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

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General discussion

Improving the cardiorespiratory fitness through testing and training is important in persons with a lower limb amputation (LLA) in rehabilitation and beyond[1,2]. With respect to testing and training, the Cruiser ergometer (Enraf Nonius) is a combined arm-leg ergometer, on which the tested person sits in supine position with back support and the arms, legs and trunk actively involved in cyclic work. With a small adaptation, a leg support connected to the seat, it is assumed to be a safe and accessible device for exercise testing and training in persons with a LLA already in early rehabilitation. The Cruiser ergometer is used by physiotherapists for years as an instrument for improving physical fitness, but research into measurement properties and effects on change of cardiorespiratory fitness in persons with a LLA has, up to now, not been performed. The substantiation of feasibility, safety, reliability and validity of the Cruiser ergometer in the measurement of cardiorespiratory fitness was performed and is reported in this thesis.

More specifically, the general aim of this thesis was to determine whether the Cruiser ergometer is clinically applicable as an instrument for cardiopulmonary exercise testing in persons with a LLA. In this respect, five studies were performed in order to reach this general aim.

Sub-aims of this thesis are:

- To compare and understand the physiology of submaximal cyclic exercise on the Cruiser ergometer, regular cycling and treadmill hand cycling on cardiorespiratory variables, gross mechanical efficiency (GE) and perceived exertion in healthy persons.
- To study potential motor learning effects during low-intensity submaximal steady state one-legged and two-legged practice on the Cruiser ergometer in healthy persons with respect to GE and cardiorespiratory strain.
- To establish the repeatability and validity of peak exercise testing on the Cruiser ergometer in a population of healthy persons.
- To determine the feasibility, safety, and reliability of (sub)maximal exercise testing on the Cruiser ergometer in a study population with a LLA.
- To determine the inter-observer and intra-observer reliability of the first (VT1) and second (VT2) ventilatory thresholds in persons with a unilateral LLA and healthy persons during a peak exercise test on the Cruiser ergometer.

In the next paragraphs the main findings of this thesis will be reviewed and specific topics are discussed in more detail, including clinical implications and suggestions for future research.

Main findings

The first aim was addressed in Chapter 2, revealing that during submaximal exercise no differences were found in GE and cardio-respiratory strain between Cruiser ergometer tests (GE at power output (PO) 45 W: male 13.0%, female 15%) and bicycle ergometer tests (GE at PO 45 W: male 13.2%, female 14.6%). The GE of the hand bike tests (GE at PO 45 W: male 11.2%, female 12.2%) was lower compared to the Cruiser and bicycle ergometer test results, while cardio-respiratory strain in hand cycling was consistently higher. Under the testing conditions in this study, males appeared less efficient than females ($P<0.05$), which may be due to the higher absolute PO in males. A PO of 45W is probably relatively lower to the men's peak PO, which may lead to a lower GE that is curvilinear associated to PO. The results suggest that the Cruiser ergometer test at identical submaximal effort has a comparable efficiency as the regular bicycle test, indicating that a relatively large muscle mass is engaged in an equally efficient motor pattern at the same energetic cost. Continued research should verify similar questions at higher submaximal intensities.

The second aim was on motor learning (Chapter 3). In healthy participants, a small degree of motor learning was indeed identified during low-intensity one-legged and two-legged exercises on the Cruiser ergometer meaning that such task-related cyclic exercises slightly optimized towards a lower energetic cost over practice time. We hypothesized that lower cardiovascular strain and higher muscular efficiency is underlying this process of motor optimization. Motor learning turned out to be more explicit in one-legged exercise as compared with two-legged exercise. Future research is required to understand in more detail how one-legged exercise on the Cruiser ergometer is optimized in clinical practice, since balance and force direction are potentially more critical in one-legged exercise, while the strain per muscle mass unit will be higher compared to two-legged exercise.

