Physical activity and energy expenditure in clinical settings using multisensor activity monitors

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a moment of beauty
a moment of enjoyment

these are great rewards
worth fighting for

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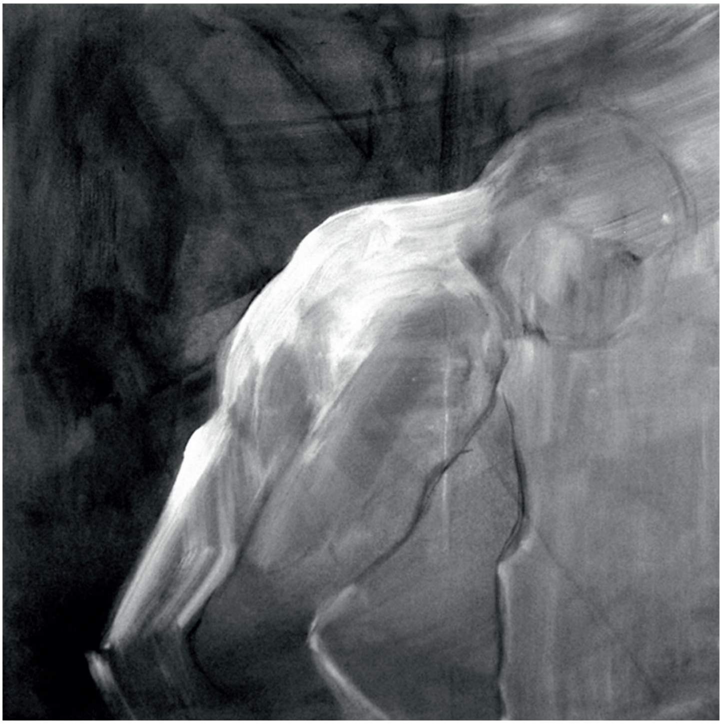

If a researcher asks me "What is the best method to measure physical activity" I will give the unpleasant answer "It depends" and ask the researcher for a comprehensive description of his/her project.

Abstract

Background: Objective methods need to replace subjective methods for accurate quantification of physical activity. To be used in clinical settings objective methods have to show high reliability, validity and feasibility. The commonly used activity monitors are unable to detect the variety of physical activities. Multisensor activity monitors have larger potential for a more accurate quantification of physical activity. Children who have undergone surgery for congenital heart defects have the possibility to a physical active lifestyle because of the progress in cardiac surgery and cardiology.

Aims: To evaluate the ability of the multisensor activity monitors ActiReg, SenseWear Armband and IDEEA to assess physical activity and energy expenditure **(I-IV)**, and to assess physical activity, sports participation and aerobic fitness in children who have undergone surgery for congenital heart defects **(V)**.

Methods: I) Patients with chronic obstructive pulmonary disease (COPD) wore the ActiReg during 7 days with doubly labelled water as criterion for energy expenditure; **II-III)** 11-13 years old children performed different physical activities while wearing the ActiReg, SenseWear Armband and IDEEA with indirect calorimetry as criterion for energy expenditure; **IV)** a new ActiReg algorithm calibrated in 11-13 years old children was tested in 14-15 years old children wearing the ActiReg but also the SenseWear Armband during 14 days using doubly labelled water as criterion for energy expenditure; **V)** children who have undergone surgery for congenital heart defects and healthy controls in the age-groups 9-11 and 14-16 years wore the ActiReg during 7 days, were interviewed about sports participation and performed a maximal exercise test with measured oxygen uptake for the assessment of aerobic fitness.

Results: I) The ActiReg showed a mean (sd) accuracy of 99 (10) % in assessing energy expenditure in COPD patients; **II-III)** the accuracy of the SenseWear Armband and IDEEA in assessing energy expenditure varied between the different activities but showed an overall value of 81 (11) %/85 (8) % for the SenseWear Armband and 96 (10) % for the IDEEA; the SenseWear Armband showed increased underestimation with increasing intensity; the ActiReg algorithm overestimated moderate physical activity and the ActiReg had a limitation in registering vigorous physical activity; **IV)** the accuracy of the ActiReg with the new algorithm and the SenseWear Armband was 99 (11) % and 96 (10) %, both with increased underestimation with increasing intensity; **V)** children who have undergone surgery for congenital heart defects showed similar physical activity as the healthy controls but a tendency to lower amount of sports participation; in the older children, especially in boys, the patients had lower aerobic fitness; still, their amount of sports participation was considered high and their aerobic fitness moderate.

Conclusions: The ActiReg, SenseWear Armband and IDEEA have to be improved to become accurate instruments in clinical settings. While children who have undergone surgery for congenital heart defects had a physical activity level comparable to healthy children, some of them may require support for their engagement in exercise and vigorous physical activity.

Sammanfattning

Bakgrund: Objektiva metoder bör ersätta subjektiva metoder för att den fysiska aktiviteten ska kunna kvantifieras. I klinisk verksamhet bör de objektiva metoderna uppvisa hög reliabilitet, validitet och användbarhet. De vanligaste aktivitetsmätarna kan inte fånga all typ av fysisk aktivitet. Multisensor-aktivitetsmätare har större potential att kvantifiera den fysiska aktiviteten. På grund av utvecklingen inom barnhjärtkirurgin och barnkardiologin har barn opererade för medfött hjärtfel idag möjlighet till en fysiskt aktiv livsstil.

Syften: I-IV) Att utvärdera förmågan hos multisensor-aktivitetsmätarna ActiReg, SenseWear Armband och IDEEA att fastställa fysisk aktivitet och energiförbrukning, och **V)** att fastställa fysisk aktivitet, idrottsdeltagande och kondition hos barn opererade för medfött hjärtfel.

Metoder: I) Patienter med kroniskt obstruktiv lungsjukdom (KOL) bar ActiReg under 7 dagar med dubbelmärkt vatten som referens för energiförbrukning; **II-III)** 11-13-åriga barn genomförde olika aktiviteter medan de hade på sig ActiReg, SenseWear Armband och IDEEA med indirekt kalorimetri som referens för energiförbrukning; **IV)** en ny ekvation för energiförbrukning utvecklades för ActiReg hos 11-13-åriga barn och testades sedan tillsammans med SenseWear Armband under 14 dagar hos 14-15-åriga barn med dubbelmärkt vatten som referens för energiförbrukning; **V)** barn opererade för medfött hjärtfel och friska kontroller i åldersgrupperna 9-11 och 14-16 bar under 7 dagar ActiReg, intervjuades om idrottsdeltagande och genomförde ett maximalt arbetsprov med uppmätt syreupptag för att fastställa konditionsnivån.

Resultat: I) ActiReg uppvisade en pålitlighet på 99 (10) % att fastställa energiförbrukning hos patienter med KOL; **II-III)** pålitligheten hos SenseWear Armband och IDEEA att fastställa energiförbrukning varierade mellan aktiviteterna men visade ett genomsnitt på 81 (11) %/85 (8) % och 96 (10) %; SenseWear Armband visade en ökad underskattning med ökad intensitet; ActiRegs originalekvation medförde överskattning av måttligt intensiv fysisk aktivitet, fast ActiReg har en begränsning att registrera hög-intensiv fysisk aktivitet; **IV)** pålitligheten hos ActiReg med den nya ekvationen och hos SenseWear Armband var 99 (11) % och 96 (10) %, där båda metoderna visade en ökad underskattning med ökad aktivitetsnivå; **V)** barn opererade för medfött hjärtfel hade jämförbar fysisk aktivitetsnivå med friska barn, men uppvisade en tendens till lägre idrottsdeltagande; i den äldre åldersgruppen hade framför allt pojkarna en lägre kondition; deras idrottsdeltagande bedömdes ändå högt och konditionen som måttligt bra.

Slutsatser: Multisensor-aktivitetsmätarna ActiReg, SenseWear och IDEEA måste förbättras för att vara pålitliga instrument i klinisk verksamhet. Även om barn opererade för medfött hjärtfel kan uppvisa samma fysiska aktivitetsnivå som friska barn, behöver en del utav dem stöd för att delta i idrott och intensiv fysisk aktivitet.

List of publications

The thesis is based on the following papers, which are referred to by their Roman numerals:

I. Arvidsson D, Slinde F, Nordenson A, Larsson S, Hulthén L. Validity of the ActiReg system in assessing energy requirement in chronic obstructive pulmonary disease patients. *Clin Nutr*. 2006; 25: 68-74.

II. Arvidsson D, Slinde F, Larsson S, Hulthén L. Energy cost of physical activities in children: Validation of SenseWear Armband. *Med Sci Sports Exerc*. 2007; 39: 2076-2084.

III. Arvidsson D, Slinde F, Larsson L, Hulthén L. Energy cost in children assessed by multisensor activity monitors. *Med Sci Sports Exerc*. 2009; 41: 603–611.

IV. Arvidsson D, Slinde F, Larsson S, Hulthén L. Free-living energy expenditure in children using multi-sensor activity monitors. *Clin Nutr.* 2009 Apr 2. [Epub ahead of print]

V. Arvidsson D, Slinde F, Hulthén L, Sunnegårdh J. Physical activity, sports participation and aerobic fitness in children who have undergone surgery for congenital heart defects. *Accepted for publication May 2009 in Acta Paediatrica.*

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Preface and aim of thesis

I was born and raised in a time when most children hadn't seen any computers, but spent most of their time outside playing or doing different kinds of sports. All of a sudden I was in the midst of a revolutionized technical development changing my world to becoming dependent of computers and distant communication. The children changed their habits and physical inactivity started to become a world wide problem contributing to child obesity and diabetes. However, the technical development also brought new exciting possibilities for high-resolution snap-shots of daily habits and recognition of physical activities and movement patterns. Small devices with large capacities integrating artificial intelligence enabled a future with nutrition epidemiology using objective methods.

When I started at the Department of clinical nutrition in the spring 2002 there were a handful of papers showing epidemiological data of physical activity using activity monitors and the second generation integrated multisensor devices were not yet introduced to the readers. In 2004 physical activity was integrated into the field of nutrition through the release of the Nordic Nutrition Recommendations 2004, and at that time the first papers of the multisensor activity monitors ActiReg, SenseWear Armband and Intelligent Device for Energy Expenditure and Activity (IDEEA) had been published.

In this thesis I report the introduction of the ActiReg, SenseWear Armband and IDEEA into the clinical research performed at the department and our evaluation of these monitors. The goal was to identify reliable, valid and feasible objective methods to be used in clinical settings in individual patients. I came in contact with two different patient groups where the assessment of physical activity was the common theme but served different purposes: patients with chronic obstructive pulmonary disease and children with congenital heart defects. In the first group the use of activity monitoring served the purpose of getting closer the prediction of the individual energy requirement. In the second group we wanted to find whether the improved survival after cardiac surgery in children during the last decades also resulted in attaining a normal physical active lifestyle.

This thesis was written as a review where our research was integrated into the context of the progress of the physical activity research and the progress of activity monitors. The thesis can be divided into one section concerning the methodological progress of physical activity monitoring and a second section concerning physical activity assessment in children with congenital heart defects. The two main questions guiding our research and the discussion in this thesis were **1)** whether activity monitors are able to quantify the dose of physical activity and **2)** whether they are reliable, valid and feasible to be used in clinical settings.

Daniel Arvidsson

Abbreviations

The attempt has been to avoid abbreviations as far as possible. In those cases where abbreviations do occur, the reason is either that the name/concept consists of too many words and/or that the abbreviations are more commonly used than the full name. In same cases the abbreviation has been put within parenthesis to show how the abbreviation looks like in the scientific literature. Below are only those abbreviations presented that are commonly used in the physical activity research field.

