MEASURING ACTIVITY IN ADULTS WITH CEREBRAL PALSY

MEASUREMENT OF BODY POSTURES AND MOVEMENTS IN ADULTS WITH CEREBRAL PALSY

By

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TITLE: Measurement of Body Postures and Movements in Adults with Cerebral Palsy

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ABSTACT

Aim: To determine the criterion validity of the Activ8[a] and VitaMove[b] activity monitors (AM) in measuring body postures and movements (P&M) in adults with spastic cerebral palsy (CP) with different gross motor functional abilities in a simulated free-living environment.

Methods: In this observational validation study participants were included between March and June 2016. Participants were divided into two groups: ambulatory and non-ambulatory adults (wheelchair users). For ambulatory adults, three Activ8 monitors (attached to the frontal thigh, lateral thigh, and in the pant pocket) and three synchronized VitaMove monitors (attached to the chest and each leg) were worn while participants were video recorded when performing a standardized activity protocol. For non-ambulatory adults, two synchronized Activ8 monitors (attached to the dominant wrist and wheelchair wheel) and three VitaMove monitors (attached to the chest and each wrist) were worn while participants were video recorded when performing a standardized wheelchair protocol. A native Dutch student provided standardized instructions while the author video recorded participants. Activities were performed in a movement laboratory and simulated free-living environment. Output data of the Activ8 and the VitaMove monitors were compared with video observation as a criterion measure. Absolute and relative time differences were calculated for each detected body P&M and for total measurement time for each participant. The following body P&M categories were detected: sitting, standing, walking, running, cycling, wheelchair driving, active upper body (stable wheelchair), and assisted driving. Agreement between the Activ8 and VitaMove during activity measurement was determined for each activity using Spearman Rho correlation coefficients, which were then compared with Meng's test. Adapted Bland-Altman plots were completed to determine agreement at an individual level and Wilcoxon Signed-Rank tests were calculated to evaluate differences between detected P&M time across measures. Relative time differences of <10% between measures were indicative of acceptable validity.

Results: Fifteen adults with spastic CP [10 men; mean(SD) age, 35.7(13) years; Gross Motor Function Classification System distribution: level I (n=6), level II (n=5), level III (n=3), level IV (n=1)] were included. For ambulatory adults (n=14), criterion validity of the Activ8 at the lateral thigh location during basic and complex daily life activities was moderate to good (average relative time differences: 0.25% for sitting, 4.69% for standing, 2.46% for walking,

3.19% for cycling, and 1.96% for light-to-moderate upright activity), except for running (34.6% average difference) The criterion validity of the VitaMove was acceptable, with the exception of standing and running (average relative time differences: 1.69% for sitting, 12.3% for standing, 4.84% for walking, 9.70% for cycling, 23.8% for running, and 0.91% for light-to-moderate upright activity). Spearman Rho correlation coefficients were significantly greater between video/lateral thigh Activ8 than video/frontal thigh Activ8 and video/pant pocket Activ8 for P&M categories sitting, basic standing, basic walking, and light-to-moderate upright activity ($p<0.01$ for all). Moreover, Spearman Rho correlation coefficients were significantly greater between video/Activ8 than video/VitaMove for basic walking and light-to-moderate upright activity P&M categories ($p<0.01$). In non-ambulatory, wheelchair users (n=3), the Wheelchair Activ8 demonstrated greater validity than the VitaMove monitor, when compared to video observation, for the detection of sedentary upper body and active upper body behaviours.

Conclusion: The Activ8, positioned on the lateral thigh, demonstrates adequate validity as a tool for monitoring of body P&M during free-living activities in ambulatory adults with spastic CP. The Activ8 demonstrated superior validity as a direct measure of body P&M compared to the VitaMove AM. The sample size of non-ambulatory adults was small (n=3) and allowed for descriptive and exploratory analysis only; therefore, validity of the Wheelchair Activ8 for has to be further examined in a larger number of participants.

Clinical relevance: The Activ8 and Wheelchair Activ8 shows promise as a clinical measurement tool of physical behaviour for adults with CP across GMFCS levels I-IV. The Activ8 could be used in the future development of health promotion initiatives, due to the features of goal setting and user feedback, while providing researchers greater insight in activity data than consumer-grade AMs.

Suppliers:

a. Activ8, trademark of Remedy Distribution Ltd. (original equipment manufacturer is 2M Engineering Ltd.), John F Kennedylaan 3, 5555XC, Valkenswaard, The Netherlands
b. VitaMove, 2M Engineering Ltd., John F Kennedylaan 3, 5555XC, Valkenswaard, The Netherlands

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TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

ADC	Analog to digital converter
AM	Activity monitor
CALO-RE	Coventry, Aberdeen, and London – Refined
CP	Cerebral palsy
CRP	C-reactive protein
CSV	Comma-separated values
CVD	Cardiovascular disease
eNOS	Endothelial nitric oxide synthase
FIFO	First in, first out
GMFCS	Gross motor function classification system
HBM	Health belief model
HDL	High-density lipoprotein
HOMA	Homeostatic model assessment
HPA	Habitual physical activity
IL	Interleukin
MEMS	Micro-electrical-mechanical system
MET	Metabolic equivalent of task
MVPA	Moderate-to-vigorous intensity physical activity
PA	Physical activity
P&M	Postures and movements
SB	Sedentary behaviour

CHAPTER 1 - LITERATURE REVIEW

Introduction

Cerebral palsy (CP), the most common cause of physical disability in children, is a neurological condition that affects the development of posture and movement (1,2). As a result, CP can affect an individual's functional motor ability over the lifespan, restricting the performance of daily physical activity (2–4).

Physical activity (PA) and sedentary behaviour (SB) play an important role in the physical health and functioning of adults with and without disability (5–8). In particular, decreased PA and increased SB have been reported to pose risks for negative health outcomes in adults, notably increased risk for cardiovascular disease (CVD) and early mortality (9,10). To mitigate the possible health consequences of inactivity, clinicians are encouraged to prescribe exercise and promote PA to patients with and without chronic health conditions as a preventive health measure (11–13). Promotion of PA is particularly important for adults with CP, as they have low levels of habitual PA (HPA), increased SB, and reduced cardiorespiratory health (14–18).

Knowledge of physical behaviour patterns is essential for clinicians to effectively promote PA and limit SB in patient populations (5,13,19). Although both direct and self-report measurement tools of physical behaviour exist, each has associated limitations (20). Self-report measures tend to underestimate true PA, often due to poor interpretation by the respondent and recall bias (20). Conversely, direct measurement tools, such as

activity monitors (AMs), are considered more robust and sensitive, as they are able to detect incidental daily movement and low intensity activities (20). The utility of AMs can stem beyond a one-day assessment of fitness. Often used to assess physical behaviour over extended periods of time, AMs play an important role when evaluating the effects of lifestyle intervention programs (21,22). AMs, which contain accelerometers, are objective in nature and can provide appropriate measurement of HPA in a natural setting, including meaningful activities of daily living such as personal care, home management, and functional mobility.

The recently developed Activ8 Physical Activity Monitor (Remedy Distribution Ltd., Valkenswaard, The Netherlands) offers a novel objective method to measure PA. The main difference with other consumer monitors is that it provides information on distinct body postures and movements (P&M). In addition, the Activ8 is unobtrusive and cost-friendly, offering potential use in rehabilitation research and clinical settings. Activ8 users have the ability to view their recorded time spent in PA and SB on a personal computer through the visually appealing dashboard (https://www.activ8all.com/app-dashboard/). In addition, researchers and clinicians can add a coaching account, providing insight into his/her patients' physical behaviour. Furthermore, features such as goal setting and an integrated feedback system may compel users to maintain a healthy and active lifestyle. These features could act as a "booster strategy" in future intervention studies, to help maintain lifestyle program effects beyond the intervention period.

Preliminary evidence for validity of the Activ8 AM in healthy adults exists (unpublished observations, see reference 23). However, for individuals with atypical gait or movement patterns, like those with CP, the validity of the device to detect unique body P&M needs to be determined before extending its use in larger research studies or in the clinical setting.

1.1 HEALTH PROMOTION

Preventive health and health promotion have long been focal point of public health and medicine in general, as preventive measures are seen to improve the well-being of individuals while remaining economically sustainable for the healthcare system (24,25). Participation in health initiatives that promote PA is fundamental for the maintenance of metabolic health and the prevention of major chronic diseases, particularly cardiovascular and metabolic diseases (8–10).

1.1.1 Health Belief Model

The Health Belief Model (HBM) is a prominent theory in medical research to evaluate and predict health behaviour, and has been used to design health initiatives that promote preventive health action (26–29). Health behaviour is defined as the activity undertaken for the purpose of preventing disease or detecting it in an asymptomatic stage (30). The HBM was developed by a group of social psychologists from the U.S. Public Health Service in the 1950s, including researchers Rosenstock, Hochbaum, and Kegels (31,32). The theoretical origins of the HBM are attributed to Lewinian tradition, which proposes that behaviour depends upon two variables: the value placed by an individual on a

particular outcome and the individual's estimate of the likelihood that a given action will result in that outcome (33).

The HBM suggests that whether an individual will undertake a recommended health action is dependent upon that individual's perceptions of their personal *susceptibility*, the degree of *severity* of the adverse health condition, the potential *benefits* of the health action in preventing or reducing susceptibility and/or severity, and the *barriers* (including physical, psychological, financial, or others) to the health action (26). Furthermore, the HBM contends that *self-efficacy* of the acting individual also influences the resulting health behaviour and that *cues to action* must occur to stimulate the health action (26). *Cues to action* is a largely unexplored construct. The HBM purports that prompting an individual through external stimuli, such as consultations, posters, or other general calls to action through the use of technology like a text message, will promote engagement in beneficial health action (26).

1.2 PHYSICAL BEHAVIOUR

Physical behaviour is a catch-all term that encompasses both PA, including HPA and exercise, as well as SB (34). PA encompasses a broad range of movements and has been generally defined by the National Institutes of Health as any body movement that uses skeletal muscles and requires more energy than resting (35). SBs, such as sitting during commuting, in the workplace, or during leisure time, are defined as any waking behaviour consisting of low levels of energy expenditure (<1.5 METs) while in a sitting or reclined position (36–39). As a comparison, moderate-to-vigorous intensity PA

(MVPA), such as bicycling or jogging, requires an energy expenditure of 3-8 METs and can be completed in a number of body positions (36,39). MET stands for Metabolic Equivalent of Task and is a physiological measure expressing the energy cost of activities (40). One MET is equal to the amount of oxygen consumed while sitting at rest or 3.5 ml O_2 / (kg of body weight)*(min) (40). To date, evidence has revealed that all types of SB are associated with lower levels of PA in adults, supporting the notion that SB replaces light intensity PA (41).