In Chapter 4 and 5 (in line with the third and fourth aim of the thesis) it was demonstrated that the Cruiser ergometer could safely and feasible be used for

peak exercise testing in healthy persons and persons with a LLA. The validity of the Cruiser ergometer was good. This was based on the fact that outcome of the VO_2peak on the Cruiser ergometer was corresponding with the VO_2peak obtained by testing on the bicycle ergometer in healthy persons, which can be considered as the gold standard. From the test-retest analysis in both healthy persons and persons with a LLA it was concluded that the Cruiser ergometer is a reliable measurement instrument. No complications occurred during the exercise tests and most persons could perform the exercise test until exhaustion. Further research was recommended to design tailor-made patient protocols for using the Cruiser ergometer as a measure instrument for exercise testing in the rehabilitation after a LLA.
To elaborate the final aim, in Chapter 6, based on the inter- and intra-observer reliability results, it is described that ventilatory thresholds can mostly be determined using the Cruiser ergometer. The inter- and intra-observer reliability of determining VT1 during a cardiopulmonary exercise test on the Cruiser ergometer in this study was sufficient for subjects with a LLA and healthy subjects in which VT1 could be assessed successfully. Determination of VT2 was less reliable in both subject groups and for both observers. Future research should address determination of peak aerobic capacity, ventilatory thresholds and their validity in and sensitivity to training interventions on the Cruiser ergometer among a wider, more variable population of persons with a LLA.

Implications

In the introduction a patient history was reported to illustrate the clinical aspect of the thesis. It concerns Mr. X, 62 years old, who has undergone a lower limb amputation, and who experienced, following the amputation and a period of perioperative inactivity, a decline in physical fitness. The physiotherapist who is involved in the exercise training program to improve physical fitness needs to know the level of physical fitness at the start of the rehabilitation and has to make choices with regard to training intensity and duration. With the results of this thesis we want to give the physiotherapist involved in the rehabilitation of Mr. X the tools and advices to perform a safe, feasible and reliable exercise *test to determine the physical fitness of the patient. Based on the outcome of this test, the physiotherapist can make choices with regard to the composition of exercise training in the rehabilitation program of Mr. X.*

Ergometry in persons with a lower limb amputation

As described in the introduction of this thesis, physical fitness is defined in several ways. A generally accepted definition is: 'the ability to carry out daily tasks with vigor and alertness, without undue fatigue, and with ample energy to enjoy leisure-time pursuits and meet unforeseen emergencies'[3]. In this concept, cardiorespiratory fitness is one of the elements of physical fitness and can be determined by measuring cardiovascular and pulmonary parameters during a cardiopulmonary exercise test (CPET)[3,4]. It is known that most persons with a LLA have a low cardiorespiratory fitness and that undergoing conventional prosthetic rehabilitation does not necessarily result in improvement in their cardiorespiratory fitness[5-7]. On top of that, walking with a prosthesis costs considerably more energy than walking with two healthy legs[8]. The percentage of persons with an amputation who regain walking ability with a prosthesis varies from 56% to 97%[9]. Also it is known that persons with a LLA due to vascular reasons have more walking problems than persons with a LLA due to a trauma. In addition, it is known that persons with a LLA due to a vascular reasons in general are older, and an older age also affects walking ability in a negative way[9]. A specific exercise program during the rehabilitation to improve cardiorespiratory fitness can probably increase the chance of achieving walking ability after a LLA. Another purpose of improving the cardiorespiratory fitness after a LLA due to vascular reasons is to preclude or abate the pathogenesis of diabetes, atherosclerosis, or both.

For persons with a LLA due to other reasons improving the cardiorespiratory fitness focuses on risk reduction for developing secondary disabilities such as cardiovascular disease, diabetes, high blood pressure, and obesity. In fact persons with a LLA have a higher risk for developing secondary cardiovascular related disabilities than nondisabled individuals because of the LLA predisposition toward living a sedentary lifestyle[1].

Pre-operative rehabilitation (also called pre-rehabilitation) could be considered in a selected small group of (mostly) younger persons without comorbidities who are scheduled for an elective, non-dysvascular lower extremity amputation.

In these situations, the preoperative rehabilitation is focused on improving the physical fitness prior to surgery. From literature and from clinical experience, however, it is known that pre-operative rehabilitation is hard to apply in the majority of persons with a dysvascular LLA because of the older age, multiple comorbidities, a lack of motivation for behavioral change and, in particular, a short time window prior to surgery[10,11].