BEE	Basal Energy Expenditure
COPD	Chronic Obstructive Pulmonary Disease
DLW	Doubly Labelled Water (British English), doubly labeled water (American English)
EE	Energy Expenditure
FaR	Fysisk aktivitet på Recept (Physical activity on Prescription)
FQ	Food Quotient (FQ≈RQ)
FYSS	Fysisk aktivitet i Sjukdomsprevention och Sjukdomsbehandling (Physical Activity in Prevention and Treatment of Diseases)
IPAQ	International Physical Activity Questionnaire
MET	Metabolic Equivalent (TEE/REE)
MVPA	Moderate-to-Vigorous Physical Activity
PA	Physical Activity
PAL	Physical Activity Level (TDEE/BEE)
PAR	Physical Activity Ratio (TEE/BEE)
REE	Resting Energy Expenditure
RER	Respiratory Exchange Ratio (VCO_2/VO_2)
ROC	Receiver Operator Characteristic
RQ	Respiratory Quotient (VCO_2/VO_2, RQ=RER)
TDEE	Total Daily Energy Expenditure
TEE	Total Energy Expenditure
VCO_2	Carbon dioxide production rate
VO_2	Oxygen uptake rate
WHO	World Health Organisation

The progression of physical activity research

Where it all started

"The best philosophers and the best doctors among the ancients have frequently stated how beneficial exercise is toward health, and that it must precede eating... I say that the best athletics... are those which not only exercise the body but are able to please the spirit... Play with a small ball is so much a people's activity that even the poorest man is able to have the equipment... [Such exercise] needs neither nets nor weapons nor horses nor hunting dogs, but only a ball, and a small one at that... This kind of exercise is the only one which moves all parts of the body so very equally... Many [other] exercises achieve an opposite effect: they make people lazy and drowsy and dull witted... I assert that every [exercise] should be practiced in moderation... "

These are the words of the Greek physician Galen (AD 131-201) and show the awareness of the importance of moderate amount of physical activity within a balanced lifestyle.[72] However, research in physical activity has its starting-point from notations by the Italian physician Bernardini Ramazzini (dedicated the title the first epidemiologist) of differences in health between various tradesmen during the 18th century:[163]

"Let tailors be advised to take physical exercise at any rate on holidays. Let them make the best use they can of some one day, and so counteract the harm done by many days of sedentary life".

With the work by professor Morris and his colleagues physical activity became epidemiological research.[152] By classifying the work intensity of occupations into heavy, intermediate, doubtful and light they showed that the risk of coronary heart disease and mortality was lower among heavy workers.[145] Their classical observation of the difference in risk of coronary heart disease between active conductors and sedentary drivers of the London's double-decker buses continued the field as studies of physical activity of occupation.[146] However, they realized that prevention of coronary heart disease has to target light workers and during leisure-time. Hence, the physical activity research shifted to become leisure-time investigations and methods to assess physical activity was created: 1) 5-minute interval log for seven days, and 2) a record of activities over the past four weeks. With these methods they demonstrated an association between moderate-to-vigorous physical activity (MVPA) and coronary heart disease.[144] With support from studies by subsequent researchers there is large amount of evidence of the preventive effect (both primary and secondary) of physical activity on all-cause mortality and coronary heart disease, and now also on diabetes, obesity, cancer and osteoporosis.[96, 97, 205] There are some supports for the preventive effect of physical activity on other conditions as well (chronic obstructive pulmonary disease, fibromyalgia, depression, cystic fibrosis), although the evidence is not that clear. In children, there is evidence of the beneficial effects of physical activity on musculoskeletal health, cardiovascular health and obesity.[191]

Assessment of physical activity using subjective methods

An important goal in the physical activity research has been to describe dose-response relationships to the risk of a getting a disease, to be able to set physical activity recommendations (Figure 1). In 1995 the Centers for Disease Control and Prevention together with the American College of Sports Medicine released the first public health recommendation for physical activity: 30 minutes or more of moderate-to-vigorous physical activity on most days of the week.[156] This recommendation was based on the well investigated association between physical activity and risk of cardiovascular disease/mortality which indicated a dose-response relationship to physical activity. Although there are strong associations between physical activity and cardiovascular disease/mortality, diabetes, obesity, cancer and osteoporosis, the dose-response relationships to these conditions have not been sufficient clear to allow for appropriate physical activity recommendations which need to take into consideration the components of the physical activity, namely intensity, frequency, duration and type of activity.[111, 205] The studies behind the associations between physical and risk of getting a disease has been criticized for their simple and imprecise methods to assess physical activity based on questionnaires, recalls or diaries.[207] Besides the limitations of assessing physical activity using subjective methods (e.g. memory, perception, opinion) there are other methodological issues that have interfered with the quality of the assessment of physical activity in the population. There are a variety of questionnaires, recalls and diaries differing in their way of administration, target population, time frame covered, type of activity measured and scales to which the exposure is reduced to. Because subjective methods are most effective in measuring easily recalled activities (e.g. sports activities) most of them are designed to cover only one aspect of physical activity. This aspect should then be carefully chosen to target the physiological or health variable of interest (e.g. high-intense physical activity and aerobic fitness, weight-bearing activities and bone density), which most often has not been the case. If moderate-to-vigorous physical activity is going to be assessed for its protective effect against cardiovascular diseases, then all contexts of physical activity (work/school, transportation and leisure-time) need to be covered.

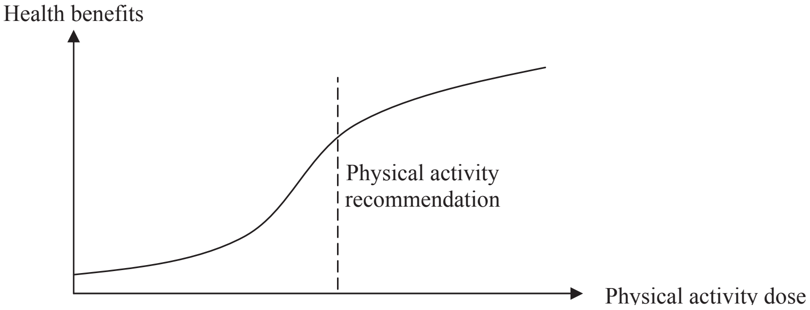


Figure 1. A sufficient clear dose-response curve for the identification of a physical activity recommendation.

Another problem concerns the validity of the method. The validity can be assessed if the output from the method is compared to a criterion method and the error of the criterion is independent from the error of the method to be validated. There is a hierarchic order of how to perform a validation and the method to be validated should always be compared to a method higher in rank (Figure 2).[187] There is an inborn limitation in this system. Calorimetry and the doubly labelled water method assess energy expenditure and hence, the output from the method to be validated has to be translated to energy expenditure through calibration algorithms. This has been a major issue in the physical activity assessment field, both for subjective and objective methods. Because most of the subjective methods do not cover all physical activity, the attempt has been to relate the method output to either the output from other subjective methods with similar output (concurrent validity) or to methods with different outputs (criterion validity; e.g. aerobic fitness, activity monitor counts). Even if validity is claimed in many papers, the true validity has not been assessed. In systematic reviews of studies in children and adults where subjective methods has been related or directly compared to objective methods, there is a large variation in correlations or agreements.[2, 160] Overall, the mean correlation was 0.3-0.4, ranging from -0.71 to 0.98. The subjective methods tended to overestimate physical activity compared to objective methods, and the overestimation was larger among children and among females. The choice of reference method (activity monitor or calorimetry/doubly labelled water) and reference variable (monitor counts, time spent in moderate-to-vigorous physical activity or energy expenditure) in relation to the design and physical activity measure of the subjective method will also affect the reported accuracy.

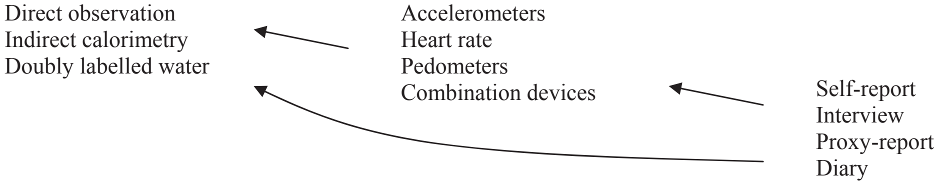


Figure 2. A validation scheme where the arrows indicate the criterion methods to perform the validation to.

In an attempt to increase the comparability between studies and between countries, to cover all contexts of physical activity and to introduce the use of a common output/unit, the International Physical Activity Questionnaire (IPAQ) was created.[45] This was the first time an international standard for subjective physical activity assessment was established. The IPAQ is frequently used all over the world and has been included in several validation studies.[23, 45, 55, 59, 74, 103, 105, 120, 122, 123, 139, 218] The correlation to physical activity assessed by accelerometry largely varied depending on the variable investigated (total physical activity or its components) but reached a mean value of approximately 0.3-0.4. It overestimated time in different physical activity levels but underestimated physical activity energy expenditure. The IPAQ has been adapted to be used in adolescents, called Physical Activity Questionnaire for Adolescents (PAQA) or Swedish Adolescent Physical Activity Questionnaire (SAPAQ). The correlation between PAQA/SAPAQ and an activity monitor for total physical activity and time spent in moderate-to-vigorous physical activity have been reported to 0.23-0.51 and between energy expenditure from PAQA/SAPAQ and doubly labelled water 0.40-0.62.[8, 44, 58] It underestimated energy expenditure from doubly labelled water,[8] but both underestimated and overestimated the amount of physical activity from the activity monitor depending on the cut-point used for defining physical activity from the activity monitor.[8, 44] Although the more standardized format covering all contexts of physical activity, the validity of the IPAQ is similar to the validity of subjective methods in general.

Assessment of physical activity using objective methods

It has been suggested that the introduction of objective methods in physical activity epidemiological research would increase the precision and quality of physical activity data of following reasons: **1)** through objective instruments we are able to quantify the physical activity components (intensity, frequency and duration) and total physical activity continuously to judge their importance for a particular health outcome; **2)** continuous collection of all physical activity and their components allows for detailed examination of relationships for linearity or thresholds; **3)** objective data with common unit makes it easier for comparing studies or comparing different social or cultural groups; and **4)** objective instruments will eliminate perception bias in behavioral interventions.[207]

The technical development has contributed to small, feasible activity monitors with high sampling frequency and with large memory capacity. However, the question is: *has the introduction of objective methods advanced our knowledge of the dose-response relationship between physical activity and health/disease, leading to an improvement in the physical activity recommendations?*

There are a limited amount of studies allowing us to answer this question. The association between cardiometabolic risk factors (waist circumference, systolic blood pressure, diastolic blood pressure, total cholesterol, HDL cholesterol, triglycerides, HOMA) and physical activity assessed from IPAQ and pedometry was compared.[180] There was a stronger association between cardiometolic risk and total physical activity assessed by pedometry (men: $P<0.001$; women: $P<0.001$) compared to assessed by

IPAQ (men: P=0.14; women: P=0.25). However, physical activity during leisure-time assess by IPAQ contributed to a stronger association to cardiometabolic risk (men: P<0.001; women: P=0.06). In this study the participants were divided into quartiles according to their physical activity level. The odds ratio between highest and lowest quartile was 0.29 and 0.40 for men and women using pedometry, and 0.64 and 1.50 using IPAQ. For leisure-time the odds ration was 0.31 and 0.62 using IPAQ. However, the amount of physical activity in each quartile was not presented to assess the shape of the dose-response relationship.