The health risks of inactivity and SB, independent of MVPA time, are becoming more evident (42). In fact, a recent systematic review has demonstrated strong evidence suggesting a causal relationship between inactivity, SB, and all-cause mortality (42). The latest Canadian Physical Activity Guidelines, released in 2011 by the Canadian Society for Exercise Physiology, suggest adults accumulate at least 150 minutes of MVPA per week in order to reduce adverse health risks and achieve health benefits (43). The health benefits of increased HPA and decreased SB have been well established (5,9,13,44) and are discussed in more detail below. When discussing future directions of Canadian Physical Activity Guidelines, Tremblay *et al.* note that future research should focus on the relationship between activity, fitness, and cardiometabolic health across the lifespan (43). Furthermore, they state that new guidelines may need to specifically address the unique needs of persons living with chronic conditions (43).

1.2.1 Physical Behaviour and Cardiometabolic Health

A large amount of research has examined the relationship between physical behaviour and morbidity in adults (9,13,45). In particular, PA is a primary modifiable risk factor for CVDs (e.g. coronary artery disease, myocardial infarction, and stroke), sarcopenia, obesity, type-II diabetes mellitus, and other chronic conditions (9,44–48). Furthermore, prolonged sedentary time is negatively associated with cardiometabolic risk factors, such as waist circumference and serum biomarkers, including C-reactive protein (CRP), interleukin-6 (IL-6), and leptin (49,50). Most individuals that develop CVD experience multiple symptoms. A cluster of interrelated conditions related to the risk of developing CVD and diabetes is called metabolic syndrome and include hypertension, hyperglycemia, dyslipidemia – such as abnormal levels of high-density lipoprotein (HDL) cholesterol, total cholesterol, and triglycerides – and excess body weight (51). CVD and diabetes are the first and fourth most prevalent non-communicable diseases worldwide and account for approximately 19.3 million deaths per year (52). As such, the World Health Organization has called upon health clinicians and researchers to better understand and effectively reduce CVD and diabetes (52).

Using the Canadian PA Guidelines (150 minutes of MVPA per week) as a benchmark, Tucker and colleagues showed that adults who did not meet these guidelines had significantly greater odds of developing metabolic syndrome than those who did meet the guidelines (OR=2.2) (45). The beneficial cardiometabolic health effects of increased HPA and reduced SB has been shown in numerous patient groups (11,13,44,53), and could not be overstated. Promoting PA and reducing sitting time are sensible intervention

targets to improve the cardiometabolic health in high-risk populations. A 4-year prospective study in persons with type II diabetes mellitus revealed that increased SB led to increased waist circumference, whereas increased MVPA reduced systolic blood pressure (54). While studying a large cohort of US adults, a regression analysis revealed that MVPA was significantly associated with cardiometabolic risk factors including waist circumference, body mass index, triglycerides, and HDL cholesterol (55). Healy *et al.* found detrimental linear associations between increased sedentary time and HDL cholesterol, triglycerides, and homeostatic model assessment (HOMA) of insulin resistance and beta-cell function. In addition, Healy's publication reported that breaks in sedentary time were beneficially associated with waist circumference, CRP, and fasting blood glucose (49).

Many clinicians and researchers have been targeting high-risk patient groups with exercise interventions and training programs. A meta-analysis of randomized control trials evaluating the effects of exercise training on cardiometabolic health showed that exercise significantly improved cardiorespiratory fitness and positively influenced levels of serum biomarkers (56). Compared to controls, exercise training led to a weighted mean difference of -5.31 mg/dL in triglycerides, 2.32 mg/dL in HDL cholesterol, 18.3 pg/mL in IL-18 (a pro-inflammatory cytokine), and -0.30 for HOMA-insulin resistance, all of which beneficially modify risk of developing CVD and diabetes (56).

1.2.1.1 Biological Mechanism of Physical Activity on Cardiometabolic Health 101

Exercise and HPA affect the body in a number of ways. Not only will PA improve respiratory fitness and muscle strength (44), but exercise is known to induce metabolic adaptations within skeletal muscle, through biochemical cascades such as peroxisome proliferator-activated receptor γ co-activator 1α (PGC-1α), leading to mitochondrial biogenesis and improved oxidative capacity (57,58). Furthermore, exercise produces a short-term, local inflammatory response; CRP and other inflammatory markers such as IL-6 increase immediately after exercise (59). However, both cross-sectional and longitudinal studies evaluating exercise training and HPA have demonstrated a long-term, systemic, anti-inflammatory effect (59). Reports of serum biomarkers, such as CRP, taken from active adults at rest have been markedly lower than inactive counterparts (59). Serum CRP, sampled at rest, has even been used to assess the physical behaviour of adults; logistic regression analysis revealed the odds of an adult with average and high CRP (0.1-0.3 mg/dL and >0.3 mg/dL, respectively) meeting the PA guideline recommendations were 41% and 64% less than an adult with low CRP (<0.1 mg/dL) (60). This is particularly noteworthy since inflammation is involved in the pathogenesis of CVD, by contributing to the atherosclerotic process and endothelial dysfunction (61). In addition to decreasing levels of inflammatory cytokines, PA improves vasodilation capacity through increased expression of endothelial nitric oxide synthase (eNOS) (62). Nitric oxide, which is produced by eNOS, helps regulate vascular tone, platelet aggregation, leukocyte adhesion and other crucial endothelial functions (63).

1.2.2 Physical Behaviour and Secondary Health Consequences

Improved physical behaviour has also been associated with secondary health consequences such as quality of life resulting in improved mental health, better management of pain and fatigue, and greater social participation (64–68). A study including 7725 Canadian adolescents found that much larger percentage of active adolescents reported having very good to excellent mental health than inactive peers. Inactive adolescents had two times greater odds of sub-optimal self-reported health (general health). Moreover, adolescents exceeding two hours of sitting time per day had 30-50% greater odds of reported sub-optimal mental health (69). However, when evaluating the relationship between mental health outcomes and PA among children and adolescent cohorts, Biddle and Asare (64) reported evidence that PA interventions have had little effect in reducing anxiety; the authors do note, though, that the evidence is limited. They go on to report that PA leads to improved cognitive performance, academic achievement, and short-term improvements in self-esteem. The evidence has consistently reported adverse effects of sedentary behaviour on mental health outcomes (64). In the general adult population, a systematic review found consistently positive associations between PA level and health-related quality of life (70).

The benefits of PA have also been shown to reduce symptoms of pain, fatigue, and depression in specific clinical cohorts. A Cochrane review published earlier this year reported beneficial effects of PA interventions in adults with chronic pain, including persons with rheumatoid arthritic, fibromyalgia, spinal cord injury, and low back pain (65). Of the 21 reviews evaluated, 18 studies reported statistically significant changes in

usual pain after intervention. Furthermore, studies reported favorable changes in mental health outcomes and quality of life, with small to moderate effect sizes (65). In adults with schizophrenia, PA reduced symptoms of schizophrenia and depression and led to improved aerobic capacity and quality of life (71). The numerous benefits have also been noted for adults with multiple sclerosis including improved fatigue, depression, cognitive function, quality of life, and ambulation (66). There is a strong, dose-response relationship between PA and fatigue. After synthesizing the evidence evaluating this relationship, Puetz (67) reported the odds that active adults experienced feelings of fatigue or low energy are 39% lower than sedentary peers.

There are also social benefits of participating in HPA and sport (68). Club-based or team-based sports are associated with improved psychological and social health outcomes, perhaps as a result of the social nature of participation. Furthermore, PA and sport of any kind leads to improved self-reported well-being, reduced stress, and can lead to greater better self-awareness (68).

The beneficial effects of HPA and reduced SB seem to be endless. Unfortunately, despite clear evidence supporting increased HPA and decreased SB, many adults are still not meeting the recommended activity guidelines and lead highly sedentary lives (72,73). One issue may be the limited awareness of the PA guidelines; a survey of Canadian adults found only 13% were aware of the guidelines, which was significantly related to the respondents' level of HPA (72). A commonly noted issue with research programs, such as exercise training and lifestyle interventions, is that positive health effects often

are not maintained beyond the intervention period itself (53,74–77). Researchers may need to re-evaluate such programs to determine more effective modes of activity promotion and find ways to better engage patients in HPA (77,78).

1.2.3 Assessment of Physical Behaviour

In order to evaluate the current physical behaviour of persons with a chronic condition and/or to assess the effectiveness of an intervention on HPA and SB, it is important to implement a valid measurement tool of physical behaviour. Though countless self-report and direct measures of physical behaviour exist, researchers need to carefully choose one that is appropriate to use within their population of interest and consider the parameters of physical behaviour that they wish to assess (34,79,80).

In a systematic review by Prince *et al*., 173 articles were identified in which both self-report and direct measures of PA were used. A scatter plot of correlation coefficients between self-report and direct measurement tools illustrates a range of correlations (-0.7 to 0.99), with the majority falling around a low-to-moderate correlation of 0.5 (20). Recent findings also suggest that self-reported sitting time is only weakly correlated with objectively measured SB in adults (81). Prince and colleagues suggest that if a self-report and direct measurement tool possess good agreement and measure the same parameter of PA, the cheaper and less invasive self-report would be an appropriate substitute for direct measures (20). However, direct measures are generally considered more robust and, as such, have been suggested to be used when possible (20,82,83).

1.2.3.1 Self-Reported Physical Behaviour

Self-report measures, often called subjective measures, include general PA diaries, 7-day recalls, or frequency questionnaires such as leisure time PA questionnaire (20). Most data supporting the relationships between HPA, morbidity, and mortality have been obtained using self-report methods (44). Many of these measures have shown reasonable validity and reliability for determining activity type, amount, and intensity. For example, a study evaluating physical behaviour of Canadian adults reported the Physical Activity Adult Questionnaire demonstrated reasonable validity when compared with AM-derived MVPA data based on correlations, absolute time differences, and the percentage of respondents who met the Canadian Physical Activity Guidelines (84). Typically, self-report measures perform better on a group level than for individuals, as some measures lack the sensitivity to detect change in activity at an individual level. One of the major benefits with self-reports is the ability to gain insight on activity type, location, as well as context. Furthermore, self-reports are relatively cheap and easy to implement in almost all patient populations (85).