In this thesis we focused us on testing the cardiorespiratory fitness after a LLA. For improving the cardiorespiratory fitness persons with a LLA should use a mode that 1) incorporates enough muscle mass to produce improvements in cardiorespiratory fitness and 2) will not cause overuse injuries, skin breakdowns, and joint pain or inflammation in the non-amputated or amputated limbs[1]. Based on the outcome of this thesis we assume that the Cruiser ergometer is suitable for this purpose because the muscles of arms, trunk and one leg are cyclically involved in the exercise and shows comparable results to bicycling exercise (chapter 2 and 4). Furthermore, the amputated leg is not involved in the exercise and can be supported during the exercise: as a consequence, there is no chance for overuse injuries and skin breakdowns in the residual limb. Before starting an exercise program after a LLA it is important to be able to provide a good exercise prescription for a rehabilitation program and to give a prediction about the walking ability after the rehabilitation program. Another goal of the peak cardiopulmonary exercise test is to investigate if there are cardiopulmonary contra-indications for a person to exercise[2].
In this thesis we studied the clinical application of the Cruiser ergometer and compared this ergometer with the common used bicycle ergometer and, on submaximal level, with the handbike. In chapter 2 of this thesis we found during submaximal exercise in healthy persons no differences in GE and cardio-respiratory strain between the submaximal exercise test on the Cruiser ergometer and the bicycle ergometer. In chapter 4 the VO_2peak on the Cruiser ergometer was found to be corresponding with the VO_2peak on the bicycle ergometer in healthy persons. From these studies we conclude that a peak exercise test on the Cruiser ergometer seems a good alternative for a peak exercise test on the bicycle ergometer. However further research is expedient for understanding the relation of cardiorespiratory fitness measured using the Cruiser ergometer and the successful regain of walking ability.

Motor learning on the Cruiser ergometer

In chapter 2 no differences were found between the two Cruiser ergometer tests on the seven different power output levels for efficiency and most of the cardiorespiratory outcomes, except for the rate of perceived exertion (RPF). On the other hand, in chapter 3 motor learning was found in a healthy study population, especially for one-legged exercise on the Cruiser ergometer. Also a low-intensity, 7-week training protocol on a wheelchair has a beneficial effect on the mechanical efficiency and metabolic cost of wheelchair propulsion in able-bodied participants in a wheelchair study[12]. Possibly, the duration of the sessions of the seven different power output levels on the Cruiser ergometer, as described in chapter 2 was too short and the exercise not intensive enough to notice differences in GE. After one day practice on the Cruiser ergometer, as described in chapter 3, this motor learning effect was noted as an improvement in GE after practice, especially in the one-legged group. In addition, when repeating a peak exercise test on the Cruiser ergometer with the same protocol under the same circumstances and without any change in physical fitness, a higher not significant different VO_2 and greater power output were seen in the 2nd measurement in healthy persons (chapter 4) and in the 2nd and 3rd measurement in persons with a LLA (chapter 5).
In chapter 5 it is also described that a maximal aerobic performance was determined when one of the following criteria was fulfilled: a heart rate of more than 85% of predicted, maximal ventilation of more than 75% of predicted and a respiratory exchange ratio (RER) of more than 1.1[13]. Following these criteria at the first test 69% of persons had a maximal exercise test and at the second and third test 71% and 82% respectively, what may rise the idea that there is a motor learning effect.