A clear description of the dose-response relationship between time spent in moderate-to-vigorous physical assessed by accelerometry and obesity has been presented in children.[148] This study showed that the largest decrease in the risk of obesity was achieved by attaining 20 minutes of moderate-to-vigorous physical activity in boys, but that there was a more continuous decrease in girls. The odds ratio between highest and lowest quintile of physical activity was 0.03 (P<0.001) in boys and 0.36 (P=0.006) in girls. By reaching 55 and 37 minutes respectively of moderate-to-vigorous physical activity these effects were attained. Another study in children, where the physical activity was assessed by accelerometry, showed a detailed dose-response relationship between blood pressure and total physical activity or time spent in moderate-to-vigorous physical activity.[125] Forty minutes of total physical activity was needed for a decrease in systolic blood pressure. Time spent in moderate-to-vigorous physical activity had a more continuous decreasing effect on the systolic pressure. In both cases no plateau was observed. For diastolic blood pressure a plateau was seen after 70 minutes of total physical activity and 40 minutes of moderate-to-vigorous physical activity. Although there was a clear dose-response relationship between physical activity and blood pressure, the total change in blood pressure was only minimal. The recommended amount of physical activity to prevent weight gain in children of least 60 minutes of moderate-to-vigorous physical activity then seems fair, but is built on lack of real evidence.[179, 208] The same holds true for the general recommendation in children of 60 minutes of moderate-to-vigorous physical activity, although it may be useful in all types of physical activity interventions.[89, 191]

Hence, the answer to the question above is that despite the large increase in objective measure of physical activity during the last 20 years we are still left with a tiny amount of studies investigating dose-response relationships.[198] In the meantime, we have to stick with the updated 2007 physical activity recommendations from the American College of Sports Medicine and the American Heart Association.[76] The next question is: *why have we not advanced much further in the assessment of dose-response relationships by using objective methods.* This question will be answered in a later section in this thesis. But before that, there is need of clarifying some concepts and definitions to better understand the field of physical activity assessment.

Physical activity – concepts and definitions

Physical activity is defined as any bodily movement produced by skeletal muscles that results in increased energy expenditure.[33] Hence, this concept consists of two parts, movement and energy expenditure, that may be measured (Figure 3).[106] While *physical activity* (movement) is a behavior, *energy expenditure* is the consequence of this behavior. Physical activity can be described by its components *intensity, frequency, duration* and *type*. Knowing intensity, frequency and duration is necessary for quantifying the dose of physical activity, but also to be able to define how physical activity mediates its health effect. The type of physical activity is not necessary for the assessment of the dose, but has other important health implications (e.g. weight-bearing activities and bone health). The components can be assessed in the three main contexts *work/school*, *transportation* and *leisure-time*. Hence, by knowing all components of physical activity together with all the contexts it was performed in we will achieve the evidence needed for a complete physical activity recommendation.

The intensity of a physical activity can be described as *sedentary/low*, *light*, *moderate* and *vigorous*. The definition of these intensity levels is based on measured energy expenditure. This is performed by relating total energy expenditure to resting energy expenditure. For a single activity the measure of intensity is expressed as metabolic equivalents (MET = total energy cost of an activity/resting energy expenditure (REE)) or as physical activity ratio (PAR = total energy cost of an activity / basal energy expenditure (BEE)).[4, 64] For a whole day the average intensity is expressed as physical activity level (PAL = total daily energy expenditure/basal energy expenditure).[64] For both subjective and objective methods these intensity measures have been used to calibrate the intensity measure of the method. Extensive tables of intensity measures have been compiled for adults.[4, 64] The threshold for moderate physical activity has been defined at *3 METs* and for vigorous physical activity at *6 METs*, and has been used extensively in physical activity surveillance studies. However, the intensity measures were originally developed in adults, but have largely been applied in children as well. Recent studies have addressed this problem with the conclusion that adult MET-values can be applied in children as well with the exception of walking and running.[75, 171] For these activities the MET-value increases by age.[171] This increase by age may be explained by that the decline in resting energy expenditure and energy cost of locomotion by age do not occur at a proportional rate. The MET may not be the most optimal intensity measure when comparing individuals of different age and body-size. When energy cost of walking and running is adjusted for body weight children spend more energy compared to adults. A large part of this difference disappears when adjusting for resting energy expenditure. Still there is as difference by age. However, when also adjusting for stature (an approximate for the body-size difference in number of steps taken) children have similar energy cost for walking and running as adults.[130, 131] Hence, the quotient of total energy expenditure and resting energy expenditure may not be used as a common measure of intensity during ambulatory physical activity. A compendium of physical activities in youth has now been developed, including an algorithm for calculating the MET-value during walking and running considering age and speed.[170] Also, the authors suggest the use of the age-adjusted resting energy expenditure when calculating energy expenditure from the MET-values.[75]

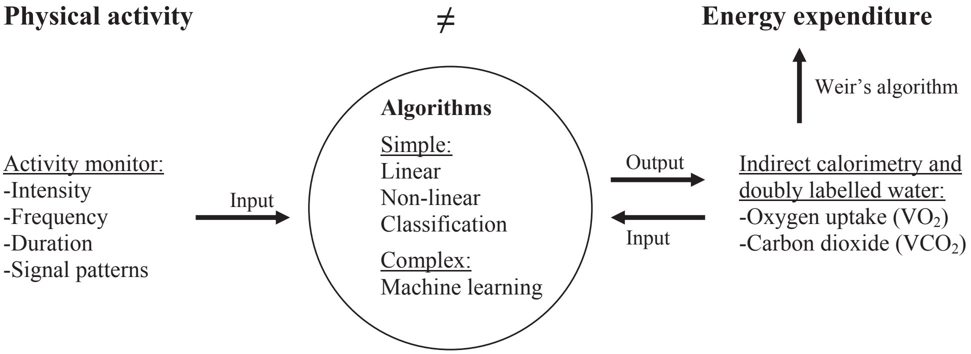


Figure 3. Separation of physical activity (behavior) from energy expenditure (consequence of behavior), the variables measured by the objective methods to describe these constructs and how the variable inputs are related to predict energy expenditure (output). Weir's algorithm is the translation from oxygen uptake and carbon dioxide to energy expenditure.

Criterion methods for physical activity

Indirect calorimetry and the doubly labelled water (DLW) method are considered the golden standards for energy expenditure during specific activities and for free-living, respectively.[3] In all metabolisms the body consumes oxygen and produces carbon dioxide and the amount depends on the energy source (carbohydrate, fat and protein) and the intensity of the physical activity. The respiratory quotient (RQ), the quotient of carbon dioxide and oxygen, indicates the contribution of each of the energy sources. The respiratory quotient in a mixed diet in the Western worlds can be assumed to 0.85.[22] The respiratory quotient for carbohydrate, fat and protein is 1.00, 0.71 and 0.83.[113] During the metabolism of amino acids part of their energy is lost through the excretion of nitrogen. Hence, to be able to calculate "the real" energy expenditure from the gas exchange the loss of nitrogen has to be assessed and subtracted from the total energy expenditure. However, this procedure is not feasible in most cases and a non-protein assessment of energy expenditure is sufficient and valid for the purposes in physical activity research.[210] In indirect calorimetry oxygen uptake and carbon dioxide production can be translated to energy expenditure using Weir's algorithm: $EE\ (kcal) = 3.9 \cdot VO_2 + 1.1 \cdot VCO_2$.[210] With increasing intensity the body relies more and more on carbohydrate as the energy source and the respiratory quotient is coming closer to 1.00.[173] When respiratory quotient passes 1.00 the body has reached its anaerobic threshold and carbon dioxide is not valid to be included in the calculation of energy expenditure, because the increased excretion is a mechanism to preserve the pH balance.[92]

In the doubly labelled water method a body-size dependent dose of the isotopes ^2H_2O and $H_2{}^{18}O_2$ is ingested.[3, 215] The isotopes equilibrium with the body water within a few hours. Hydrogen and oxygen are involved in all metabolisms and are subsequently excreted from the body in a rate in proportion to the metabolic rate. The oxygen isotope is excreted as $C^{18}O_2$ and $H_2{}^{18}O$ but the hydrogen isotope only as ^2H_2O. By measuring the difference in excretion rate in the urine the excretion rate of carbon dioxide can be assessed. Weir's algorithm is then used to calculate energy expenditure but takes the amount of oxygen consumed. The food quotient (FQ ≈ RQ) estimated from a food diary or the assumed respiratory quotient of 0.85 in a mixed diet is used to assess oxygen consumption.[22] Because indirect calorimetry is the older of the two methods the precision of the doubly labelled water method is determined by comparing it to indirect calorimtery and has been reported to between 2 and 8%.[184] However, both indirect calorimetry and the doubly labelled water method take expensive analytical equipments (there is also a high cost for the ^{18}O isotope), laboratory contexts and technical skilled staff to be reliable methods. Also, while indirect calorimetry interferes with normal living, the doubly labelled water method only assesses average energy expenditure over the analytical period (4-21 days) and no information is obtained about the variation within this period. Although, these methods can serve as criterion methods in the development of other methods more feasible in epidemiological research.

Activity monitors

Accelerometers and pedometers are the most common activity monitors today (Table 1).[40, 43, 51, 134, 165] Another method used in physical activity research is heart rate monitoring, but a review of this method is not the scope in this thesis. Shortly, the principle behind heart rate monitors is the relationship between heart rate and oxygen uptake (and indirectly energy expenditure).[43] However, the heart rate is affected by other factors like emotional stress, temperature, humidity, dehydration, posture, illness, fitness level and type of work (arm or leg), which makes heart rate monitoring less suitable for the assessment of physical activity. Also, because of the large intra- and inter-individual variation the heart rate monitor needs to be individually calibrated before usage. Although, it can make important contributions in multisensor devices.

Both accelerometers and pedometers register acceleration forces of movement.[36, 40, 43, 51, 134, 165] While pedometers are limited to frequencies of movements (number of steps), accelerometers also registers the acceleration force of each movement (number of steps and intensity of each step). Older pedometers use a spring-suspended horizontal lever arm that moves up and down in response to the hip's vertical accelerations. This movement opens and closes an electrical circuit. The lever arm makes an electrical contact and a step is registered. Newer pedometers use a piezoelectric accelerometer mechanism that has a horizontal cantilevered beam with a weight on the end, which compresses a piezoelectric crystal when subjected to acceleration. This generates voltage and the number of voltage changes is used to record steps. The later technique is less susceptible to error because of tilts (an important aspect when measuring in overweight individuals).[49] Accelerometers consist of a piezoelectric element that generates a voltage when compressed because of acceleration.[36] The magnitude of the voltage is proportional to the acceleration force and is recorded as the intensity of the movement and translated to the unit "counts". Accelerometers can be uni-, bi- or triaxial depending on the number of axes acceleration is registered from (vertical,

Table 1. Activity monitors commonly used in research with useful reference papers for learning the method.