There are several limitations that researchers must consider when implementing a self-report measurement tool. Correlations between self-report and objective measures of physical behaviour are moderate to weak ($r<0.5$), both in healthy adults (20) and adults with chronic conditions (86). To evaluate agreement between self-report and direct measures of PA, Steene-Johanessen and colleagues evaluated MVPA in nine different European countries using the Recent Physical Activity Questionnaire, the International Physical Activity Questionnaire, the European Prospective Investigation in Cancer and

Nutrition Physical Activity Questionnaire, as well as the Actiheart AM (direct measure). Using the Actiheart as the criterion measure of PA, the pooled estimates of agreement (Cohen's kappa coefficients) between self-reported and Actiheart-derived PA were poor, ranging from 0.07 to 0.19 (87).

Over-reporting of PA and under-reporting SB on self-report measures have been associated with social desirability (88). A systematic review by Adamo *et al*. revealed that self-report measures, in comparison with the direct measure of activity monitoring, led to an overestimation of PA time by 114% in boys and 584% in girls (83). When using a 7-day PA recall measure, Adams *et al.* reported energy expenditure was overestimated by 0.65 kcal/day and activity duration was overestimated by more than 10 minutes per day (88). The magnitude of the gap between self-report and direct measures must be a result of either a widespread social desirability bias or inaccurate measurement by AMs.

Another possible reason for poor agreement between self-reported and direct measures of PA is a poor shared understanding between respondents and researchers of essential terms like "habitual physical activity", "moderate intensity", or "leisure time" (79). As a result of these limitations, several authors have stated that caution should be taken when interpreting self-reported physical behaviour (85,86,88,89). Therefore, researchers have encouraged the use of valid, objective methods to assess PA (20,82,89).

1.2.3.2 Direct Measures of Physical Behaviour

Direct measures, also referred as objective measures, of physical behaviour include indirect calorimetry, doubly labeled water, AMs (including both pedometers and accelerometers) and heart rate monitors (20). All offer a unique approach to assess physical behaviour. Indirect calorimetry and the doubly labeled water technique are often cited as criterion measures of energy expenditure (83,90–93). Though AMs can provide estimates of energy expenditure, they are primarily used to evaluate an individual's physical behaviour in terms of body postures (e.g. sitting, standing), body movements (e.g. walking, cycling), or time within various activity intensities (e.g. sedentary, light, moderate-to-vigorous intensity PA) (20,83). With the commercialization of pedometers and accelerometers, the ability of AMs to measure physical behaviour during activities of daily living in natural life settings has improved considerably (94). Though one study in 1949 implemented a pedometer to evaluate the walking load of women attending college (95), research implementing AMs as measurement tools of physical behaviour accelerated in the mid 1990's (96–98). Over time, devices have become smaller, require less power, and storage capacity has increased.

As of November 2016, 414 models of consumer physical AMs were available on the market (94). According to a survey released in January 2015, 1 out of 10 US adults wear a consumer AM (99). Researchers from the Netherlands compared 10 consumer-grade AMs with the activPAL (PAL Technologies Ltd, Glasgow, UK), a research-grade AM, in healthy adults to detect steps in free-living situation. They found that 8 of the 10 AMs

demonstrated good or adequate validity, with mean absolute percent errors ranging from (-7.9 to 3.7%; <±10% was deemed acceptable) (100).

One of the advantages of consumer AMs over research-grade AMs is that data can be collected and transferred frequently and easily to a smartphone or website. They offer the possibility of continuous assessment of physical behaviour over long periods of time (months or even years). Moreover, these AMs are relatively cheaper in cost. As a result, they are being used more frequently in research programs (94). Current consumer-grade AMs also have the ability to offer users feedback. A number of studies have reported that feedback generated by consumer AM brands on their website, such as Fitbit, was associated with positive health action (101,102). In a 16-week program for postmenopausal women, feedback on the Fitbit website was more effective at motivating women to engage in PA than simple step information provided by a pedometer (101). In another study, user feedback, through an online website or via a smart phone app, was associated with an increased likelihood to log >10,000 steps per day over a 90-day study period compared with those who did not receive this feedback (102). "Wearable" technologies such as AMs, with direct-to-consumer portals, align with behaviour change theories (101), are well accepted among study participants (90), and can possibly bolster PA interventions.

Research-grade AMs, however, provide raw data, unique insight into physical behaviour patterns, and greater flexibility with activity data interpretation. Furthermore, though consumer AMs have shown good validity in detecting steps, the ability to measure

MVPA or energy expenditure is in question. Lee, Kim and Welk have reported intriguing results after evaluating the validity of both consumer- and research-grade AMs to estimate energy expenditure compared when compared to a portable indirect calorimeter. The mean relative difference values ranged from 9.3 to 23.5% between AM-derived and calorimetry-derived energy expenditure during free-living activity, with the best results for the BodyMedia FIT and Fitbit Zip (103). These results, however, are in conflict with the growing body of literature in this field.

In a recent systematic review including 28 studies, Jeran, Steinbrecher, and Pischon (104) aimed to determine if monitor or study characteristics influenced the association between AM-derived energy expenditure (research-grade AMs) and doubly labeled water-derived energy expenditure. Crude R^2 values ranged from 0.04 to 0.8. This means 4 to 80% of the variance in the univariate model comparing AM-derived and doubly labeled water-derived measures of energy expenditure is due to AM characteristics, including the monitor attachment position on the body, the recording period, and the output metric. Though sample size was the only study parameter that was significantly associated with the crude R^2, these results suggest that procedures of data processing among different AMs contribute to the heterogeneity across studies (104). Another notable systematic review by Evenson, Goto, and Furberg evaluated the research evidence pertaining to FitBit and Jawbone AMs (90), the two leading consumer-grade brands in the US (105). Several studies included in the review reported relatively high validity for the detection of steps. These monitors, however, frequently overestimated MVPA and underestimated energy expenditure, leading to overall low validity for measurement of physical

behaviour outcomes, despite having high inter-device reliability (90). Therefore, AM-derived energy expenditure estimates from both research-grade and consumer-grade monitors need to be interpreted with caution.

Further research on the consumer-grade monitor Fitbit has reported that after a one- to two-week measurement period, the Fitbit significantly underestimated the proportion of time participants spent in sedentary and light intensity activity by 20 and 34%, respectively, when compared to a research-grade AM (106). The valid detection of step counts but poor measurement of other activity outcomes is also supported by Ferguson *et al*. who reported absolute time differences between consumer- and research-grade AMs in the detection of MVPA ranging from 26 to 298% (107).

1.2.3.2.1 Accelerometer Technical Details

Most direct measures of physical behaviour detect acceleration with a micro-electrical-mechanical system (MEMS). Piezoelectric ceramic sensors were the first MEMS accelerometer introduced into the field of activity monitoring as early as 1981 (108). In addition to piezoelectric sensors, current monitors are based on piezoresistive and capacitive technology (109). In most publications regarding accelerometers in medical applications, capacitive sensors are used because they are more accurate than piezoelectric and piezoresistive sensors (110).

The principal behind activity measurement with a MEMS capacitive accelerometer is by measuring the effect of acceleration on a seismic mass, which is part of the MEMS

(109,110). The seismic mass is a suspended silicon weight held within the conductive MEMS circuit containing capacitors; the mass forms one plate of a plate capacitor. This seismic mass will move in response to gravitational and accelerative forces. When the seismic mass moves, the distance between capacitor plates will change, resulting in a change in capacitance. Capacitance is measured as

$$C = \varepsilon_r * \varepsilon_0 * A/d$$

where C is capacitance, measured in farads, ε_r is the dielectric constant (a measure of permittivity of the material between the two plates), ε_0 is the electric constant ($\varepsilon_0 = 8.85 \times 10^{-12}$ Fm^{-1}), A is the area of the plates, in meters squared, and d is the distance between plates, in meters. As a result in change in capacitance, the electrical output, measured as a voltage, of the conductive circuit will change. Many AMs use an analog signal to measure acceleration, allowing acceleration to be recorded continuously. For monitors that detect body P&M, relatively static electrical output signals correspond with static positions (e.g. sitting, standing). Changes in electrical output signals refer to dynamic movements (e.g. walking, running). The electrical output signal is then amplified and digitized with an analog to digital converter (ADC). Digitization allows for quantization of sampled signals into discrete, unsigned digital numbers proportional to the voltage output. A 14-bit ADC digitizes sampled signals into one of 2^{14} levels (i.e. 16 384 levels). Lastly, the signal is rectified; full-wave rectification converts whole input waveforms to constant polarity, for example (110,111).

The rate at which electrical signals are collected changes between AMs and is referred as the sampling rate. Many accelerometers function by integrating a filtered acceleration

signal over a user-defined sampling interval, which is commonly referred to as an epoch. At the end of each epoch, the summed value (i.e. activity count) is stored in the monitor memory (112). Obeid *et al.* has reported that longer epoch lengths result in more missed minutes of MVPA, in a population of preschool children (113). This finding was also shown in adults (114), and is an important consideration when using accelerometers to assess PA, particularly MVPA .

1.3 CEREBRAL PALSY

One of the earliest published definitions of CP was by Bax in 1964 (115). Today, the most commonly cited definition by Rosenbaum and colleagues describes CP as "a group of permanent disorders of the development of movement and posture attributed to non-progressive disturbances that occurred in the developing fetal or infant brain" (2). CP is a neurodevelopmental condition that is heterogeneous in both etiology and manifestation, leading to variable severity of motor impairment (2). Physiological descriptors of CP are spastic, ataxic, dyskinetic, and mixed, with spastic CP being the most common (116,117).

Today, over 60,000 Canadians live with CP (118). Meta-analysis by Oskoui and colleagues revealed an overall prevalence of CP being 2.11 per 1000 live births (95% CI = 1.98-2.59) (119), making it the leading cause of physical neurodevelopmental disability (1,2). The prevalence of CP changes in relation to birth weight; the prevalence in low birth weight children (<1500g) is significantly higher (60 per 1000 live births) than children weighing 1500-2499g (8.33 per 1000 live births) and children weighing >2500g (1.16 per 1000 live births) (119). Furthermore, the prevalence of CP among children born

before 28 weeks of gestation is significantly higher (112 per 1000 live births) than children born after 36 weeks (1.35 per 1000 live births) (119).