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In literature movement economy is defined as the metabolic energy expended to achieve the objective or goal[14,15]. There is a principal of least metabolic energy expenditure: organisms select the least effortful coordination and control function and with practice the selected control parameters are refined to attain the task goal with less metabolic energy expenditure. Also there is thought to be a relation between cardiovascular responses to exercise and timing characteristics of limb movement[14,16].
We hypothesize that by practice the movement on the Cruiser ergometer will be done with less energy expenditure and that the cardiovascular responses

to exercise will initially slightly drop. We found that when the peak exercise test on the Cruiser ergometer is done for the 2nd and 3rd time the cardiovascular responses improved. Also for bicycle ergometry a familiarization effect is described for cardiovascular variables, with persistently better values on the second test[17]. Probably this familiarization effect will be greater for an exercise test on the Cruiser ergometer because exercising on a bicycle ergometer is for most people in the Netherlands a more familiar movement which they have practiced already for a very long time and since early age. The movement on the Cruiser ergometer however is for most persons less familiar and somewhat complicated by the potentially three or four limbs actively involved in a consecutive cyclic order. We therefore expect that more changes in metabolic energy expenditure, as well as in muscle activation and force production patterns, will potentially be seen by practice. Probably this change in metabolic energy expenditure and motor behavior as consequence of an innate drive to minimize the cost of movement (i.e. motor learning) already happens continuously when the patient exercises on the Cruiser ergometer. Therefore, before performing the peak exercise test, exercising on the Cruiser ergometer is advised in order to get used to this specific movement with the arms and leg.

Feasibility, safety and reliability of the Cruiser ergometer

Based on earlier research[5,18-21] it is important to test the cardiorespiratory fitness as soon as possible after the amputation. Therefore it is important that the test procedure, on the Cruiser ergometer with one leg and two arms and good support for the residual limb, is feasible, safe and reliable. In chapter 5 the feasibility and safety of the Cruiser ergometer is described.

To evaluate the feasibility in this study the indicators acceptability, demand and practicality were used[22]. Three of the 21 preselected persons with a LLA dropped out of this study. One person had an allergic skin reaction to the ECG suction cups, which were used in this period. To solve this problem, ECGs are now in clinical practice recorded using self-adhesive electrodes. Another person showed signs of cardiac ischemia during the first maximal exercise test and was referred to a cardiologist. This can be seen as a positive point in relation to the safety of the Cruiser ergometer, because one of the goals of the exercise test is to screen for contra-indications for exercising. The third person dropped out because his pre-existent stump pain worsened after test 2, despite the use of a special residual limb support attached to the Cruiser. Most subjects, however, felt the stump support was sufficiently comfortable and did not experience pain or discomfort in their stump. The Borg scores were relatively low and the majority of the subjects had a maximal aerobic performance. Based on these outcomes, application of the Cruiser ergometer is likely to be feasible.

Relevant outcomes for safety among the currently studied group of persons with a LLA as described in chapter 5 were the occurrence of ECG abnormalities or the occurrence of adverse effects during the test. No adverse events or complications occurred however during the peak exercise tests on the Cruiser ergometer.
Although, in general, the risk of cardiovascular complications resulting from a CPET is low[4,23], it is still important to monitor ECG, blood pressure and the well-being of the person who performs the CPET. At peak performance, measurement of the ECG and blood pressure was complicated by the movement of the trunk and arms. In some subjects the test leader had to stop the test because the interpretation of the ECG was not possible anymore. For the first test this percentage was higher (31.3%; 5/16) than for the second (23.5%; 4/17) and third test (17.7%; 3/17). Because of movement of the arms and trunk and contractions of trunk muscles, resulting in artifacts in ECG registration during the exercise on the Cruiser ergometer, a fully adequate ECG registration was not possible, especially at peak exercise. Although the heart rate can be measured during the procedure, it is not possible to assess other important aspects of the ECG pattern, like ST-depressions. Directly after stopping the test these ECG abnormalities can be seen on a rest ECG[24]. To put these findings in perspective, in other forms of ergometry like arm ergometry, rowing ergometry and treadmill tests the ECG registration is also affected by the movement of the trunk and arm muscles[1]. Already in 1984 Van Alste et al. found difficulties in adequate ECG registration during their research into the clinically applicability of rowing ergometry in persons with a LLA[25]. Even in leg ergometry, applying a bicycle-ergometer, clear ECG registration is sometimes not achievable. In order to address this issue, Wezenberg et al used a discontinuous one-legged cycle exercise test[26]. In the rest phase between active blocks an ECG and blood pressure was interpreted. A discontinuous protocol for the Cruiser ergometer was tried and tested, but turned out to be impractical while using the iso-power mode, since starting the movement at zero speed on the Cruiser ergometer at