Type	Model	Sensor	Placement	References	Manufacturer
Accelerometers					
The ActiGraph	GT1M	Accelerometer; vertical axis (x)	Waist	Adults: [1, 69, 175, 177] Children: [41]	ActiGraph, FL, USA www.theactigraph.com
RT3		Accelerometer; vertical (x), anteroposterior (y) and mediolateral (z) axes	Waist	Adults: [87, 91, 175, 178] Children: [38, 84, 192]	Stayhealthy, Inc, CA, USA www.stayhealthy.com
Actical		Acceleration; vertical (x) axis	Waist	Adults: [46, 48, 175] Children: [62, 159, 162]	Philips Respironics, OR, USA actical.respironics.com
Actiwatch		Acceleration; biaxial	Wrist	Adults: [35] Children: [114, 161, 162]	Philips Respironics, Bend, OR, USA www.camntech.com
Biotrainer	PRO	Accelerometer; vertical (x) and anteroposterior (y) axes	Waist	Adults: [99, 211] Children: [213]	IM Systems, Inc, MD, USA www.imsystems.net
Kenz Lifecorder	EX	Accelerometer; vertical axis (x)	Waist	Adults: [1, 102, 132] Children: [133]	Suzuken Company Ltd, Japan suzuken-kenz.com
Multisensors					
Actiheart		Accelerometer; vertical (x) axis; heart rate	Chest	Adults: [47, 223] Children: [42]	CamNtech Ltd, UK www.camntech.com
ActiReg		Mercury sensors for position and motion	Chest and thigh	Adults: [11, 21, 39, 85, 86] Children: [9, 12]	PreMed AS, Norway olaro@bredband.net
IDEEA		Multiple accelerometers	Chest, thigh, feet	Adults: [225, 226] Children: [9]	MiniSun LLC, CA, USA www.minisun.com
SenseWear Armband		Accelerometer, temperature, heat, sweating	Upper arm	Adults: [21] Children: [9, 10]	BodyMedia, Inc, PA, USA www.bodymedia.com
Pedometers					
Kenz Lifecorder	EX	Accelerometer	Waist	Adults: [50, 182, 183] Children: [133]	Suzuken Company Ltd, Japan suzuken-kenz.com
New Lifestyles	NL-2000	Accelerometer	Waist	Adults: [49, 50, 71, 182, 183] Children: [56]	New Lifestyles, Inc, MO, USA www.new-lifestyles.com
Yamax Digiwalker	SW-701	Spring lever	Waist	Adults: [50, 182, 183] Children: [19]	Great Performance Ltd, UK www.digiwalker.co.uk
Yamax Digiwalker	SW-200	Spring lever	Waist	Adults: [49, 71, 109, 110, 138, 182] Children: [19, 56, 88, 140, 151]	Great Performance Ltd, UK www.digiwalker.co.uk

anteroposterior or/and mediolateral). They can be used alone or as a part of a multi-sensor system. The counts can be integrated for predefined time periods (epoch), most commonly "counts·min^{-1}", which can be used as a measure of the average physical activity intensity for the particular time period. The choice of epoch-length depends on the physical activity pattern to be registered and may be critical for proper classification of physical activity (e.g. moderate or vigorous) or description of physical activity pattern. An intermittent pattern with short bursts of high-intense physical activity shown in children may be best captured by applying a short epoch (1-15 seconds), while 1 minute epoch may be enough for more continuous activities often shown in adults.[14, 150, 176]

Because the physical activity recommendations are defined around time spent at different intensity levels (e.g. at least 30 minutes of moderate-to-vigorous physical activity), cut-points for moderate and vigorous physical activity has been calibrated using indirect calorimetry as the reference method for intensity. Mainly, two different statistical approaches have been used in the calibration process. Traditionally, a mean group regression line (counts versus oxygen uptake, energy expenditure or METs) has been calculated including multiple bouts of activity to determine the cut-point.[161] Because this violates the independence assumption of multiple regression, mixed modeling is to prefer allowing for repeated measures (individual slopes and intercepts are calculated). Although this procedure was employed by Treuth et al to relate accelerometer counts to MET-values of different activities, they used a newer approach to define the cut-points for moderate and vigorous physical activity, the receiver operator characteristic (ROC) curves.[197] The cut-point was defined to minimize misclassifications, i.e. accurately captures moderate physical activity (sensitivity) without capturing inactivity (1 – specificity). This procedure has then been used by subsequent researchers.[38] Guidelines for performing or evaluating calibration, reproducibility and validity studies of activity monitors are presented in Table 2.

Activity monitors in clinical settings

The steepest increase in the number of studies using activity monitors, preferably accelerometers, started at the end of the 1990s and multisensor activity monitoring was introduced.[198] The technical progress now allowed the integration of fast microprocessors, mini-sensors, large storing capacity and high rate communication (including wireless communication) into a device easily worn on the body. These devices either use an array of motionsensors attached to different body segments, or combines motion-sensors with other physiological sensors (heart rate, temperature, heat flux, sweat rate). Also, for the first time the type of activity could be assessed. This was made possible by applying machine-learning techniques and artificial intelligence. The decrease in cost and need of technical expertise together with the increase acceptability of using activity monitors have introduced objectively physical activity assessment into epidemiological research. Despite all the progress in the field of physical activity assessment the question remains: *why have we not advanced much further in the assessment of dose-response relationships by using objective methods?*

Table 2. Summary guidelines for performing physical activity assessment.

Activity	Options	Comments
1. Selecting the of physical activity variable	Steps; mean intensity (mean MET, PAL); time at different intensity levels (min·d^{-1}); intensity, frequency and duration of physical activity boots; total energy expenditure/physical activity (kJ/kcal, counts); type of activity (walking, running, strength exercise).	The choice of physical activity variable depends on the health outcome to be addressed, e.g. bone health and bone loading activities at different intensity levels, body fatness and total energy expenditure, cardiovascular health or diabetes and time spent at different intensity levels.
2. Selecting the activity monitor	Pedometers, uni- and multiaxial accelerometers, multisensor activity monitors.	The choice of activity monitor is based on the physical activity variable to be assessed, but also on evidence on reproducibility (intra- and inter-monitor reliability), validity (criterion and concurrent validity) and feasibility (cost, required expertise and acceptability)
3. Placement of activity monitor	Waist, wrists, chest, legs, feet, arms	The activity monitor may be constructed for an optimal placement, but in many cases there can be several options. The choice of placement is based on what signals are to be registered and how they best are captured for the activities monitored.
4. Selecting days of wear	3-8 days (including weekend)	The number of days of wears needs to cover the variability of the physical activity. Children generally need more days of ware compared to adults. After data collection one can calculate the number of days needed for a reliable estimate of habitual physical activity.[199]
5. Selecting epoch length	1-15 seconds or 1 minute	An intermittent physical activity pattern seen in children may need shorter epoch length. The choice of activity monitor is based on the sample frequency and memory capacity to be able to capture the expected movement pattern.
6. Selecting intensity thresholds, algorithm	Time spent in moderate (3 METs) or high (6 METs) physical activity; energy expenditure	For some activity monitors thresholds or algorithms for physical activity intensity and energy expenditure are published. The thresholds or algorithms should only be applied on subjects as similar as possible in characteristics as the subjects where they were developed from.
7. Defining wearing-time	10-12 hours, >60% of time awaken, >80% of time awaken	The quality of the collected data depends on the time that the subject actually wore the activity monitor. Hence, it is necessary to define minimal wear requirement for a valid day.
8. Performing calibration of physical activity monitor	Indirect calorimetry or doubly labelled water as reference methods; activities represent free-living.	The selected activities should mimic free-living as much as possible. Suggested statistical methods for simple accelerometer counts are mixed modeling regression allowing for repeated measures or receiver operator characteristics (ROC). For signal patterns received from multisensor monitors more complex models are used, e.g. branched equation modeling or artificial neural network.
9. Performing test of reliability and validity of physical activity monitor	Indirect calorimetry and doubly labelled water as criterion for energy expenditure for single activities and for free-living, respectively.	Intraclass correlation (ICC) for intra- and inter-monitor reliability. ICC≥0.70 is rated as “good”. Sensitivity/specificity or correlation together with t-test/Wilcoxon’s test can be used for validity. The Bland-Altman plot combined with the correlation between energy expenditure level and activity monitor error may complement or replace the numerical statistics. A mean error of ≤5% with a standard deviation ≤5% may be considered as good accuracy, while a mean error of 5-10% with a standard deviation of 5-10% may be considered as acceptable.

Another question concerns the accuracy of using activity monitors in clinical settings. In Sweden, FYSS was created to ensemble all available knowledge of the preventive and treatment effect of physical activity on different diseases into one handbook, supporting the medical service with practical recommendations for patients to attain better health.[221] A product of this work is Physical Activity on Prescription (FaR®) which is practiced more and more in the medical service. These important events are milestones also for introducing physical activity and energy expenditure assessment in routine medical service. The requirements put on the methods for this purpose are high *reproducibility*, high *precision (validity)* at individual level and high *feasibility* (Table 2). *Can these requirements be met by the modern activity monitors?* The next section will try to answer these two questions.

Enjoyment…

The progression of activity monitors

Uniaxial activity monitors

Large Scale Integrated Motor Activity Monitor

The first activity monitor for epidemiological purposes that went through a more thorough evaluation of reproducibility (intra- and inter-monitor reliability), validity and feasibility was the Large Scale Integrated (LSI) Motor Activity Monitor.[108, 135, 136] However, the validation was performed with energy expenditure from logged physical activity.[108] At the size of a wrist-watch it consisted of a cylinder with a mercury ball which came in contact with a mercury switch during body movement. These studies indicated high reproducibility and feasibility. Also, the LSI counts were related to energy expenditure when attached to the waist ($r=0.69$, $p<0.01$) but not to the ankle ($r=0.43$, $p<0.07$).

Caltrac

The LSI was soon challenged by an uniaxial (vertical) accelerometer in a study where measured oxygen consumption was used as criterion.[142] The output of the accelerometer followed the relationship $f=ma$ (f=force, m=mass, a=acceleration) and able to predict oxygen consumption.[219] The accelerometer, when attached to the waist, was a large improvement compared to the LSI when related to oxygen consumption.[142] This accelerometer was made commercial available through the Caltrac Personal Activity Computer and again compared to the LSI in both adults and children using observed physical activity as criterion.[100] The Caltrac counts showed higher correlation to intensity ($r=0.81$, $p<0.01$) compared to the LSI counts ($r=0.65$, $p<0.01$) in adults. However, both monitors showed considerable lower ability to predict the physical activity intensity in children. The authors speculated whether the monitors were unable to capture the movement pattern in children characterized by short bursts. Subsequent studies, where the Caltrac estimated energy expenditure (manufacturer's algorithm) was compared directly to energy expenditure from direct and indirect calorimetry in both children and adults, revealed that the Caltrac overestimated energy expenditure for moderate physical activity/walking but did not respond to higher running speeds than 8 $\text{km}\cdot\text{h}^{-1}$.[13, 28, 78, 153] Also, the Caltrac was of limited use to assess an individual's physical activity level because there were large individual errors. An algorithm for predicting energy expenditure from the Caltrac counts was developed from treadmill walking.[13] In this study the standard error was considerable lower compared to the study by Montoye et al where a variety of activities were used.[142] This indicates that if an activity monitor is going to be used to record physical activity under free-living, it has to be calibrated in a variety of activities.