Abnormal gross motor functioning and muscle control are core features of CP (2). To classify severity of CP in a meaningful and functional manner, the Gross Motor Functioning Classification System (GMFCS) identifies five levels of gross motor functioning ranging from "walks without restrictions" (level I) to "self-mobility is severely limited even with use of assistive technology" (level V). Although originally developed and validated for children (120), the expanded and revised version (GMFCS – E&R) has demonstrated good content validity and reliability for describing gross motor ability in adolescents and adults with CP (121,122). With respect to limb distribution, Gorter and colleagues reported that children with hemi- and diplegia were most represented in GMFCS levels I, II, and III, whereas those with tri- and quadriplegia were represented in GMFCS levels IV and V (123). GMFCS level I is the most common gross motor function classification level among children living with CP with a prevalence of 1.3 per 1000 live births, whereas levels II-V averaged 0.3 per 1000 live births (124).

1.3.1 Cerebral Palsy Mortality and Life Expectancy

Morality rates among children with CP have been described in several studies (125). Using extrapolated data published from 17 different studies, Day and colleagues were able to report life expectancy estimates for different cohorts of individuals with CP (125). The life expectancy of children with CP is highly dependent on the number and severity of CP-associated disabilities such as gross motor impairment, intellectual impairment,

and even visual impairment (125–128). Among children with two CP-associated disabilities, 78% survived until adulthood, whereas those with four CP-associated disabilities had a survival rate of just 33% (126,127). Researchers from California reported an improvement in survival over the lifespan; mortality among severely impaired children improved at an average rate of 3.4% per year (129). In 2010, children with severe motor impairments who are tube fed lived an estimated 6.2 years longer than children in 1983 (130). Furthermore, children with CP who reach the age of 20 years old have an estimated 85% survival rate to the age of 50 years, which is comparable to the survival rate of the general population at 96% (131). With high survival rates for those with minor impairment and increasingly better survival for the most impaired (130), virtually all children with CP survive into adulthood. Since the majority of research in CP has been focused on children, researchers have called for more research in adults to better understand how the effects of CP manifest throughout the lifespan (128).

1.3.2 Cerebral Palsy and Functional Decline

A longitudinal study assessing the gross motor function of 657 children found that children classified in GMFCS levels III, IV, and V experience significant functional decline during their adolescence (132). Other researchers have noted that such decline in children is related to muscle strength and weight; independent ambulation is less likely to be achieved as the strength to weight ratio decreases (133). In a cohort of 62 adults, 40% showed a change in their GMFCS classification to a lower level of function compared to when they were 10 to 12 years old (134). A systematic review by Morgan and McGinley supports this finding, reporting more than 25% of ambulant adults with CP experience

ambulation decline, with a higher risk of decline present in those with higher levels of pain or fatigue, bilateral motor impairment, and who are older (135). A recently published longitudinal study following Dutch adults with CP reported the number of adults walking indoors and short distances outdoors significantly decreased over a 14-year period (136). Furthermore, subjective measures show the percentage of adults worrying about their health and being limited in their daily activities as a result of health problems significantly increased (29% and 26% increase, respectively) over a 10 year period (136).

1.3.3 Cerebral Palsy and Physical Activity

Over the past decade, the number of studies evaluating health related physical fitness, HPA, and SB in individuals with CP has grown substantially (137). A recent study evaluating the physical behaviour of young children with CP (aged 1 year 6 months) found HPA to significantly decrease over a 4 year period for those in GMFCS levels III-V, but not those in GMFCS levels I-II (138). In the same study, however, SB significantly increased in all children (138). In cross-sectional studies evaluating fitness and physical behaviour, children with CP have been shown to have low total energy expenditure, decreased HPA and increased SB compared to typically developing children (92,139–141). Children with CP have higher mean resting heart rate values compared to their typically developing peers (141). Furthermore, though total energy expenditure is similar between higher functioning children with CP and typically developing peers, energy expenditure associated with walking is greater in children with CP that have lower

HPA (142). Higher HPA in children with CP has been associated with better biomechanical walking economy (143), and an overall higher motor capacity (144).

Though the majority of these studies pertain to children with CP (92,140,145–149), many researchers are now focusing on the adult population where similar trends are found (14–16,18,150,151). Young adults with CP having moderate to high gross motor function participated in 53% less HPA than peers (139). Adults with more severe motor impairments, classified at GMFCS levels III-V, are significantly less active and more sedentary than their higher functioning counterparts (14). Furthermore, adults who are able to walk without assistive devices, who are younger in age and have positive perceptions of health are more likely to be active (152). Limited walking time is related to physical strain during walking, measured via oxygen uptake with a portable gas analyzer (153). This implies that as gross motor function decreases, adults with CP would have lower HPA and walking time, but greater energy expenditure during walking.

The consequences of this inactivity include long-term negative health consequences such as risk of CVD, metabolic dysfunction, and poor bone density (139). MVPA is markedly reduced in adults with CP and has been associated with traditional indicators of risk including increased waist circumference, systolic blood pressure, and diastolic blood pressure (18,154). Clinicians and researchers agree that HPA and breaks from SB need to be promoted in individuals with CP (12,53). Not only could improved PA and reduced SB decrease the risk of adverse cardiovascular and metabolic health consequences (12,18,155), but active behaviour may also improve secondary health consequences

including management of fatigue (151,156,157), pain (158,159), and social participation (160).

1.3.3.1 Cerebral Palsy and Activity Monitoring

Several different AMs have been used to measure the physical behaviour of persons with CP, each with its own limitations (14,148,161–163). The primary activity outcome of the most popular research-grade AM, the ActiGraph (Actigraph LLC Pensacola, FL), provides time durations that the wearer spends in various levels of activity intensity (109). Such an activity outcome allows one to quantify activity time of a wearer, including sedentary time per day, and can identify whether the wearer achieved recommended activity according to PA guidelines. The issue with such an activity outcome is that the threshold "cut-point" values used to classify measured activity into the various intensity categories have been designed for and calibrated with healthy people. Though reports have validated the use of certain "cut-point" algorithms for use in ambulatory persons with CP (164,165), they may not provide accurate assessment of physical behaviour in non-ambulatory individuals with physical disabilities, such as individuals with CP classified in GMFCS levels III-V (166).

Children with CP have increased energy expenditure compared to age-matched peers who developed typically (92,167), with similar rates of energy expenditure decline observed between groups with growth and age (168). Children with CP have high O_2 uptake during isometric endurance testing and work harder than their peers at a given load, causing them to fatigue more easily during prolonged exercise (169). In a study

evaluating the energy expenditure of walking, children with CP were found to use 53.5% of their maximal O_2 consumption while walking compared to only 22.5% used by typically developing youth (170). The cause of higher O_2 uptake is due to co-contraction of both agonist and antagonist muscles (169,170). Additionally, increased energy expenditure is associated with increased mechanical work, indicating that both the type and severity of CP will influence energy expenditure (171). Therefore, the use of AMs to estimate energy expenditure within the CP population is problematic. Ryan *et al*. compared three AMs (SWA, RT3, and IDEEA) with indirect calorimetry in the measurement of energy expenditure among children and adults with CP. The three AMs had large errors in energy expenditure estimates and mean absolute percent errors of 35.5%, 17.2%, and 16.3% for the SWA, RT3, and IDEEA AMs, respectively. As a result of the inconsistent estimates by all three AMs, the authors stated AMs should not be used to estimate energy expenditure among persons with CP until calibrations of CP-specific equations for each GMFCS level have been completed (161).

Another common activity outcome among AMs is the detection of body P&M and time within a P&M category. One of the first methods to evaluate HPA through detection of body P&M was the Activity Monitor (97,172), a precursor to the VitaMove activity monitoring system. Other AMs that measure activity in this manner, such as the activPAL, have been used in healthy middle-aged adults (173), elderly (174), adults with neurological conditions (175), as well as in persons with CP (163,176,177). Though it has demonstrated reasonable inter-device reliability and concurrent validity (163,176,178), the activPAL provides a rather limited data output, providing sitting, standing, and

walking time, and total step counts. Products like the VitaMove provide much greater insight into physical behaviour, but are much more expensive and burdensome (93).

Not only do researchers need to consider the cost of the device, the cost of the analysis software, the bulk and obtrusiveness of the AM, but also the placement and/or method of attachment (93). Monitors attached to the thigh, ankle, or hip, though quite appropriate for ambulatory persons, may not accurately detect activity among persons with abnormal gait patterns and/or persons who rely on wheelchairs for mobility. To assess activity in these patient groups, researchers may need to be adaptive and creative: attaching monitors to different body/wheelchair locations (179), attaching and synchonizing multiple monitors (173), and/or using custom-made algorithms to analyze data (180). In a systematic review of literature pertaining to activity monitoring in wheelchair users, 19 AMs were identified, 10 of which used custom-made analysis algorithms or were a custom-made device altogether (181). Overall, multi-sensor AMs using default algorithms to estimate energy expenditure had a mean error of -55.3%. Comparatively, the use of custom-made algorithms/devices to estimate energy expenditure resulted in a mean error of only 4.6% and showed an accuracy of 87% in detecting movement. The authors urge future research in this field to better detect and qualify activity movements among manual wheelchair users (181).

1.3.4 Cerebral Palsy and Health Complications

Middle-aged adults with CP are at an increased risk of secondary health complications such as frailty and cardiometabolic morbidities, including diabetes, stroke, and coronary

artery disease (4). Evaluation of traditional risk factors show that waist to height ratio and body mass index were independently associated with indices of cardiometabolic risk including HDL cholesterol and triglycerides (155). Conversely, a cross-sectional study evaluating novel indicators of cardiometabolic risk among adults with CP found values of central pulse wave velocity, a measure of arterial stiffness, to be comparable to the general adult population (182), despite these adults having low MVPA and being highly sedentary. The authors did note that the lack of group differences could be explained by the young mean age of their cohort as well as the small sample size (182).

Regardless of risk indices, adults with CP have significantly higher odds of having chronic conditions than adults without CP (183). Using data collected from 207 615 US adults (including 1015 adults with CP) through the Medical Expenditure Panel Survey, adults with CP reported significantly greater prevalence rates of diabetes (9.2% versus 6.3% for adults with CP and adults without CP, respectively), asthma (20.7% vs 9.4%), hypertension (30.0% vs 22.1%), stroke (4.6% vs 2.3%), emphysema (3.8% vs 1.4%), joint pain (43.6% vs 28.0%), and arthritis (31.4% vs 17.4%) (183). It was later found that the prevalence of multimorbidity was significantly higher among obese adults with CP across GMFCS levels I-III compared with non-obese adults with CP. Also, multimorbidity was significantly higher in non-obese individuals in GMFCS levels IV-V (64.2%) compared with individuals in GMFCS levels I-III (53.6%) (184).