the high resistance is too hard to accomplish. In other words, the discontinuous protocol was demanding too much effort during the re-start phases from the subjects and was therefore not applicable. Maybe in future the Cruiser ergometer can be adapted , e.g. by using a power assisted mode as discussed in the paragraph future developments and research, to make it possible to use also a discontinuous protocol as in the study of Wezenberg et al.[26]. For now, in clinical practice it is advised to perform an ECG registration in rest prior to testing and subsequently just after termination of the peak exercise test for an additional 2 minutes in order to detect exercise-related ECG abnormalities[24,27].
Blood pressure measurement during the peak exercise test on the Cruiser ergometer was not possible because of movement of the arms and the exertion of the muscles of the arms. It has to be noted that also in other forms of ergometry when the arms are involved in the movement, measuring of the blood pressure during the exercise test is not possible due to the same reasons[28,29]. Further research has to be done into the question whether an alternative measure of the blood pressure is possible, for example on another location, like the wrist[30,31]. And as mentioned above maybe in future the Cruiser ergometer can be adapted to a power assisted mode to make it possible to use a discontinuous protocol. With this adaptation the blood pressure can be measured in the rest phase when the arms are not involved in the exercise. Another point of view is that, as we did in our research, before the test all subjects are screened on cardiovascular risk factors by a questionnaire and measuring ECG and blood pressure in rest. When there are no major cardiovascular contra-indications as a history of a stroke or ischemic heart disease and it will not be expected that a high blood pressure will be a reason to stop the exercise test, the blood pressure can be measured directly after the exercise test[29].

Reliability of the peak exercise test on the Cruiser ergometer in the test-retest analysis in both healthy persons and persons with a LLA was good (chapter 4 and 5), but there was a not significant change in VO_2peak for the 2nd and 3rd test. This is the same as for the CPET on the bicycle ergometer, in literature also a familiarization effect for bicycle ergometry is described, unlikely to be of clinical relevance[17]. Consequently, the reliability of the peak exercise test on the Cruiser ergometer is corresponding with the bicycle ergometer.

Training prescription for exercising on the Cruiser ergometer

It is important to test and train cardiorespiratory fitness on the same type of ergometer because VO_2peak and ventilatory thresholds can vary between different modes of exercise[32]. An advantage of the Cruiser ergometer in the rehabilitation after a LLA is that it can be used both as a testing and training instrument. The Cruiser ergometer can be used as a testing instrument at the start of the rehabilitation program, for monitoring during the rehabilitation and at the end to evaluate the program. In addition, the Cruiser ergometer can be used as a training instrument during the rehabilitation, which is facilitated by the fact that a person with a LLA is able to exercise on the Cruiser ergometer with two arms and one leg without help and also without the prosthesis. Moreover, training load of the Cruiser ergometer and bicycle ergometer are comparable, with respect to GE and cardiorespiratory strain in the healthy individuals. In chapter 3 we studied the difference in submaximal exercise on the Cruiser ergometer with one and two legs in healthy persons. We found that the GE was lower for the one-legged group and the heart rate (HR) was higher for the one-legged group. We assume that balance and force direction are potentially more critical in one-legged exercise, while the strain per muscle mass unit will be higher in one-legged exercise, compared to two-legged exercise. Furthermore, it could be hypothesized that in one-legged exercise on the Cruiser ergometer the arms, during a lower training load, are more involved than during two-legged exercise. However, the current Cruiser ergometer does not produce output of each extremity separately, and therefore, the difference in output specifically of the arms in one-legged and two-legged exercise on the Cruiser ergometer cannot be measured. If it is possible to measure the output of the arms and legs separately with the use of sensor technology, it will allow us to understand the involvement of separate legs and arms in power production and thus to give more sharp training instructions for the exercise on the Cruiser ergometer for each of the limbs.

Training prescription for exercising on the Cruiser ergometer is possible when ventilatory thresholds are available[33]. In chapter 6 it is described that the first ventilatory threshold (VT1) could be determined in the majority of the healthy subjects and subjects with a LLA, but determination of the second ventilatory threshold (VT2) was less reliable. However when the first ventilatory threshold is known, an exercise program can be designed[33]. Further research into the effects of a different rehabilitation programs after a LLA with this training prescription is needed.