ActiGraph

In 1994 the Computer Science and Applications, Inc. (CSA) activity monitor (uniaxial) was introduced in the scientific literature.[90] Although it showed similar accuracy as the Caltrac in predicting energy expenditure, it turn to be the most investigated activity monitor.[137] Over the years the CSA activity monitor has changed owner and name, through Manufacturing Technology Inc. (MTI) activity monitor to the ActiGraph activity monitor. Whatever name, this accelerometer has provided us with the understanding of the limitations and challenges of objective physical activity assessment. Because energy expenditure has been considered a meaningful variable and also because calorimetry and doubly labelled water have been considered the criterion methods to be validated against, great effort was put on deriving algorithms predicting energy expenditure from monitor counts. Early studies performed calibration of the CSA during treadmill walking and running and assessed the linear relationship between monitor counts and energy expenditure from indirect calorimetry.[68, 137, 200] However, these algorithms may work well in ambulatory activities but not in activities where there is little or no vertical acceleration.[17, 80] Also, there are different relationships between monitor counts and energy expenditure for different activities. Hence, no single algorithm accurately predicts all activities. In activities with higher metabolic rate but without vertical acceleration (e.g. strength exercise) other sensors may be needed to detect this. Later calibration studies have included multiple activities and have also been performed under free-living conditions.[60, 62, 129, 155, 161, 181, 197] From validation studies including some of these algorithms it can be concluded that an energy expenditure algorithm should only be used in similar age-groups and activities from which it was derived, an uniaxial accelerometer is not able to capture all movement pattern and energy expenditure algorithms are not useful at individual level.[1, 60, 149, 164, 175, 201, 212]

Triaxial activity monitors

Tritrac and RT3

The Tritrac triaxial accelerometer was introduced to be able to capture more movement patterns.[24, 101] An early observation was that Tritrac was able to capture higher intensities not shown by the uniaxial accelerometers.[101] The same result has been investigated in more detail in later studies.[27, 177] During treadmill walking and running the monitor counts from the CSA and its successor the ActiGraph reached a plateau at 9-10 $\text{km}\cdot\text{h}^{-1}$, while the RT3 (the successor of Tritrac) responded to speeds of at least 25 $\text{km}\cdot\text{h}^{-1}$. This is explained by that the vertical acceleration force increases with increased walking speed up to 10 $\text{km}\cdot\text{h}^{-1}$ after which it is constant and does not change with increasing running speed.[34] On the contrary, the horizontal acceleration continues to increase after 10 $\text{km}\cdot\text{h}^{-1}$. Hence, uniaxial accelerometers are improper to use to assess the variety of activity intensities. Although the triaxial accelerometer increased the precision in assessing physical activity, the overall difference in the accuracy compared to uniaxial accelerometers was generally small.[61, 80, 178, 212] However, if the study sample is expected to have a variety of activities and activity intensities it is recommended to use triaxial instead of uniaxial accelerometers to be able to capture more of the variation. Because different activities produces different responses in the three axes and that all relationships are not linear, activity-specific algorithms applying non-linear models may improve the precision of using triaxial accelerometers even further.[32, 37] Still, there was a considerable individual error. The technical development has contributed to faster data processing, higher sampling frequency and larger storing capacity allowing larger amount of data extracted from waist-worn accelerometers. This has made it possible to apply more complex analytical approaches including automated pattern recognition and machine-learning.

Using biaxial data from a waist-worn accelerometer in an artificial neural network model resulted in a mean (sd) accuracy of 96 (4) % in assessing energy expenditure for a variety of activities during a 24-h stay in a room-calorimeter, while the accuracy for the ActiGraph was 83 (7) %.[174] Hence, high precision can be achieved from single waist-worn accelerometers using proper analytical models.

Multisensor activity monitors

Actiheart

Another approach to increase the precision of physical activity monitoring was to combine the output from multiple sensors. When the information from a vibration sensor attached to the thigh and a heart rate monitor was combined into linear or non-linear algorithms the accuracy of assessing energy expenditure for waken time or all 24 hours in a room-calorimeter was 97 (4) % and 97 (5) %.[143, 196] In another study the information from the CSA attached both to the arm and leg was used to discriminate between arm and leg work, applying different linear heart-energy expenditure algorithms.[190] This combination resulted in considerable higher precision compared to using either CSA or heart rate alone. However, the monitor combinations used in these studies decrease the feasibility of physical activity assessment under free-living conditions. A solution came with the Actiheart (the first water-proof activity monitor), combining an accelerometer with a heart rate monitor into a single light-weight (8g) unit attached to the chest.[25] The Actiheart uses a branched equation modeling where the contribution from the accelerometer and the heart rate to the energy expenditure estimate depends on the intensity level and the output from the accelerometer and the heart rate monitor.[26] The Actiheart has been shown to increase the precision in assessing energy expenditure compared to using accelerometry or heart rate monitoring alone.[47, 223] In children, the accuracy for a 24-h stay in a room-calorimeter was 99 (9) %.[223] The Actiheart has not yet been evaluated under free-living conditions.

ActiReg

The ActiReg was introduced in 2004 combining motion sensor with body position sensor to predict energy expenditure.[85] The development started in the early 1990s and applied similar technique as the LSI monitor, i.e. mercury switches. Hence, the ActiReg is not an accelerometer but records the number of movements per minute. The two sensor-units are attached to the chest and to the right thigh. Thin, flexible cables connect the sensors to a storing unit attached to an elastic belt around the waist. The mean intensity per minute is calculated and stored, and is used together with body position and resting energy expenditure (calculated or measured) in the software ActiCalc to calculate energy expenditure. In the algorithm for energy expenditure PAR-values are used for the different body positions depending on the intensity level (see Paper IV summary box page 20).[64]

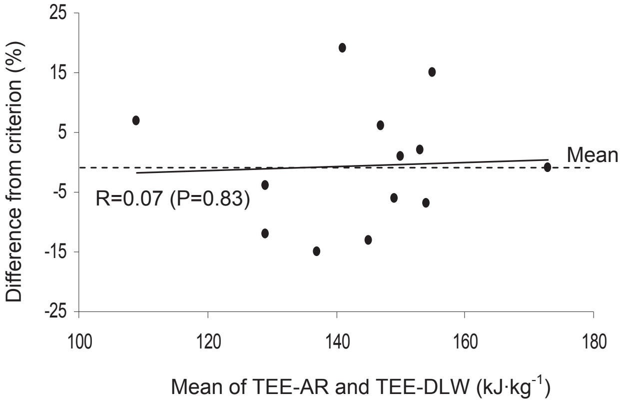
In the attempt to prevent malnutrition in patients with chronic obstructive pulmonary disease (COPD) we used the ActiReg together with measured resting energy expenditure to assess the energy requirement of these patients. Before that, a validation study of the ActiReg was performed under free-living conditions using doubly

Paper I, ActiReg

Aim
To validate the ActiReg under free-living conditions in patients with COPD.

Methods
-13 COPD patients
-7 days ActiReg
-Measured BEE
-14 days DLW as criterion.

Main findings
The mean (sd) accuracy of the ActiReg was 99 (10) %. (P=0.69). No significant correlation (R=0.07) between the difference and mean of TEE-AR and TEE-DLW.



labelled water as criterion **(I)**.[11] COPD patients may be a heterogeneous group concerning their physical activity level.[188] Hence, including physical activity assessment may better capture the variation in energy requirement than just measuring resting energy expenditure. Indeed, resting energy expenditure explained 52% of the variation in total energy expenditure but adding also physical activity assessment explained another 16% of the variation.[11] The accuracy of assessing total energy expenditure was 99 (10) %. Although good agreement at group level, there was considerable variation at individual level. It has been shown that the ActiReg underestimated energy expenditure in individuals with a higher physical activity level.[39, 85] The same error was not observed in our study. This difference in results was explained by that the physical activity level of the COPD patients was not as high as in the subjects in the other two studies.

In children, it was shown that the ActiReg has an upper level of assessing activity intensity at 8 km·h^{-1} **(III)**.[9] This explains why the ActiReg underestimates energy expenditure in individuals with a high physical activity level. However, in the same study it was also shown that the ActiReg largely overestimates energy expenditure at moderate intensity. Although, this error does not depends on the sensors but rather the energy expenditure algorithm. In the algorithm the activity intensity is divided into three intensity levels. For the highest intensity level, moderate-to-vigorous physical activity level, the PAR-value 5 has been applied which causes the overestimation of energy expenditure. We attempted to recalibrate the algorithm to better predict energy expenditure for moderate intensity. This was performed in 11-13 years old children during treadmill walking and running using indirect calorimetry as criterion for energy expenditure **(IV)**.[12] These children represented the average age of the 9-16 years old children in a larger study where the ActiReg was used to assess physical activity **(V)**.[7] Hence, the goal was to apply the new algorithm in any of the ages 9-16 years. The calibration study resulted in a new cut-point for moderate physical activity and a considerable improvement in the prediction of energy expenditure.[12] The new algorithm put more weight on the intensity output from the ActiReg and diminished the effect of the PAR-values. The ActiReg with the original and the new algorithm was validated in 14-15 years old children under free-living conditions using doubly labelled water as the criterion for energy expenditure.[12] The accuracy using the original and new algorithm was 93 (13) % and 99 (11) %, respectively. The limitation of detecting high intense physical activity was more evident with the new algorithm. The correlation between the error (%) and the physical activity level changed from -0.43 (P=0.056) to -0.51 (P=0.021). Hence, the sensors need to be sensitive to a wider intensity range before the ActiReg can accurately assess children's physical activity. Also, the crude algorithm together with the low storing frequency may not be adequate to capture the variety of movement pattern seen in children.[14, 150, 176]

Intelligent Device for Energy Expenditure and Activity

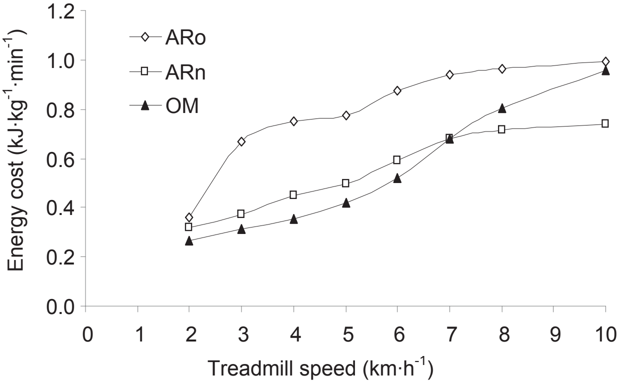
There has been a vast interest in developing devices that are able to recognize and classify movement patterns, activities and postures since the 1990s.[5, 30, 63, 79, 94, 98, 107, 118, 119, 127, 128, 147, 157, 174, 220] The goal has not only been to assess energy expenditure more accurately but also for example tracking activity patterns during rehabilitation or monitoring daily activities in elderly. The results of this development have often been presented in more technical oriented journals. These devices are either single- or multisensors (e.g. mini-accelerometers), may combine fast microprocessors with large

Paper IV, ActiReg

Aims
To recalibrate the algorithm for energy expenditure and validate it under free-living conditions in children.

Methods
-Calibration during treadmill walking and running in 20 11-13 years old children.
-14 days ActiReg in 20 14-15 years old children.
-Indirect calorimetry (OM) and DLW as criterions.

Main findings
New algorithm (ARn) improved EE assessment compared to original algorithm (ARo), but the ActiReg has a limited ability to detect high intensity.

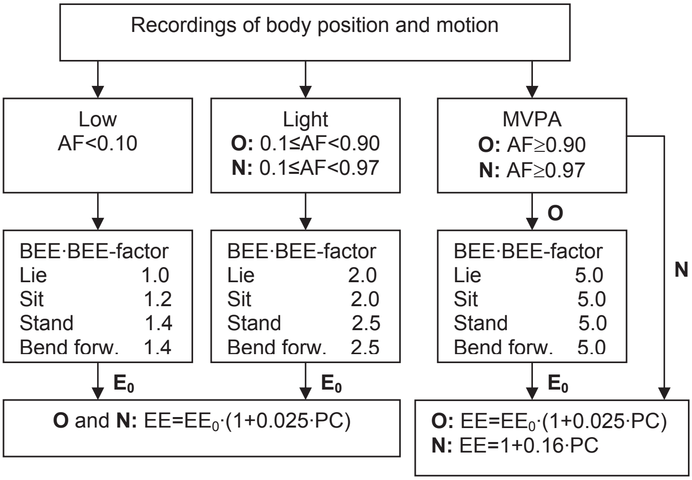


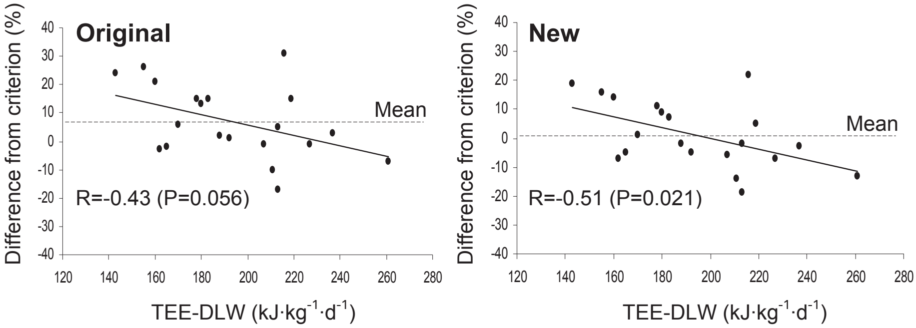
Paper IV, ActiReg
Continues

Main findings
Under free-living conditions the new algorithm (N) improved the accuracy at group-level compared to the original algorithm (O), but the limitation of the ActiReg to register high intensity became more obvious.