Comparatively, self-reported mental health outcomes have been variable; despite adults with CP reporting low levels of HPA and physical function, they report high social

functioning, low levels of negative mood states and high social support (185). In Dutch study samples, adults with CP reported experiencing significantly greater amount of depressive symptoms than healthy Dutch reference samples. In addition, these adults also reported significantly more musculoskeletal pain and fatigue (186), both of which are commonly reported health issues in this population (136,187). A recently published study by McPhee and colleagues showed fatigue scores were highest in adults within GMFCS level III, suggesting those who use arm crutches and manual wheelchairs experience more fatigue than lower functioning adults who rely on power wheelchairs (156).

Mobility impairment and functional decline has been closely associated with symptoms of pain and fatigue. During a 7-year follow-up study of adults with CP, Opheim *et al.* found that the percentage of respondents who experienced a decline in walking increased from 39% to 52%, and was most common in those with bilateral spasticity (188). This functional deterioration was associated with musculoskeletal pain and physical fatigue, as these symptoms were reported as a health issue by almost double the number of respondents at the end of the 7-year period (188).

1.3.5 Cerebral Palsy and Exercise / Lifestyle Interventions

There are a number of different facilitators and barriers that influence participation in PA for adults with physical disabilities (3). Focus groups with persons with CP identified the following barriers to PA participation: emotional and psychological factors; equipment issues; poor professional knowledge and training issues; perceptions and attitudes of persons without disabilities; policies and procedures at the facility and community level;

and availability of resources (3). Intervention programs addressing some of these barriers and promoting activity have been shown to be feasible in adults with CP, even those with severe gross motor limitations (189).

Unfortunately, to date, exercise and lifestyle intervention programs aiming to promote PA participation among individuals with CP have shown limited success (190–193). Though these programs were able to improve levels of PA and secondary health outcomes during the intervention period, participants returned to their inactive lifestyles and baseline levels of health once the program was completed (190–192). A multicenter randomized controlled trial aiming to stimulate PA in children with CP through a six-month intervention involved motivational interviewing, physiotherapy, and fitness training. Though positive trends were found for parent-reported MVPA immediately after the intervention, there were no significant improvements in HPA post-intervention or at follow-up 6 months later (193). Slaman *et al*. found similar results when implementing a lifestyle intervention for adolescents and young adults with CP; though the intervention was effective in improving aerobic capacity and body composition, the improvements were not retained long-term (191). In ambulatory adults with CP, a 12-week exercise program led to significant positive changes in reports of pain and fatigue following the intervention, but these positive changes diminished during follow-up (194). Researchers have recommended that future studies should explore strategies that foster maintenance of PA participation beyond the intervention period (190,191).

1.4 OBJECTIVES

This review of the current scientific literature has identified CP as a disability that limits activity across the lifespan (2,136). Persons with CP have low HPA and are highly sedentary (16,139), particularly those who with more severe motor limitations (14). As people with CP age, they undergo a notable decline in functioning (135,188), which negatively impacts their health and wellness (136). Not only does this place adults with CP at an increased risk of cardiometabolic disease (44), but may impede on their daily functioning, management of pain, and worsen muscle fatigue (151,188). Lifestyle intervention programs that have aimed at improving activity in adults with CP have shown limited effects, as benefits of the intervention are not maintained beyond the intervention period itself (190,191). Researchers must now look at integrating *cues to action* and booster strategies to help engage these adults in preventive health action, namely HPA. To assess HPA, evaluate activity intervention programs, better understand the health of aging adults with CP, and to characterize the relationships among sedentary lifestyles, mobility impairments and cardiometabolic conditions, it is imperative that valid and appropriate measures of physical behaviour are used. Though several direct measures of physical behaviour exist, there are many limitations associated with their use in this population, particularly when assessing the physical behaviour of those who are wheelchair dependent. Implementation of a novel AM that can validly detect activity, offer users ongoing feedback, and can provide clinicians and researchers remote access to activity data, would be a valuable addition to a lifestyle intervention or clinical practice.

Preliminary evidence for validity of the Activ8 AM in healthy adults exists (unpublished observations, 23). However, for individuals with atypical gait or movement patterns, like those with CP, the validity of the device to detect body P&M needs to be determined before extending its use in larger research studies or in the clinical setting.

Therefore, the objectives of this thesis are as follows:

1.4.1 OBJECTIVE 1

1A) To estimate the criterion validity of the Activ8 AM attached to the frontal thigh in the measurement of body P&M in ambulatory adults with spastic CP (GMFCS level I-III) compared to direct video observation (reference method);

1B) To evaluate the extent that positioning of the Activ8 AM on the thigh or in the pocket affects the criterion validity of the device in the measurement of body P&M in ambulatory adults with spastic CP (GMFCS level I-III) compared to direct video observation (reference method);

1.4.2 OBJECTIVE 2

2A) To evaluate the criterion validity of the VitaMove, a high-end research-grade AM, in the measurement of body P&M in ambulatory adults with spastic CP (GMFCS level I-III) compared to direct video observation (reference method);

2B) To compare the validity of the Activ8 and the VitaMove AMs in the measurement of body P&M in ambulatory adults with spastic CP (GMFCS level I-III) compared to direct video observation (reference method);

1.4.3 OBJECTIVE 3

3) To evaluate the criterion validity of the Wheelchair Activ8 monitor and the VitaMove wheelchair AM in the measurement of P&M in non-ambulatory, wheelchair-dependent adults with spastic CP (GMFCS level III-IV) compared to direct video observation (reference method).

1.5 THESIS STRUCTURE

To structure my thesis, Chapter 1 comprises of all background information. Chapter 2 describes the methods for each objective. Chapter 3 follows a similar pattern, whereby results and interpretations are reported for each objective. Interpretations are presented with the results, rather than in the discussion section, to promote clarity when addressing each individual objective. Chapter 4 is a general discussion of all results, the implications of this research on the field of activity monitoring and rehabilitation, and the limitations of the whole study. Since Chapters 2 and 3 are broken down to address each objective separately, there may be some repetition, since I analyzed data from the same study sample to answer the objectives. However, this is to ensure methods, results, and corresponding interpretations for each objective are distinguishable.

CHAPTER 2 - METHODS

2.1 Methods – OBJECTIVE 1

2.1.1 Participant Recruitment & Eligibility

A convenience clinical sample of fourteen adults with spastic CP [9 men; mean (SD) age, 35.4 (13.1) years] was recruited between February and June 2016. The sample size was based on comparable studies evaluating the validity of an AM in both children and adults with disability (162,163,195). Participants were recruited through physicians from Erasmus MC and Rijndam Rehabilitation in Rotterdam, the Netherlands. In addition, participants of past research studies who had indicated they would be interested in future research studies were contacted by mail and eligibility was confirmed by telephone.

The inclusion criteria for this objective were: ≥18 years of age; diagnosis of spastic CP; ambulatory, with or without the use of assistive devices; and physically able to perform the activities in the assessment protocol. Participants were excluded if they had: disabilities other than CP affecting daily PA; severe cognitive disorder; insufficient comprehension of either English or Dutch to follow instructions for testing, as determined during a screening telephone conversation; or orthopaedic surgery within the past 6 months. All participants gave their written informed consent. The study was approved by the Medical Ethics Committee of Erasmus MC University Medical Centre, Rotterdam, the Netherlands.

2.1.2 Measures

2.1.2.1 Gross Motor Function Classification System – Expanded and Revised (GMFCS – E&R)

Participants' gross motor function was classified by the GMFCS – E&R, which identifies 5 levels of gross motor functioning ranging from "walks without restrictions" (level I) to "self-mobility is severely limited even with use of assistive technology" (level V). Although originally developed and validated for children (120), the expanded and revised version (GMFCS – E&R) has demonstrated good content validity and reliability for describing gross motor ability in adolescents and adults with CP (121,122). Participants were asked to report their own GMFCS level at the beginning of their assessment, based on anamnesis or a self-assessment of gross motor functional ability. Self-reported GMFCS level rating has shown excellent agreement to professional ratings in adults with CP (134).

2.1.2.2 Activ8

The Activ8 Physical Activity Monitor produced by 2M Engineering Ltd (Remedy Distribution Ltd., Valkenswaard, The Netherlands) weighs 20 grams and has dimensions of 34 x 30 x 10 mm (see Figure 1A). It contains a tri-axial, capacitive accelerometer (MMA 8541, Freescale Semiconductor, Denver, USA) and is capable of measuring accelerations ranging from ± 4.0g in magnitude. The Activ8 monitor has a sampling rate of 12.5 Hz and uses a 14-bit analog-to-digital converter to digitize sampled accelerations. The Activ8 monitor then stores digitized acceleration samples using a First In, First Out

(FIFO) data buffer that can hold 32 samples; therefore, each FIFO buffer holds 2.56 seconds of activity data.

Automated analysis of the angular position of the Activ8 monitor, based on the signal from the z-axis accelerometer, as well as the vector magnitude acceleration (from x, y, and z-axes) allows raw acceleration samples to be converted into six distinct body P&M activity classes: non-wear/lying, sitting, standing, walking, bicycling, or running. The monitor was set to record P&M data using a 5-second epoch, the lowest epoch setting available. Each epoch included 8 non-time stamped "points", allowing researchers to determine the specific amount of time each Activ8 class was scored in a given epoch, but not – in the case of two or more Activ8 classes – in which part(s) of the epoch. The Activ8 is unable to distinguish transient lying (<5 minutes) from sitting, as the angular position of the monitor would remain the same for both static postures.

2.1.2.3 Video Observation

A handheld digital video camera was used as reference method for detection of body P&M. Video recordings were analysed by one researcher and scored independently of the Activ8 data output. Using a 1-second time resolution, observed activity was assigned one of the following categories based on pre-defined definitions: non-wear; lying; sitting; standing; standing with movement; walking (including shuffling); stair climbing; running; bicycling; or transfer time. Transfer time was defined as: "the distinct transition from a stable sitting position to a stable standing position (sit-to-stand) or from a stable standing position to a stable sitting position (stand-to-sit)". Please refer to Appendix G

for the full list of P&M definitions and video codes. To allow comparison between measures, the following video classes were merged: lying to sitting; transfer time to standing; and stair climbing to walking. The video class "standing with movement" was considered a grey area between standing and walking.

