. Bland and Altman plot for maximal oxygen consumption (VO_2max) measured on the bicycle and Cruiser ergometer. Diff VO_2maxB-C_2: difference between the VO_2max in l/min between the test on the bicycle ergometer and the second test on the Cruiser ergometer; Mean VO_2maxB-C_2, mean VO_2max in l/min of the test on the bicycle ergometer and the second test on the Cruiser ergometer.

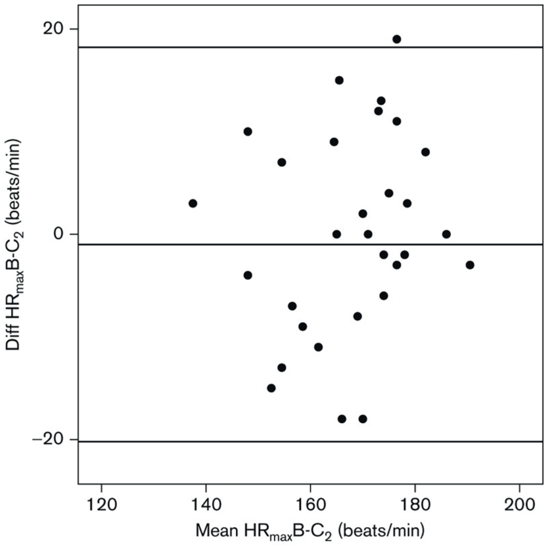

Figure 4. Bland and Altman plot for maximal heart rate (HRmax) measured on the bicycle and Cruiser ergometer. Diff HRmaxB-C_2, difference between the HRmax in beats/min between the test on the bicycle ergometer and the second test on the Cruiser ergometer; Mean HRmaxB-C_2, mean HRmax in beats/min of the test on bicycle ergometer and the second test on the Cruiser ergometer.

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Borg score, reason for stopping the test and test of preference

Borg scores for muscle fatigue were significantly higher than for dyspnoea on all tests. On the Cruiser ergometer, maximal Borg score for fatigue of the legs was 4.3 and 4.5 (Cruiser first and second tests), which was significantly lower than on the bicycle (5.5) (Table 5).

Reasons for stopping the test on the bicycle ergometer were leg fatigue (80%), dyspnoea (3%), high blood pressure (13%) and dry mouth (3%). Reasons for stopping the first test on the Cruiser ergometer were leg fatigue (13%), arm fatigue (37%), arm and leg fatigue (37%), dyspnoea (7%) and disturbed coordination (7%). For the second test on the Cruiser ergometer, the reasons for stopping the test were leg fatigue (20%), arm fatigue (30%), arm and leg fatigue (40%) and dyspnoea (10%). The bicycle test was preferred by 80% of the participants, 10% preferred the test on the Cruiser ergometer and 10% had no preference.

Table 5. Borg score

	Bicycle	**Cruiser first test**	**Cruiser second test**
mean (SD)			
Dyspne max	2.6 (1.9)	1.8 (2.1)[a]	2.6 (2.7)
Fatigue legs max	5.5 (2.7)[b]	4.3 (2.7)[a]	4.5 (2.5)
Fatigue arms max		4.9 (2.1)	5.0 (2.4)

[a]Significant difference between test on the bicycle ergometer and first test on the Cruiser ergometer.
[b]Significant difference between test on the bicycle ergometer and second test on the Cruiser ergometer

Discussion

This study shows that the Cruiser ergometer provides a repeatable and valid measurement of physical fitness in healthy volunteers. However, accurate ECG recordings were not possible in all volunteers during the Cruiser ergometry because of the movement of the trunk. Automatic measurement of blood pressure was only possible just before and after the test.

It is advocated that an ICC of >0.75 indicates good agreement[15,16]. Laskin et al.[17] found for another frequently used exercise test, the 6-min walk test an ICC for distance, ratings of perceived exertion and HR of 0.78, 0.83 and 0.77, respectively. The ICC for the repeated measurements on the Cruiser ergometer was 0.84 for the VO_2max and 0.71 for the HRmax, and the Bland and Altman plots were very acceptable with bias close to zero and high accuracy, both reflecting good to reasonable repeatability. Validity, defined by ICC between Cruiser and bicycle, was also reasonable to good: 0.86 for the VO_2max and 0.73 for the HRmax, and the Bland and Altman plots were in agreement with these. We can conclude that there is a good repeatability and validity for the outcome parameter VO_2max and a reasonable repeatability and validity for the outcome parameter HRmax. For individual patient use, we advice using the VO_2max as the primary outcome parameter to measure the physical fitness on the Cruiser ergometer.