Activity Factor (AF) and Position Changes (PC) are measures of intensity by the ActiReg.

Original (O) and new (N) algorithm





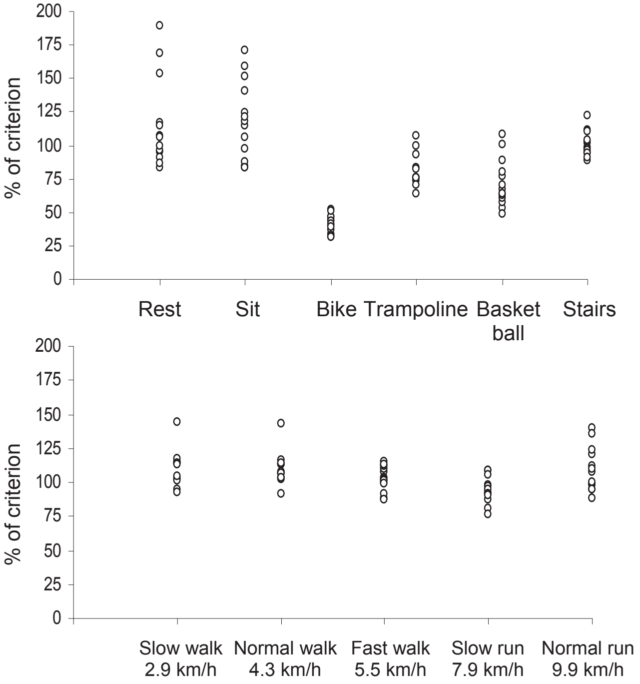
storing capacities, can detect both static and dynamic activity, use more sophisticated data-analyzing methods (e.g. artificial neural network) and explore the field of artificial intelligence. The Intelligent Device for Energy Expenditure and Activity (IDEEA) may serve as a representative of these devices. Its original version consists of five mini-accelerometers attached to the chest, to both thighs and under both feet. Through thin flexible wires the information is sent to a fast micro-processor worn at the waist where data also is stored on a flash-memory. Through the application of artificial intelligence and neural network it recognizes most activities (not bicycling) and postures with high accuracy.[226] The IDEEA was validated during both inactivity and walking/running on a treadmill using mask calorimetry and a 23-h stay in room-calorimeter for a variety of activities, showing an accuracy of 99 (6) % and 95 (2) %.[225] We performed a validation study in 11-13 years old children during activities of varying intensity with indirect calorimetry as criterion for energy expenditure **(III)**.[9] The mean (sd) accuracy across these activities was 96 (10) %. Although the IDEEA

Paper III, IDEEA

Aims
To validate the IDEEA in children.

Methods
-14 children 11-13 years old performed different physical activities.
-Indirect calorimetry as criterion.

Main findings
The accuracy of the IDEEA varied across the activities but the overall accuracy was
96 (10) %



showed high accuracy under controlled settings, but with higher individual error in children, it has yet to be validated under free-living conditions. However, its design may make it less feasible monitoring daily physical activity and may be more useful for analyzes within clinical settings.

SenseWear Armband

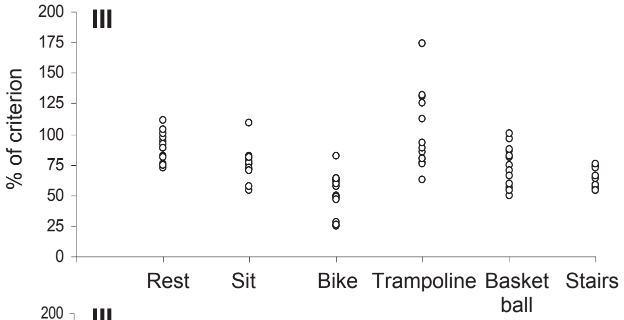
Although the ActiReg, the IDEEA and other activity monitors using motion sensors may serve the purpose of assessing the physical activity level, they do not directly detect the metabolic variation of the body and hence, not optimal to assess total energy expenditure. In some patients where the illness/disease has induced abnormal metabolism this may be important. If this metabolic variation only affects the resting energy expenditure (e.g. inflammatory processes) it can be assessed by calorimetry and be included in the energy expenditure algorithm of the activity monitor (e.g. ActiReg). However, if the illness/disease affects other components included in the total energy expenditure this variation is left undetected by motion sensors. For example, a higher inflammatory response to exercise was observed in muscle-wasted patients with COPD compared to non-muscle-wasted COPD patients and healthy subjects in.[204] Also, there may be a variation in mechanical efficiency in this patient group, although there is a limited amount of research to confirm this.[158] Obese patients endures respiratory complications like a heightened demand for ventilation, elevated work of breathing, respiratory muscle inefficiency and diminished respiratory compliance.[154] Hence, in both patient groups there may be metabolic variation during exercise not covered when assessing physical activity using motion sensors.

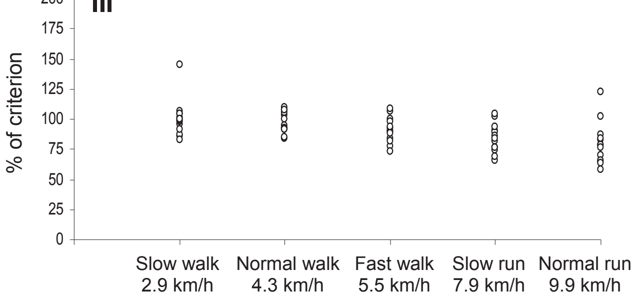
Paper II-III, SenseWear

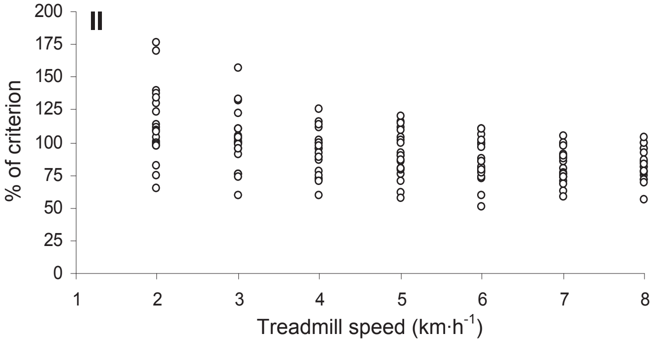
Aims
To validate the SenseWear Armband in children.

Methods
-20 **(II)** and 14 **(III)** children 11-13 years old performed different physical activities.
-Indirect calorimetry as criterion.

Main findings
The accuracy of the SenseWear Armband varied across the activities but the overall accuracy was 81 (11) % and 85 (8) %. There was an increased underestimation with increasing intensity.







The SenseWear Armband combines sensors for body temperature, heat flux, the galvanic response of the skin (sweating) and motion into one device worn as an armband around the upper arm. Through the use of machine-learning and a variety of data modeling techniques (e.g. decision tress, neural network) the signal patterns of individual activities are recognized and an activity-specific algorithm for energy expenditure is applied.[6] According to the manufacturer the SenseWear Armband was accurate for subjects between 7 and 65 years old who are engaging in resting, ambulatory, stationary biking, motoring and weight-lifting (Manual in SenseWear Professional Software 6.1). The SenseWear Armband showed higher accuracy in assessing energy expenditure compared to other common activity monitors, including the ActiReg.[21] The accuracy reported for a variety of activities was 91%. The ActiReg showed an accuracy of 79% in this study. Both monitors underestimated energy expenditure at higher intensities and showed large individual errors.

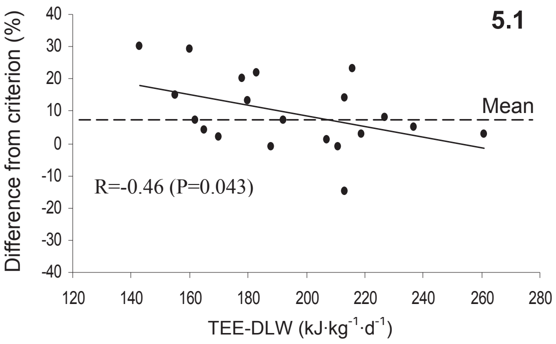
We investigated the accuracy of the SenseWear Armband for a variety of activities including walking and running in 11-13 years old children **(II-III)**.[9, 10] The mean accuracy across all activities in the two studies was 81 (11) % and 85 (8) %. Although calibrated for stationary bike, the accuracy was only 50 (15) % for this activity when data from the two studies were pooled (n=33). Large error for stationary bike was also shown for the ActiReg and the IDEEA. At the time when the measurements were performed the IDEEA was not yet calibrated for bicycling explaining the large underestimation shown for all children. The ActiReg showed a different pattern with both underestimation and overestimation. This was explained by a large variation in the response from the sensor. Because the acceleration force during bicycling is constantly changing direction it limits the use of motion sensors without applying pattern analysis. Across the walking and running intensities the SenseWear Armband showed a continuous decrease in accuracy. This error was confirmed under free-living conditions where the SenseWear Armband underestimated energy expenditure for those children with a high physical activity level **(IV)**.[12] The accuracy was 96 (10) % using the latest version of the energy expenditure algorithms (SenseWear Professional Software 6.1) with a correlation between the error and the physical activity level of -0.70 (P<0.001).

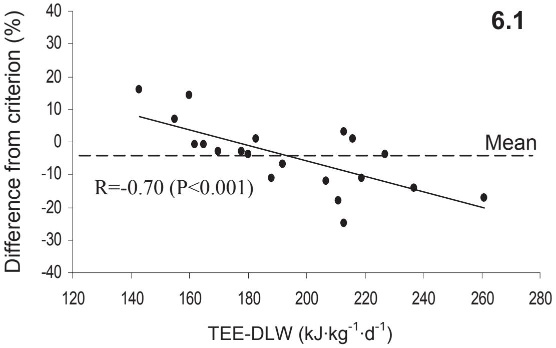
Paper IV, SenseWear

Aims
To validate the SenseWear Armband under free-living conditions in children.

Methods
-20 children 14-15 years old.
-14 days SenseWear and DLW.
-SenseWear Professional Software 5.1 and 6.1.

Main findings
The software version 6.1 improved the accuracy at group-level, but there was a stronger correlation between the error and physical activity level.





Conclusions of the progression of activity monitors

Although the almost exponential increase in the number of studies using objective methods to assess physical activity, we are still left with methodological problems that decrease the accuracy of the physical activity data collected in these studies. These problems concern the limitations of the monitor sensors to detect the variety of physical activity patterns and the translation of raw data to energy expenditure. Together with the fact that it is only during the latest decade that activity monitors have been feasible/affordable alternative to subjective methods for epidemiological research it explains why we have not advanced much further in the assessment of dose-response relationships. Also, the large individual variation in the monitor output for a particular activity and the moderate individual precision for predicting energy expenditure make the activity monitors of limited use today in clinical settings where individual patients are monitored. Here, an accuracy of 95-105 (5) % may be required.