The following steps were taken to minimize bias when scoring the criterion measure of video observation: 1) each 1-second video frame was coded based on rigid definitions of P&M (see Appendix G); 2) the first video recording was analysed by the author and an experienced researcher - any discrepancies or areas of contention were discussed and a precedent was set for future issues encountered; and 3) any new issues encountered or periods of ambiguous P&M during subsequent video recordings were highlighted and discussed with the experienced researcher until an agreed solution was reached.

A. B.

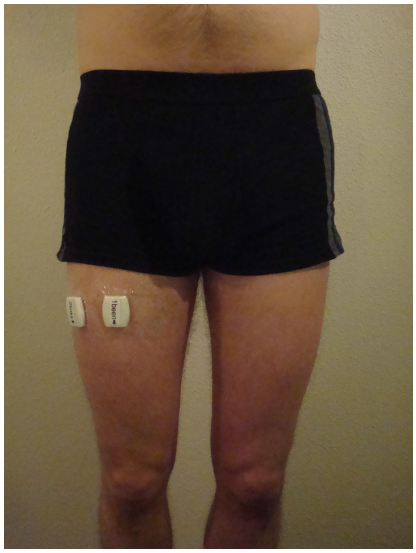


Figure 1. A) The Activ8 Physical Activity Monitor.
B) Lateral thigh and frontal thigh positioning of Activ8 on the leg.
**Frontal thigh is superior to the patella, along the midline of the thigh. Lateral thigh is at the same height, but positioned approximately 2cm laterally from the frontal position.

2.1.3 Monitor Placement on the Body

Participants were asked to wear 3 Activ8 monitors, two taped directly on the thigh with Tegaderm™ skin tape (lateral thigh and frontal thigh locations – see Figure 1B) and one placed in the pocket of the trousers. The Activ8 has been developed for pocket placement, but initial research evaluating the validity of the Activ8 in healthy adults indicated that due to issues regarding varying pocket positions and sizes and the potential for excessive movement, direct attachment to the front of the thigh ($1/3^{rd}$ the length of the thigh as measured from the greater trochanter to the patella) would be more advantageous for use in research (unpublished observations). Therefore, the frontal thigh position was chosen as the primary Activ8 position. A slightly lateral thigh location (unit positioning 2cm laterally from the thigh's midline), which resembles a pocket position more closely, was also used. All three monitors were placed at the side least affected by spasticity, or simply at the right side if there was no difference in spasticity among lower limbs.

2.1.4 Procedure

All participants performed a series of daily life activities according to a standardized protocol in a simulated home environment within the occupational therapy department and human movement laboratory at Erasmus MC, Rotterdam, the Netherlands. The Activity Protocol for Ambulatory Adults (see Table 1) consisted of meaningful activities representative of daily life in individuals with CP, as informed by the literature (150,162,196). This protocol included both basic, involving just one posture or movement, and complex activities, involving a number of P&M (e.g. mopping the floor consists of standing and walking) and was completed in the same order each assessment.

Participants were video recorded for the duration of the assessment, while concurrently wearing the appropriate AMs. Assessment instructions given by a native Dutch student while the author video recorded participants were standardized for all participants and all activities were timed to be 80 seconds duration or less if the activity was completed before then (e.g. stair climbing up two flights varied in duration). All activity start and stop times were noted during measurement, to ensure video and AM measures can be properly synchronized and compared. Participants were closely supervised throughout the assessment to ensure safety. Upon completion of the assessment, the raw accelerometry data as well as the recorded body P&M activity data were downloaded using the professional Activ8 software (Version 2.1.0.22). Please refer to Appendix F for the full measurement protocol.

Continuous Activ8 activity output (5-second resolution) was then compared to the synchronized video observation (1-second resolution). Activ8 epochs do not display the order that numerous body P&M were performed. For example, a 5-second epoch may indicate that 2 seconds were spent standing and 3 seconds were spent walking, but it does not specify whether standing time preceded walking time or vice-versa. Therefore, the whole duration of each performed activity was analysed, after removal of the first and last epoch sample due to the potential overlap of the Activ8 epoch with the start and end time of each activity. An example of the Activ8 data output can be found in Appendix G.

Table 1. Activity Protocol for Ambulatory Adults

Basic Activities
Sitting
Standing
Walking on a flat surface
- normal / comfortable pace
- slower than normal
- faster than normal
Running
Bicycling on a stationary bicycle
- normal / comfortable pace
- slower than normal
- faster than normal
Browsing through a magazine (sitting)
Office work - Typing on a computer (sitting)
Climbing the stairs (walking)
Descending the stairs (walking)
Complex Activities
Donning and doffing a jacket
Mopping the floor
Unpacking and packing a grocery bag
Folding laundry
Washing dishes
Ball sport exercise
- dribbling and passing a soccer ball
- dribbling and passing a basketball
- throwing and catching a tennis ball

2.1.5 Data Analysis

Absolute time differences (seconds) and relative time differences [(|video time-Activ8 time|)/video time, %] were calculated for each P&M category across Activ8 positions, based on simple sum values of video and AM time, to evaluate agreement between measures. Additionally, median and quartile values of absolute and relative time differences were determined to illustrate the central tendency and dispersion across participants. During complex activities (e.g. mopping), participants would often quickly

alternate between standing and walking. It may not be appropriate to merge all "standing with movement" time to either the standing or walking P&M class during these complex activities. Therefore, basic and complex activities were analysed separately (please refer to Table 1). "Standing with movement" time was allocated to the standing class during basic standing activities and to the walking class during basic walking activities. For complex activities, all standing, "standing with movement", and walking time was allocated to a new, merged category labelled "light-to-moderate upright activity". Furthermore, bicycling and running were merged to create a "moderate-to-vigorous upright activity" category.

For the primary analyses, which address Objective 1A, an average relative difference of 10% or less between video and Activ8 measures was considered acceptable. This acceptable percentage difference has been used in previous validation studies of accelerometers and consumer-grade pedometers, and is indicative of good validity (100,162,197). Subsequently, the absolute time differences and relative time differences were calculated for all activity categories without merging any P&M classes (i.e. leaving "standing with movement" as a video-only category).

In secondary data analyses, addressing Objective 1B - comparing data from the three Activ8 monitor positions (frontal thigh, lateral thigh, and pant pocket) - the statistical program Stata (Version 13.1, Texas, USA) was used. Normality was assessed with the Shapiro-Wilk test. The total time allocated to each P&M class was compared between video observation and Activ8 monitors using four statistical steps. First, correlation

coefficients were calculated between all measures. Second, Meng's test for comparing correlated correlation coefficients (198) was completed to determine whether correlation coefficients between video/frontal thigh Activ8, video/lateral thigh Activ8, and video/pant pocket Activ8 were statistically different. Though correlation coefficients are a good indicator of association between different measurement tools on a group level, measures may be highly correlated but may not agree well. Therefore, to estimate the intervals of agreement between the two measures on an individual level and to evaluate potential biases between the mean differences, adapted Bland-Altman plot analyses (199,200) were completed using data collected from the three Activ8 monitor positions. Adapted plots compared the difference between measures (video time-Activ8 time, in sec) to the criterion, reference measure (video time) as recommended by Krouwer (201). Bland-Altman plots illustrate data variability across individuals as well as potential data biases. However, a t-test is needed to confirm whether any possible bias is significant. Thus, dependent t-tests were completed to determine whether there is a statistically significant difference between measures. If the data met the assumption of normality and homogeneity of variances, Pearson correlation coefficients were calculated and paired samples t-test were completed. If the data were not normally distributed, the non-parametric Spearman Rho correlation coefficients were calculated and Wilcoxon Signed-Rank tests were performed.

2.2 Methods – OBJECTIVE 2

2.2.1 Participant Recruitment & Eligibility

The convenience sample of fourteen adults with spastic CP [9 men; mean (SD) age, 35.4 (13.1) years] used to address Objective 1 was also used here to address Objective 2. The sample size was based on comparable studies evaluating the validity of an AM in both children and adults with disability (162,163,195). Please refer to section 2.1.1 for details about participant recruitment, inclusion criteria, and exclusion criteria.

2.2.2 Measures

2.2.2.1 VitaMove

The VitaMove is a high-end, research-grade monitoring system (2M Engineering Ltd, Valkenswaard, The Netherlands) that contains multiple, body-fixed AMs (see Figure 2A). Each monitor weighs 52 grams, is 40 x 80 x 15 mm in size, and contains a tri-axial, capacitive accelerometer (MMA 7260Q, Freescale Semiconductor, Denver, USA), capable of measuring acceleration ranging from ± 4.0g in magnitude. To measure activity time in ambulatory adults, the VitaMove system consists of three monitors that are wirelessly connected and synchronized automatically every 10 seconds. The VitaMove monitors sample acceleration signals at a rate of 128 Hz. Sampled accelerations are then digitized using a 14-bit analog-to-digital converter and stored on a micro Secure Digital memory. Afterward assessment completion, measurements were uploaded to computer for kinematic analysis using the VitaScore software (VitaScore BV, Gemert, the Netherlands).

The kinematic data analysis consists of feature processing and activity detection. Measured signals are converted into estimates of angular position (degrees) and motility (g) through low- and high-pass filtering, respectively, and then data rectification. Additionally, a frequency signal, derived from a fast Fourier transform algorithm, and a phase feature signal provide insight into the frequency of acceleration and the phase between the two leg monitors. All monitors use a time resolution of one second. Based on these feature signals, a posture or activity (sub)category is selected from a large set of possible body P&M every second. Later, subcategories are merged into the main P&M categories of lying, sitting, standing, walking, bicycling, and running.

The precursor of VitaMove monitoring system, the Vitaport AM, has been previously validated in healthy adults as well as adults with chronic health conditions (172,195,202). The VitaMove has shown good validity in the measurement of activity in ambulatory and non-ambulatory youth with spina bifida and non-ambulatory youth with CP (162). However, to date, this monitoring system has yet to be validated in adults with CP.