The *W*max reached on the bicycle ergometer was significantly higher than that reached on the Cruiser ergometer, despite similar VO_2max. At the end of the steady-state period at 50W, VO_2, VCO_2 and *V*E were significantly higher on the Cruiser ergometer than on the bicycle ergometer. Volunteers experienced more fatigue of the arms than of the legs on the Cruiser ergometer, and the reason for stopping the test was in most cases fatigue of the arms or fatigue of the arms and legs. One explanation for the lower *W*max reached on the Cruiser ergometer can thus be that muscle fatigue of the arms already limits exercise capacity, whereas leg effort is still submaximal. In this respect, Toner et al.[18] evaluated the hemodynamic responses during arm crank and leg exercise during several exercise trials with varying proportions of power from the arms and legs. They found that when exercise was carried out with a 50% combination of the arms and legs, peak VO_2 was similar to leg-only exercise, and there was a significantly lower peak VO_2 when exercise was carried out for 75 or 100% of the arms. In addition, HR and Wmax were higher when a greater percentage of the exercise was carried out by the legs. In this study, we were not able to differentiate how much of the power was delivered by the arms and legs during the Cruiser ergometry. It is possible that in the training or adaptation process, each patient develops a unique exercise pattern, best suited to the individual exercise tolerance of upper and lower extremities.
Another explanation might lie in the precision of the ergometers. However, factory data show an accuracy of power of ±3% for the bicycle ergometer and ±10% for the Cruiser ergometer, which cannot be responsible for the observed differences in *W*max.

A final issue with regard to the lower *W*max reached on the Cruiser ergometer is that the movement on the Cruiser ergometer is definitely less energy efficient than on the bicycle ergometer: volunteers reached a higher *W*max on the bicycle ergometer with similar VO_2. Patients with a lower limb amputation are not able to carry out an exercise test on the bicycle ergometer, and the Cruiser ergometer seems to be a repeatable and valid alternative.
In future when we will develop diagnostic and therapeutic protocols for patients with a lower limb amputation, we have to take into account that the Cruiser ergometer is less energy efficient than the bicycle ergometer.
Feasibility of usage of the Cruiser ergometer in lower limb amputees has already been shown. Vestering et al.[11] tested five patients with a lower limb amputation ranging in age from 15 to 58 years on the Cruiser ergometer and found a VO_2max varying from 1.36 to 2.27l/min and a *W*max reached varying from 65 to 115W. The mean values of two tests, VO_2max (2.63l/min) and *W*max (204W), in our study with healthy volunteers were considerably higher. The difference between our results and Vestering et al.[11] may be because of a considerably lower muscle mass in the leg amputees, but also because of decreased physical condition after amputation, concomitant cardiovascular disease and the older age in the lower limb amputation group. Further research is need Noord Nederland ed to develop appropriate test protocols and normal values for the older age group.

There are some limitations to this study. First, getting used to the Cruiser ergometer may be more important than getting used to the bicycle ergometer, as the movement is more complex and less familiar. This is supported by the higher load on the second Cruiser ergometer test and a lower VO_2 in the second steady-state period. In contrast to this, however, VO_2max and HRmax were comparable, which suggests that a maximal state was reached, providing reliable evaluation of limitation of exercise tolerance and safety issues. Second, our volunteers were all healthy persons. Before using the Cruiser ergometer for patients with a lower limb amputation, we have to adapt our protocol because these patients will reach a lower maximal load. We have to use a protocol with increments of less than the 20 and 30W to achieve a maximal level in 10–12 min, which is recommended for symptom-limited exercise tests. Finally, ECG recordings were not accurate in all volunteers because of excessive noise. Accurate ECG recording is absolutely necessary in patients such as lower limb amputees, who often have concomitant cardiovascular disease. Although it can be anticipated that these patients may have less disturbing movement of the trunk as they reach lower peak workload, a fair ECG measurement needs to be developed.

In conclusion, this study shows that the Cruiser ergometer provides a repeatable and valid measurement of physical fitness in healthy volunteers. The bicycle ergometer is preferred over the Cruiser ergometer because it is more energy-efficient and ECG recording is possible. However, for patients with a lower limb amputation, the Cruiser ergometer seems to be a good alternative. Further research is needed before the Cruiser ergometer can be used in lower limb amputees, particularly with regard to appropriate diagnostic and therapeutic protocols and a fair ECG measurement.

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