It has been suggested to use only raw data (counts or counts·min^{-1}) to decrease the error introduced in the prediction of energy expenditure. Practically, physical activity and physical activity recommendations are best described by intensity, frequency and duration. This takes a calibration of intensity thresholds against a criterion method. However, one has to choose carefully among the variety of cut-points published. Large discrepancies may occur in attaining the physical activity recommendations when comparing the different cut-points or when applying different epoch-length.[14, 52, 73, 150, 176, 189] Calibration algorithms adjusted for body-size (body weight, height, leg length) may account for some of the variation in monitor out-put between individuals.

The introduction of fast micro-processors, high sampling frequencies and large memory capacities has facilitated the use of more sophisticated data analysis techniques (e.g. artificial neural network) for pattern-recognition. This has improved the use of waist-worn accelerometers. By combining these techniques in multisensor activity monitors we may capture larger variety of physical activities. The ActiReg, the IDEEA and the SenseWear Armband have taken advantage of these techniques but are still in the development stage and are today unable to satisfy the high requirements of being clinical tools. Activity monitors integrating multiple sensors may in the future make it possible for a higher control of inter-individual variations. Even in such a simple activity as walking we need a better measure of intensity to compare individuals of different body size.

In this thesis I have provided a table presenting the activity monitors commonly used in research (Table 1) and some guidelines when performing physical activity assessment (Table 2). It is further recommended to consult the November issue 2005 of Medicine and Science in Sports and Exercise and also the review by de Vries et al before using activity monitors.[53]

…beauty…

Physical activity monitoring in clinical settings

There are many diseases where physical activity and knowledge about the energy expenditure may have importance for the outcome of the disease. For example, improving the glucose regulation in diabetes patients, decreasing the risk of mortality in cardiovascular disease patients, preventing waste of fat-free mass in COPD patients and controlling energy balance and body composition in obese patients. These examples represent the two main contexts of applying physical activity and energy expenditure monitoring in clinical settings: 1) providing energy requirement for adequate nutritional support, and 2) follow-up of the prescription of physical activity for adequate support to a physical active lifestyle. Both contexts follow a common treatment-plan of Treatment goal-Action plan-Action-Monitoring-Adjustment. In the second context the activity monitor may work as a feedback tool to follow-up and facilitate the progress towards the treatment goal.

In the behavior change process towards a physical active lifestyle, there are several important psychosocial factors mediating the effect of an intervention.[18, 112, 115, 121, 185, 217] An intervention needs specifically be designed to target these factors to be really effective. These factors can be categorized into *cognitive* (e.g. self-efficacy, outcome expectancy, enjoyment, perceived barriers, perceived benefits and attitudes), *behavioral* (e.g. goal setting, commitment to planning, stimulus control and counter conditioning) and *interpersonal* (e.g. social support).[115] The relationship between these factors to the physical activity outcome is described in theoretical models like the Social Cognitive Theory or the Trans-Theoretical Model. There has been an increased interest in applying psychosocial theories into physical activity research attempting to explain the success or failure of an intervention by investigating the psychosocial factors.[81, 93, 124, 195] Also, there has been a growing interest in educating clinical practitioners to coaches facilitating the patient's behavioral change process towards a healthy lifestyle.[29, 31, 57, 77, 83, 202, 203, 216, 222] Coaching is a patient-centered approach, a framework integrating different psychosocial theories to provide tools for the clinical practitioners to support individual patients reaching their goals. Indeed, it has been shown that by educating nurses to coaches strengthen their professional competence and the use of coaching strategies was more effective than traditional care in promoting an active lifestyle with improved health.[104, 202, 203] The feedback from an activity monitor may be important for the motivation and adherence to an intervention program.[206] Today, data from modern physical activity monitors can be communicated and presented through web-based solutions, available to both the patient and clinical practitioner. In combination with web-meetings this enables coaching on distance, further facilitating patient-centered health-care.

Children with congenital heart defects

There has been an improved survival in children with congenital heart defects during the last decades, introducing new challenges to the health care.[116, 194] One of these is to provide support to an enjoyable physical active lifestyle. Physical training interventions seem to increase the physical activity and aerobic fitness in children with congenital heart defects.[67] This has been the case also for those children with more complex congenital heart defects.[167, 168] Apart from the improvements in physical performance, there have also been positive effects on self-efficacy, behavior and emotional state. Hence, it is recommended to promote a physical active lifestyle in all children with congenital heart defects, with special attention being given to patients with more complex heart defects.[82] However, there seems to be an overprotection of children with congenital heart defects and a restrictive approach to exercise may be practiced by pediatric cardiologists.[15, 166] Self-efficacy, rather than the severity of the congenital heart defect, was the most important factor for physical activity, and it was affected by the recommendation of the cardiologist and the attitude of the mother.[15] Hence, individual recommendations should be based on direct assessments and follow-ups of the exercise capacity of the child in conjunction with a feedback system for self-regulation of the physical activity level. This may give the patient and his/her parents better control and security of performing proper amount of physical activity. Feedback from a heart rate motor was shown to be a suitable approach to define the physical activity level at individual level.[16]

A suggested coaching system in clinical settings may consist of: 1) exercise testing together with other investigations to determine heart function/capacity; 2) translation of the results to a recommendation by the cardiologist (e.g. the physical activity intensity should not exceed 160bpm); 3) the patient is referred to a coaching nurse or a physiotherapist who provide the support for meeting the recommendation (e.g. implementing the use of a heart rate monitor for a limited time-period for the patient's self-control; the clinic may provide Actiheart to their patients); 4) the physical activity/heart rate recordings can be communicated through internet and be used by the nurse or physiotherapist as part of their coaching strategies; and 5) a follow-up with exercise testing together with other investigations to confirm any changes in heart function/capacity for adjustment of the recommendation.

There have only been a few investigations of physical activity and fitness in children with congenital heart defects to determine whether their physical activity level differ from healthy children.[65, 66, 117, 141] Fredriksen et al showed that the physical activity level in children with congenital heart defects was lower compared to healthy controls in boys but not in girls.[65] They also showed that the aerobic fitness was lower in the patients for both genders.[66] They used the uniaxial CSA accelerometer to assess physical activity. An interesting finding in their study was that the aerobic fitness in patient boys declined at the age of 12-13 years, while it slightly increased in the healthy boys. There may be several explanations for this. First, the increased physical demands in sports by age may bring about an elimination of individuals with low aerobic capacity from competitive sports and vigorous physical activity. Because boys usually engage more frequently in high-intense sports than girls, the largest difference in aerobic fitness may appear between patient boys and healthy boys in older children. Secondly, although randomly chosen the voluntary controls may be those who are interested in and with a high amount of sports. This may occur also in the patients, but there are other factors as well that make them participate (e.g. parents´concern). Thirdly, the random sample of children with congenital heart defects may include those with other dysfunctions (e.g. Down's syndrome, neurological) or in a need of reoperation. Lunt et al investigated self-reported physical activity in children with congenital heart defects.[117] In their study children with acquired cardiac conditions, intellectual or physical disabilities, or very severe cardiac illness had been excluded. They found that fewer patient boys engaged in vigorous physical activity compared to their controls, but that the total physical activity was similar for patients and controls. Because subjective methods to assess physical activity are influenced by the perception, attitude and self-efficacy to the performance of physical activity, and these may differ between children with congenital heart defects and healthy children, this may bias the results. Although differences in methods and study sample, there were similarities in the results between the studies by Fredriksen et al and Lunt et al. There is a large variation in exercise capacity and physical activity depending on the severity of the congenital heart defects which takes different amount of support for an enjoyable physical active lifestyle.[66, 141] An oxygen uptake lower than 30 $\mathrm{ml{\cdot}kg^{-1}{\cdot}min^{-1}}$ is reported for univentricular palliated children.[141]

Study of physical activity, sports participation and aerobic fitness

To assess the need of interventions to support a physical active lifestyle, we performed a cross-sectional study of physical activity, sports participation and aerobic fitness in children who have undergone surgery for congenital heart defects at the Queen Silvia Children's Hospital **(V)**.[7] We were interested in children with completed surgery for congenital heart defects and with no other physical or mental dysfunctions that would interfere with normal physical activity. They belong to the group of patients where the medical care has been successful and may be expected to attain normal physical activity. Hence, we excluded those with anticipated surgery (reoperation) within a year, occurrence of chromosomal aberrations (e.g. Down's syndrome) and/or neurological dysfunction. All children, 9-11 and 14-16 years old, fulfilling the inclusion criteria, living in Gothenburg with surroundings were contacted. Healthy controls were recruited from randomly selected schools in Gothenburg.

According to studies of physical activity in healthy children using accelerometers the number of days needed for a reliable estimate of physical activity showed a variation between 4-8 days.[199] Hence, we included seven consecutive days to capture normal variation and used the activity monitor ActiReg. As a quality insurance of the collected physical activity data we required at least 80% wearing-time all days during waken time. Compared to other studies presenting the wearing-time we applied stricter criteria.[126] Waken time and time when the ActiReg was attached to the body was assessed from a diary. Aerobic fitness was assessed by measuring gas exchange breath-by-breath during a continuously incremental exercise test until maximal performance on a stationary bike. An individually adapted protocol for maximal exercise test was used for warm-up, start load, increase in load (ramp) for a predicted duration of 8–12 minutes, and recovery.[95] The subject was instructed to keep a pedal rate of 60 rpm during the whole exercise test. The criteria for maximal performance were: 1) termination because of exhaustion or unable to maintain the pedal rate despite encouragement to continue; 2) a heart rate ≥ the predicted maximal heart rate; and 3) a respiratory exchange ratio of > 1.

There has been a long debate concerning how to properly adjust metabolic rate for difference in body size.[70, 172, 209, 224] The most common way has been to use the simple ratio standard ($VO_2 \cdot kg^{-1}$). However, the consensus is to use allometric models that construct power functions with exponents other than 1.0. The body mass powers 0.67 and 0.75 ($kg^{-0.67}$ and $kg^{-0.75}$) have been suggested to more correctly adjust for differences in body size. Although these powers have been shown to adjust for differences in body size,[172, 224] their universal use for all activities and intensities has been criticized and a higher value for maximal performance has been suggested.[70, 209] Because no study have investigated the power function for maximal performance on a stationary bike, the lack of consensus of the power to body mass for maximal performance, and the simple ratio standard is commonly used in clinical settings, we decided to present the results from the exercise test in our study as $VO_2 \cdot kg^{-1}$.

The participating patients represented the variety of congenital heart defects found among the total number of eligible patients.[7] Generally, children with congenital heart defects show similar physical activity level as healthy children, although among younger girls the patients showed a significant lower physical activity level compared to their controls. However, this difference was not considered of clinical importance because the patients were still considered as being moderately physical active according to the physical activity levels defined by FAO/WHO/UNU.[64] This is in contrast to the study by Fredriksen et al where the patient boys, but not the patient girls, showed lower physical activity level compared to the controls.[65] In contrast to the results from the physical activity assessment, there was a tendency of a higher amount of sports participation in the controls and the aerobic fitness was higher in the controls in the older age-group, especially in the boys, compared to the patients. The aerobic fitness results confirm the results presented by Fredriksen et al.[66] Still, the patients in our study were considered as having moderate-to-high aerobic fitness according to reference values in children,[186] and their rate of sports participation was high in comparison to other studies,[20, 193, 214] 80-94% were doing sports at least once a week and 29-79% more than once a week.