2.2.2.2 Activ8

The Activ8 Physical Activity Monitor (see Figure 1A) is also produced by 2M Engineering Ltd (Remedy Distribution Ltd., Valkenswaard, The Netherlands). Please refer to section 2.1.2.2 for full technical details about the Activ8. Recorded acceleration signals are converted into six distinct body P&M categories: non-wear/lying, sitting, standing, walking, bicycling, or running. The monitor was set to record activity data

using a 5-second epoch. Each epoch included 8 non-time stamped "points", allowing researchers to determine the specific amount of time each Activ8 activity category was scored in a given epoch. The Activ8 is unable to distinguish transient lying (<5 minutes) from sitting, as the angular position of the monitor would remain the same for both static postures.

2.2.2.3 Video Observation

A handheld digital video camera was used as reference method for detection of body P&M. The methods related to video observation have been described previously; please refer to section 2.1.2.3. Video recordings were analysed by one researcher and scored independently of the Activ8 and VitaMove data output. Observed activity was assigned one of the ten categories based on pre-defined definitions (see Appendix G), some of which were merged to allow for comparison with the AM measurement tools.

2.2.3 Monitor Placement on the Body

Participants were asked to wear 3 VitaMove activity monitors. One monitor was attached to the sternum while the two other monitors were attached to each mid-thigh on the lateral side (see Figure 2B). The Activ8 monitor was attached in a slightly lateral thigh location (see Figure 1B). This monitor was placed at the side least affected by spasticity, or simply at the right side if there was no difference in spasticity among lower limbs. All AMs were attached directly to the participant with Tegaderm™ skin tape. Though three Activ8 monitors were attached to all ambulatory or partly-ambulatory participants, the data collected from the Activ8 in the lateral thigh position were used to compare activity

measures as it was able to better detect body P&M in ambulatory adults with CP (please refer to section 3.1 for results).

2.2.4 Procedure

All participants performed a series of daily life activities according to a standard protocol in a simulated home environment within the occupational therapy department and human movement laboratory at Erasmus MC, Rotterdam, the Netherlands. For full details of the assessment procedure and Activity Protocol for Ambulatory Adults please refer to section 2.1.4 and Table 1. A native Dutch student gave instructions while the author video recorded participants. Participants were closely supervised throughout the assessment to ensure safety. Upon completion of the assessment, accelerometry data were uploaded to the computer for processing using the VitaScore software for VitaMove AMs and the professional Activ8 software (Version 2.1.0.22) for the Activ8 AM. Please refer to Appendix F for the full measurement protocol.

After kinematic data analysis using the VitaScore software, the categorized activity data collected from the VitaMove AMs were then exported into a comma-separated values (CSV) file format using a custom-made MATLAB (MathWorks, Natick, USA) program. This allows continuous VitaMove activity data (1-second resolution) to be compared to synchronized video observation (1-second resolution) as well as continuous Activ8 activity output (5-second resolution). To allow comparison of all three measures, the whole duration of each performed activity was analysed. This is because Activ8 epochs

do not display the order that numerous body P&M were performed. Please refer to Appendix G for a screenshot example of the Activ8 data output.

A.

B.

Figure 2. A) The VitaMove AM.
B) Positioning of VitaMove AMs on the chest and legs (lateral aspect of the thigh).

2.2.5 Data Analysis

The absolute time difference (seconds) and the relative time difference [(|video time-VitaMove time|)/video time, %] were calculated for each VitaMove P&M category, based on simple sum values of video and AM time, to evaluate agreement between VitaMove and video observation (addressing Objective 2A). Additionally, median and

quartile values of absolute and relative time differences were determined to illustrate the central tendency and dispersion across participants. As was completed for Objective 1, basic and complex activities (please refer to Table 1) were analysed separately. Activity time from the video class "standing with movement" was allocated to the standing class during basic standing activities and to the walking class during basic walking activities. For complex activities, all standing, "standing with movement", and walking time was allocated to the merged category "light-to-moderate upright activity". Bicycling and running were merged to create a "moderate-to-vigorous upright activity" category. An average relative difference of 10% or less between video and VitaMove measures was considered acceptable and is indicative of good validity (100,162,197).

To compare data from all three measures of body P&M (video observation, Activ8 AM, and VitaMove AM), and to address Objective 2B, the statistical program Stata (Version 13.1, Texas, USA) was used. Normality was assessed with the Shapiro-Wilk test. The total time for each P&M class was compared between video observation, Activ8, and VitaMove measures through four statistical tests. First, correlation coefficients were calculated between all measures. Second, Meng's test for comparing correlated correlation coefficients (198) was completed to determine whether correlation coefficients between video/Activ8 and video/VitaMove were statistically different. Though correlation coefficients are a good indicator of association between different measurement tools, measures may be highly correlated but may not agree well. Therefore, adapted Bland-Altman plot analyses (199,200) were completed using data collected from each AM to evaluate whether data biases exist. Adapted plots compared

the difference between measures (video time-AM time, in sec) to the criterion measure (video time, in sec) as suggested by Krouwer (201). Though Bland-Altman plots illustrate data variability across individuals as well as potential data biases, a t-test is needed to confirm whether any possible bias is significant. Therefore, dependent t-tests were completed to determine whether there is a statistically significant difference between measures. If the data met the assumption of normality and homogeneity of variances, Pearson correlation coefficients were calculated and paired samples t-test were completed. If the data were not normally distributed, the non-parametric Spearman Rho correlation coefficients were calculated and Wilcoxon Signed-Rank tests were performed.

2.3 Methods – OBJECTIVE 3

2.3.1 Participant Recruitment & Eligibility

Of the fifteen participants recruited between February and June 2016 to evaluate the validity of the Acitv8 and VitaMove AMs, only three of these adults with spastic CP were partly or completely wheelchair dependent [2 men; mean (SD) age, 41.7 (11.2) years; GMFCS level III (n=2) and level IV (n=1)]. Participants were recruited through the same manner as described in section 2.1.1 and 2.2.1.

The inclusion criteria for Objective 3 were: ≥18 years of age; diagnosis of spastic CP; partly or completely wheelchair dependent; uses a manual wheelchair; and physically able to perform the activities in the assessment protocol. Participants were excluded if they had: disabilities other than CP affecting daily PA; severe cognitive disorder; insufficient comprehension of either English or Dutch to follow instructions for testing, as determined during a screening telephone conversation; or orthopaedic surgery within the past 6 months.

2.3.2 Measures

2.3.2.1 Wheelchair Activ8

The Wheelchair Activ8 consists of two Activ8 AMs, which are produced by 2M Engineering Ltd (Remedy Distribution Ltd., Valkenswaard, The Netherlands). Please refer to section 2.1.2.2 for full technical details about the Activ8 AM. The two monitors used in the Wheelchair Activ8 configuration were set to record P&M data using a 5-

second epoch, the lowest epoch setting available. Each second of recorded activity displayed an associated vector magnitude "count", providing researchers with an estimate of the intensity with which activity was completed. After conclusion of the Wheelchair Activity Protocol (see Table 3), the data output files (CSV format) were stored on a personal computer. These output files were later processed and analyzed using a custom-made MATLAB (MathWorks, Natick, USA) program and analysis algorithm.

Prior to data analysis, the MATLAB program synchronized the two Activ8 monitors (wrist and wheelchair locations, see section 2.3.3 for positioning information) to create uniform time intervals between both output files. The custom-made wheelchair algorithm uses vector magnitude counts and body P&M duration collected from both Activ8 monitors to re-allocate activity data into wheelchair specific P&M categories according to the uniform time intervals. Wheelchair driving differs from other upper-limb activities due to the simultaneous movement of both the arms and the wheelchair wheels. It was this concept that allowed wheelchair driving to be distinguished from other activities, such as sitting with minimal to no arm movement (sitting - sedentary upper body) and sitting with upper-limb activity (sitting - active upper body; e.g. folding laundry while sitting). A previously published algorithm (180), using two ActiGraph GT3X+ accelerometers to categorize wheelchair activity, was adapted for use with Activ8 AMs. ActiGraph vector magnitude counts were translated into corresponding Activ8 vector magnitude counts; ActiGraph counts were increased by a factor of 1.55 for the wheel position and by 1.95 for the wrist position. The resulting classification algorithm for the Wheelchair Activ8, using a wrist and wheelchair wheel monitor, is displayed in Table 2.

Table 2. Wheelchair Activ8 activity classification algorithm based on vector magnitude counts and duration from wrist and wheelchair wheel monitor positions

	Wrist monitor		**Wheelchair wheel monitor**	
Wheelchair P&M Category	Vector Magnitude (in counts)	Duration (in sec)	Vector Magnitude (in counts)	Duration (in sec)
Non-wear	0	> 1800	0	> 1800
Sitting - Sedentary Upper Body	≤ 98	-	< 31	-
Sitting - Active Upper Body	> 98	-	< 31	-
Assisted Driving	< 98	> 5	> 310	> 5
Maneuvering	-	-	> 31 and < 310	-
			> 310	< 5
Wheelchair Driving	> 98	-	> 310	> 5
	< 98	< 5		

P&M: Postures and movements

2.3.2.2 VitaMove

As mentioned previously, the VitaMove monitoring system, produced by 2M Engineering Ltd (Valkenswaard, The Netherlands), contains multiple, body-fixed AMs (see Figure 2A). For all technical specifications of the VitaMove AM, please refer to section 2.2.2.1. To measure activity time in wheelchair users, the VitaMove system consists of three monitors that are wirelessly connected and synchronized automatically every 10 seconds. All monitors sample accelerations with a time resolution of one

second. Sampled accelerations from all three monitors were digitized and stored on a micro Secure Digital memory. Upon completion of the wheelchair activity protocol, measurements were uploaded to computer for kinematic analysis using the VitaScore software. Kinematic data analysis leads to the classification of activity into body P&M (sub)categories for every second. Please refer to section 2.2.2.1 for full details about the kinematic analysis. Subcategories were later merged into the three major categories of: lying; sedentary upper body; and active upper body. The "active upper body" category includes the subcategories of "wheelchair" and "move". The VitaMove has shown good validity in the measurement of body P&Ms in youth with spina bifida and CP who are wheelchair dependent (162).