> *Implications for Mister X: Taken the results of this thesis together, we can recommend the physiotherapist of mister X to compose a training prescription based on a CPET performed on the Cruiser ergometer. Before the cardiopulmonary exercise test is started it is advised that mister X will exercise on the Cruiser ergometer to get acquainted with this ergometer, if possible a couple of days before the CPET. Mister X can perform the CPET even before a prosthesis is developed and placed, because the exercise on the Cruiser ergometer can be safely done with two arms and one leg and the residual limb can be supported. The CPET reveals whether is it necessary to investigate underlying problems with heart or lungs, and enables the composition of a training program, especially in the presence of the first ventilatory threshold.*

Limitations

A limitation of the thesis is that we only focused on measuring cardiorespiratory fitness on the Cruiser ergometer. Physical fitness is a much broader concept, consisting of strength, flexibility, coordination, anaerobic and aerobic capacity, which could all be the focus of training and the basis for daily life activities in rehabilitation and beyond[34]. It is generally acknowledged that these different aspects of physical fitness should be improved after a LLA[3,8]. Consequently, a training program after a LLA should include exercise modes to improve not only cardiorespiratory fitness but also the other aspects of physical fitness. Future research into the possibilities of the Cruiser ergometer as an instrument to measure and improve for example anaerobic capacity and muscular strength should be considered.

A second limitation is the fact that we used the same test protocol for all persons with a LLA. For some of the subjects the warming up on 20W was already strenuous whereas others had to exercise more than 10 minutes to reach VO_2 peak. In chapter 5 the protocol for subjects with a LLA is described. Each peak exercise test started with 3 minutes rest on the Cruiser ergometer and was followed by a 3 minutes warm-up at 20W at 50 rpm. After the warm-up, workload was increased by 10W per minute, keeping speed at 50 rpm, until the point of exhaustion was reached or until the physician stopped the test. Consequently, it is advised to use a protocol in which the workload is increased dependent of the age, gender and activity level of the subject.

A technical limitation of the Cruiser ergometer was, that the lowest accurate workload setting on the Cruiser ergometer was 20 Watt. As mentioned above for some of the subjects the warming up on 20W was already strenuous. We therefor suggest that in developing a new version of the Cruiser, lower workloads should be possible. Furthermore the iso-power mode of the Cruiser used in the current experiments are typical in clinical ergometry applications. It means that the system regulates a constant power output (W); based on the definition of power output as the product of resistance force and speed: when the speed goes down, the resistance goes up and vice versa. A more natural - real life mode – is the iso-inertial mode where the eventual power output is dependent on the actual speed. When speed drops, power output will drop. Future research should focus on such mode related characteristics and the (dis)continuity of the protocol and the feasibility.
Another technical limitation was that the workload of the Cruiser ergometer had to be noted manually because it was not connected to the machinery and software that controls the cardiorespiratory variables.

Also a limitation was that only in chapter 5 and 6 persons with a LLA were involved in the study. In chapter 2 and 3 research was done to the cardiorespiratory strain, GE and motor learning on the Cruiser ergometer in healthy persons. It is quite possible that GE and motor learning are different in elderly subjects with a LLA, in particular as cardiorespiratory physical fitness is diminished as a result of decreased activity pattern, age, and chronic disease. These aspects require considerable continued research in the rehabilitation setting, both cross-sectional as well as longitudinal. The latter provides indications of time-(i.e. rehabilitation and age) associated changes in performance capacity.
For individual training-related exercise prescription, it is often recommended to use VT1 and VT2[33]. However, VT2 could not be determined in the majority of our subjects. It is obviously possible to compose training programs just on the VT1, and further study should focus on the efficacy of such programs. A limitation

in this study is that it was not investigated whether such an exercise intensity prescription based on VT1 or VT2 is favorable to exercise prescription based on other parameters as rate of perceived exertion, percentage of heart rate reserve or percentage of peak power output. Such studies are advised to be conducted in future rehabilitation contexts, for instance, in multicenter collaborations with larger numbers of patients with a LLA.