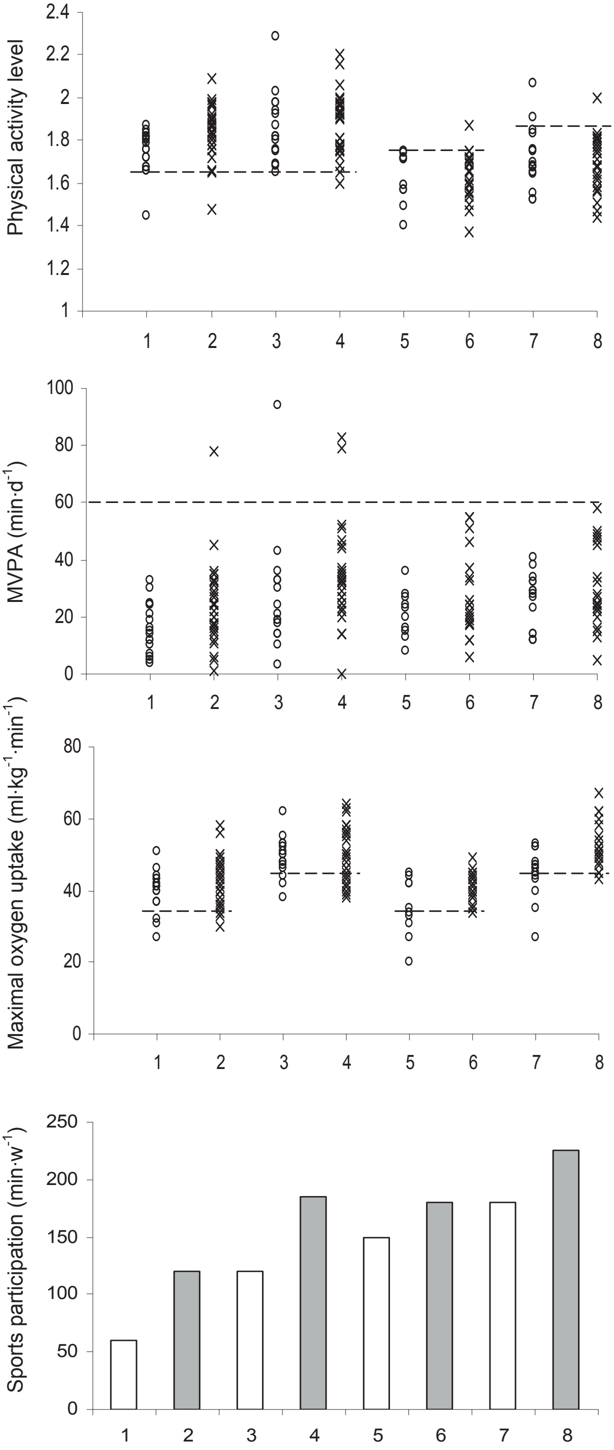
The difference in aerobic fitness may have several possible explanations. First, the increased physical demands in sports by age will eliminate those children with lower physical capacity from participation. Secondly, there was a considerable drop-out and the drop-out rate was higher among the controls, especially among older children. This may lead to differential selection bias including those children interested and highly involved in sports, explaining differences in for example aerobic fitness between patients and controls. There may be other factors influencing the participation rate in the patients, e.g. the concerns of their parents. Despite the difference in aerobic fitness between older patients and controls, this was not reflected by any difference in the physical activity, neither in the physical activity level nor in the time spent in moderate-to-vigorous physical activity. The physical activity does not explain all variability in aerobic fitness. It was shown in children that the correlation between physical activity assessed by accelerometry and measured maximal oxygen uptake reached only 0.3.[54] Another explanation may concern the ability of the ActiReg to

Paper V

Aims
To investigate physical activity, sports participation and aerobic fitness in children who have undergone surgery for congenital heart defects.

Methods
-7 days physical activity using the ActiReg.
-Participants were interviewed about sports participation.
-Maximal exercise test on stationary bike with measured oxygen uptake to assess aerobic fitness.

Main findings
Children who have undergone surgery for congenital heart defects showed similar physical activity level as healthy controls. However, they tended to have lower sports participation, and among older children, especially in boys, they showed lower aerobic fitness. Still, their sports participation was considered high and their aerobic fitness moderate.



9-11 years
1=patient girls (n=17)
2=control girls (n=31)
3=patient boys (n=15)
4=control boys (n=30)

14-16 years
5=patient girls (n=10)
6=control girls (n=21)
7=patient boys (n=15)
8=control boys (n=24)

Dashed lines are moderate levels for physical activity level[64] and maximal oxygen uptake[186] and recommended time of moderate-to-vigorous physical activity[191].

Sports participation is presented as the median.

capture the all variation of physical activity intensity. We showed that the ActiReg in its present form has a limitation in registering vigorous physical activity, causing an underestimation of total physical activity in highly active children.[12] If the controls in the older age-group were more physical active than the patients, the ActiReg failed detect this. Because the error of the monitor is the same for the patients, we are unable to confirm this hypothesis.

Another finding was that only a few children attained the recommendation of 60 minutes daily of moderate-to-vigorous physical activity. The mean time of this physical activity for all children was 26 minutes. Although this may be a true result,[169] the low value may also be the consequence of the storing frequency of the ActiReg. It stores the average intensity of all physical activity each minute. This resolution is too low to capture the intermittent physical activity pattern with short bursts of high-intense physical activity.[14, 150, 176] The physical activity will be classified as light contributing to the relative high total physical activity observed among the younger children, but the time spent in moderate-to-vigorous physical will be low. The possibility of reaching the recommendations also depends on the calibrated cut-points for moderate-to-vigorous physical activity. Because the cut-points are age and body-size dependent, there can be large discrepancies in results depending on choosing an appropriate cut-point or not.[73, 189] The ActiReg was calibrated in 11-13 years old children and applied to 9-11 and 14-16 years old children in the present study. The ActiReg registers the number of movements per minute as a measure of intensity. Shorter individuals take more steps for a particular speed and hence, reach higher ActiReg ouput compared to taller individuals. Taking more steps leads to a higher energy cost, explaining why children have a higher energy cost per kg body weight compared to adults at the same walking/running speed.[130, 131] Hence, size-specific calibration algorithms need to be developed. Because patients and controls showed similar body weight and height, the use of a general cut-point for moderate-to-vigorous physical activity may not affect the comparison between these groups. However, it will affect the inter-individual comparison and the comparison between younger and older children. Hence, one needs to be cautious when drawing conclusions about who did reach and who did not reach the physical activity recommendation.

VO_2max in patients who have undergone surgery for more complex heart defects has been reported to be less than 30 $ml\cdot kg^{-1}\cdot min^{-1}$,[141] which is considered as being a low aerobic fitness level.[186] Some of the patients in our study showed low aerobic fitness, among them two girls with univentricular palliation. They did not do any sports at all. However, there was a patient with univentricular palliation showing moderate aerobic fitness. This patient practiced soccer and had a moderate physical activity level. Hence, individual prescriptions of physical activity and exercise based on follow-ups of exercise capacity and physical activity monitoring (direct feed-back) within a systematic coaching strategy may support children with a variety of congenital heart defects to enjoy a physical active lifestyle.

…passion…

Conclusions

- Subjective methods have limited abilities in quantifying the dose of physical activity requiring the assessment of intensity, frequency and duration.

- Physical activity recommendations are based on crude methods to assess physical activity which does not allow a sufficient detailed dose-response relationship.

- Objective methods to quantify physical activity have developed from simple motion-sensors using simple data-analyzing techniques to more sophisticated multisensor devices applying artificial intelligence to recognize patterns and individual activities.

- Simple activity monitors show limited abilities in detecting the variation of physical activities, but in combination with other sensors and/or by using more sophisticated data analyzing techniques their accuracy can be improved. Also, body-size adjusted calibration algorithms may better account for the large inter-individual variation in monitor output.

- The more sophisticated multisensor activity monitors have large potential for a more precise estimate of physical activity and energy expenditure. However, they need further development before reaching a high level of accuracy.

- Because objective methods are in the development stage concerning reliability, validity and feasibility, they have not contributed much to the progress of the dose-response research. This also explains the limitation of using activity monitors in clinical settings, where a high precision is needed for accurately assessing physical activity and energy expenditure in individuals.

- The ActiReg combines the registration of body position and movement to assess physical activity and energy expenditure. By using the original algorithm it overestimated moderate physical activity in children. Through the newly calibrated algorithm this error was improved. However, like the commonly uniaxial accelerometers it has an upper limitation in registering physical activity intensity at 8-10 km·h^{-1}.

- The Intelligent Device for Energy Expenditure and Activity (IDEEA) combines multiple mini-accelerometers with artificial intelligence and neural network to recognize specific activities for a closer estimate of physical activity. Although it showed a relatively high accuracy in children, it is not feasible for free-living and it has not yet been evaluated under free-living conditions.

- The SenseWear Armband combines different types of sensors integrated into a single device worn around the upper arm. By using machine-learning and different data modelling techniques it recognizes the signal pattern of individual activities and applies activity-specific algorithms to assess physical activity. It showed moderate accuracy in children and an error that was related to the physical activity intensity. However, it is a feasible instrument in children.

♥ Previous studies in children with congenital heart defects have shown that they have lower aerobic fitness compared to healthy controls, especially in boys and at older ages, but a difference in physical activity was noticed only in boys. We showed that the difference in aerobic fitness was larger among older boys. There was a tendency of lower amount of sports participation in the patients, although their sports participation was considered high compared to other studies. However, children who have undergone surgery for congenital heart defects showed similar physical activity as healthy controls.

♥ There is a large variation in physical activity and aerobic fitness in children who have undergone surgery for congenital heart defects. Some of the patients need support for choosing a physical active lifestyle. This support may be improved by follow-up and feedback from activity monitoring and exercise-testing.

…and the natural spontaneity are cornerstones
of the true inspiration of life: love.

Acknowledgements

A common form of composing music during the classical period (1750-1825) was the *sonata* which divided a movement into three sections called *exposition*, *development* and *recapitulation*. The first section presented the main themes which were elaborated and contrasted in the second section, and resolved in the final section. The sonata form was acknowledged the resemblance to the human life with its opportunities, challenges and solutions. In my sonata there are important elements (significant persons) that have contributed to the different sections and to the movement of the main contrasting themes in my life: music and natural sciences. These extraordinary persons I would like to acknowledge:

My parents **Kjell and Ing-Marie Arvidsson** lay the foundation for introducing the two themes and have always been of wonderful support to my interests of exploration. Without you I would not have been exposed to the opportunities and faced the challenges. Without you I would not be where I am today.

I have had three contrasting but eminent supervisor during my doctoral education. Professor **Lena Hulthén,** my main supervisor, has a fire that never stops. You always believed in me, even at times when I was doubtful myself. Above your vast knowledge and experience in nutrition shared with me, there are two qualities that I have appreciated very much: you always had time for me when there was no time, and your open-mindness that I discovered during our more personal discussions. I enjoyed the dinner at Hos Pelle.

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Associate professor **Jan Sunnegårdh**, my clinical supervisor, brought me into the challenges of congenital heart defects and physical activity, and provided me with new exciting knowledge and experience. We shared the interests in sports and music (piano), but you never realized the suggestion of bringing an electrical piano to your office (I know that you really wanted it). However, we experienced Chopin together at the Chopin museum in Warsaw. Thank you for an exciting time together at the bike.

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The music has contributed to challenging the obstacles of life with enjoyment, beauty, passion and spontaneity. It is wonderful to observe these qualities in other persons. I remember my music-teacher **Inga Petrén-Hansson** who exuded such energy in her profession. You always told me that I will never stop playing the piano. Mozart´s Symhony 40 had an impressive effect on me (thank you for that music-tape). Many thanks to you and to all the wonderful piano-teachers in my life.

I was inspired to bring up my piano-playing again after 13 years of sleep by a wonderful woman that personifies the integration of enjoyment, beauty, passion and spontaneity. **Patricia Olaya**, you have a special place in my heart.

Codetta

By completing this thesis I end a great sonata with wonderful themes combined into harmony. A new sonata starts tomorrow. However, there will always be old, gilding elements…

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