Future developments and research (Cruiser 2.0)

We demonstrated that de Cruiser ergometer is useful in testing cardiorespiratory fitness in persons with a LLA. Based on our experience with the Cruiser ergometer, we hypothesize that this ergometer is also useful in exercise training as component of a rehabilitation program. In addition, the Cruiser ergometer is possibly useful in other persons with unilateral impairments (i.e. stroke) or persons with limited balance control or capacity to stand or walk, i.e. elderly or people with overweight.

The Cruiser ergometer is currently out of production. Initiatives are undertaken to develop and produce an updated version of the Cruiser ergometer, stimulated by the outcome of this thesis that arm-leg ergometry should be used in favor of one-leg bicycle ergometry in persons with a LLA. The benefits of the Cruiser ergometer above the one-leg bicycle ergometer as mentioned in the introduction are evident. The Cruiser ergometer can be used as a testing and probably also as a training instrument in persons with a lower limb impairment, possibly also in those with stroke or other fragile patient populations. The latter is of even greater value in the concept of testing and training with the same equipment[32].
Based on the outcome of this thesis and taking the reported limitations into account, when developing a new ergometer the following points as mentioned earlier are important: 1) adequate and reliable ECG registration; 2) blood pressure measurement; 3) connection with the software to enable control of Cruiser load from the software that also controls the cardiorespiratory variables; 4) possibility of accurate and low loads from 0W upwards obviously in smaller steps as well as discontinuous patterns in an iso-inertial mode; 5) provide the user with isometric, iso-power as well as iso-inertial modes of operation; and 6) being able to measure the effort of the arms and leg(s) separately with the use

of sensor technology .
For some populations of patients starting levels of work or power may be too high, which suggests the use of a power-assist technology that support personal effort. Because of movements of trunk and contraction of trunk muscles a discontinuous protocol which enables ECG and blood pressure monitoring is advised, but therefore the iso-power function has to be changed to, for example, a function in which power-assistance is possible in the rest phase when ECG registration and blood pressure monitoring can be done. When developing this new Cruiser ergometer, technical innovations from the power assisted wheelchair[35] or Servo-Driven Dual-Roller Handrim (Essada) Wheelchair Ergometer[36] could be considered.
We expect that there will be a motor learning effect when exercising on the Cruiser ergometer. Because the movement on the Cruiser ergometer is a less natural movement than, for instance, the movement on the bicycle ergometer it is important that the person with a LLA has tried the Cruiser ergometer before performing the exercise test. When developing a testing protocol for this new ergometer it is important to take into account motor learning effects. Also different protocols have to be developed for the exercise test dependent on the age, gender and activity level of the person. We suggest a test protocol starting with 2 minutes rest, followed by a warm-up of 3-5 minutes at a low level, under the VT1. Thereafter, an incremental load should be applied, 1 minute per step, aiming at a duration of this phase of 8-12 minutes, which is in accordance with current protocols. After reaching the maximal level, subjects should be observed for 2-3 minutes, with continuation of measurement of ECG, blood pressure and ventilation. These testing protocols for the Cruiser ergometer should be tested on validity, reliability, feasibility and safety in a population of persons with a LLA especially in older persons with cardiovascular risk factors.

Further research into the clinical use of the ventilatory thresholds that can be determined from the results of the exercise test on this new version of the Cruiser ergometer, has to be done. With these thresholds an individually tailored training protocol can be developed to improve the cardiorespiratory fitness during the rehabilitation after a LLA. Research on the effects of such a training protocol applied on the newly developed Cruiser ergometer should be performed before this new version of the ergometer can be used as a training instrument in the rehabilitation after a LLA.

General conclusion

It can be concluded that the Cruiser ergometer is useful as an instrument for clinical exercise testing in persons with a LLA and probably in future also for training. Suggestions for innovation of the Cruiser ergometer emanated from the experiments. Based on these outcomes, recommendations are made to develop and produce an updated version of the Cruiser ergometer.

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