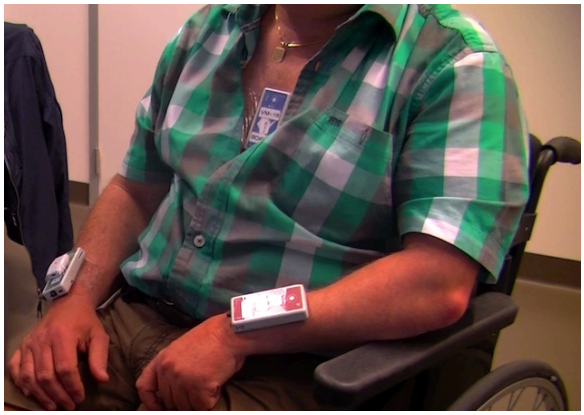
2.3.2.3 Video Observation

A handheld digital video camera was used as reference method for detection of body P&M in wheelchair users. Video recordings were analysed by one researcher and scored independently of the Activ8 and VitaMove data output. Using a 1-second time resolution, observed activity was assigned one of the following categories based on pre-set definitions: non-wear; lying; sitting; active upper body; wheelchair driving (including maneuvering); assisted driving (i.e. being pushed in a wheelchair); or transfer time (see Appendix G). Transfer time was defined as: "the distinct transition from a stable sitting position to another stable sitting position (sit-to-sit) or from a stable sitting position to a stable lying position (sit-to-lie)". Three steps were taken to minimize bias when scoring the criterion measure of video observation, which are outlined in section 2.1.2.3.

2.3.3 Monitor Placement on the Body

For the wheelchair configuration of the AMs, participants were asked to wear three VitaMove and two Activ8 monitors. One VitaMove monitor was attached to the sternum while the other two monitors were attached to each wrist (see Figure 3A). With the Wheelchair Activ8 monitors, one was attached to the dominant wrist, directly on top of the VitaMove wrist monitor, and the other attached to the spokes of the corresponding wheelchair wheel (see Figure 3B). All AMs, except the Activ8 on the wheelchair wheel, were attached directly to the participant with Tegaderm™ skin tape.

A.



B.

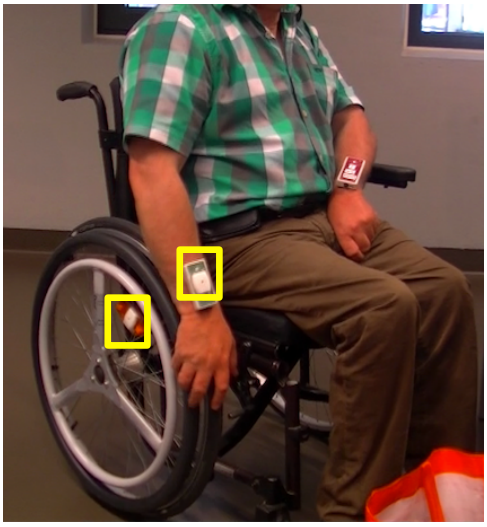


Figure 3. Positioning of the Activ8 and VitaMove AMs on wheelchair users.

A) VitaMove AMs positioned on each wrist and the chest.

B) Activ8 AMs attached to the spokes of the wheelchair and to the wrist (secured on top of the VitaMove wrist monitor).

2.3.4 Procedure

Participants performed a sequence of daily life activities according to a standardized Wheelchair Activity Protocol (see Table 3), in a simulated home environment within the occupational therapy department and human movement laboratory at Erasmus MC, Rotterdam, the Netherlands. The activity protocol consisted of activities representative of daily life for manual wheelchair users, as informed by the literature (162,195,203), and was performed in the same order during each assessment. A native Dutch student provided standardized assessment instructions while the author video recorded participants throughout the assessment. Participants were closely supervised, to ensure safety. All activities were timed for 80 seconds duration, or less if the activity was completed before then, and noted during measurement. Upon completion of the assessment, accelerometry data were uploaded to the computer for processing using the VitaScore software for VitaMove AMs and the professional Activ8 software for both Activ8 AMs.

Once uploaded, VitaMove activity data underwent data analysis using the VitaScore software. Resulting activity data, allocated to one of three VitaMove wheelchair P&Ms categories for each second, were exported into a CSV file format using a custom-made MATLAB program. Processed Activ8 activity data from both wrist and wheelchair wheel were uploaded, synchronized, and analyzed using another custom-made MATLAB algorithm (please refer to section 2.3.2.1 for more details). After data analysis with the Wheelchair Activ8 MATLAB algorithm, a new CSV file classifying wheelchair activity into appropriate P&M categories can then be exported. These CSV files, outlining the

continuous VitaMove data (1-second resolution) and continuous Wheelchair Activ8 data (5-second resolution), allow activity data to be compared to synchronized video observation (1-second resolution). Once again, the whole duration of each performed activity was analysed to allow comparison between all three measures. Please refer to Appendix F for the full measurement protocol.

Table 3. Wheelchair Activity Protocol

Sitting
Wheelchair driving – self-propulsion
Browsing through a magazine
Folding laundry
Unpacking and packing a grocery bag
Washing dishes
Being pushed in wheelchair
Being pushed in wheelchair while using cellular phone
Opening, driving through, and closing a door (maneuvering)
Office work - Typing on a computer
Donning and doffing a jacket
Ball sport exercise
- dribbling and passing a basketball
- throwing and catching a tennis ball

2.3.5 Data Analysis

To allow comparison across all three measurement tools, certain P&M categories from video observation and the Wheelchair Activ8 needed to be merged into the three broad categories of lying, sedentary upper body, and active upper body. The following classes were merged: sitting, sitting – sedentary upper body, and assisted driving to sedentary upper body; sitting – active upper body, transfer time, maneuvering, and wheelchair

driving to active upper body. The total absolute time difference (seconds) and relative time difference [(|video time-AM time|)/video time, %] were calculated for sedentary and active upper body categories between Wheelchair Activ8 and video observation as well as VitaMove and video observation.

The statistical program Stata (Version 13.1, Texas, USA) was used to compare data from all three measures of body P&M (video observation, Activ8 AM, and VitaMove AM). Normality was assessed with the Shapiro-Wilk test. The total time for each P&M class was compared between video observation, Wheelchair Activ8, and VitaMove measures using dependent t-tests, or non-parametric Wilcoxon Signed Rank tests.

CHAPTER 3 – RESULTS & INTERPRETATION

3.1 Results & Interpretation – OBJECTIVE 1

3.1.1 Participants

Participant characteristics are displayed in Table 4. Participants numbered 1 to 14 were part of this research objective and analysis. Half of these participating adults had unilateral spastic CP (hemiplegic distribution, n=7) and half had bilateral spastic CP (diplegic or quadriplegic distribution, n=7). As a result of lower-limb spasticity, four participants had a prominent crouched stance or a crouch gait pattern. Self-reported GMFCS levels were as follows: level I (n=6), level II (n=5), and level III (n=3).

3.1.2 Criterion Validity of the Activ8 – Objective 1A

The absolute and relative differences in time between video and Activ8 measures of body P&M detection, split between basic and complex activities, are reported in Table 5. The average relative time difference between video and Activ8 methods for detection of body P&M ranged from 2.92% (bicycling) to 34.9% (running) during basic activities. The body P&M categories of sitting, walking, bicycling, and the combined light-to-moderate upright activity category were well detected by the Activ8 monitor attached to the frontal thigh (<10% relative time difference for all). At this thigh location, however, the Activ8 grossly underestimated total standing time, which led to an overestimation of total sitting time by 248 seconds. Upon further investigation, it was apparent that Activ8 frontal thigh activity data from the three participants with a crouched stance or crouch gait pattern comprised the majority of this misclassified P&M data (overestimation by 249 sec). This

led the median relative time difference for standing to be much lower than the average value (median: 7.30% vs average: 24.4%). These three outliers, which can be seen in Figure 4B, greatly affected the absolute and relative time difference between video and Activ8 measures. Furthermore, among these participants, walking was misclassified as bicycling in the frontal thigh Activ8 data output. These misclassifications, more frequently observed in the four adults with a crouched stance or gait, is a result of the integrated Activ8 classification algorithm, which considers both vector magnitude acceleration and the angular position (as determined by the z-axis accelerometer).

During a crouched stance, the angular position of the Activ8 in the frontal thigh position surpasses the threshold angle that differentiates between sitting and standing. Therefore, in this case, true standing time would be misclassified as sitting time. Similarly, during complex activities, 150 seconds of true walking time was misclassified as bicycling, resulting in a much lower median relative time difference (1.30%) compared to the average (7.68%) for the light-to-moderate upright activity category. The Bland-Altman plot (see Figure 4D) reveals that one participant lies well outside the limits of agreement, contributing to this large difference between median and average relative time difference. Furthermore, the overestimation of moderate-to-vigorous upright activity (running plus bicycling time) may be due to a crouched or toed gait pattern (147 of the 150 second came from the four participants with a couched gait), and is particularly conspicuous with only 8 seconds of true moderate-to-vigorous upright activity detected during complex activities.

Lastly, the Activ8 AM overestimated running time. When participants were asked to bicycle at a pace faster than normal, three participants cycled with notable vigour. Though this activity was detected and coded as bicycling by video observation, the Activ8 misclassified this activity time as running. According to the integrated classification algorithm from the Activ8 AM, any activity that surpasses a certain vector magnitude count threshold (i.e. high intensity activities) will be classified as "running", regardless of the angular position. Therefore, the P&M category title "running" is a bit of a misnomer. Instead, renaming this Activ8 output category as "vigorous activity" may better represent activity categorized as such.

3.1.3 Comparison of Activ8 Monitor Positions – Objective 1B

The results shown in Table 5 also display the absolute and relative time differences between the Activ8 AM and video observation for lateral thigh and pant pocket Activ8 positions. From the pant pocket position, the body P&M categories of sitting, standing, walking, and the combined upright activity categories were adequately detected (<10% average relative time difference for all). Bicycling and running time was not as well detected during basic activities, although the median relative time differences are much less than the average relative time differences indicating that larger differences may be due to a few outliers rather than consistent misclassification by the Activ8 device. Nonetheless, the Activ8 AM overestimated running time at all three monitor positions (34.6 to 35.4% average difference). Bicycling was frequently misclassified as running and fast pace walking was misclassified as either bicycling or running. Misclassification of these two P&M categories may be a result of a few participants who wore trousers

with loose pant pockets. The increased space within a loose pant pocket allows the Activ8 to excessively shift and turn during activity. Overestimation of bicycling and running time may be an artifact of Activ8 monitor placement within these loose pockets. Overall, body P&M were more consistently properly detected by the Activ8 at the lateral thigh location, resulting in lower median relative time difference values for all P&M categories than frontal thigh and pant pocket locations. The categories of sitting (0.25% average difference), standing (4.69% average difference), walking (2.46% average difference), bicycling (3.19% average difference), and the combined upright activity categories (4.1% and 1.96% average difference for moderate-to-vigorous and light-to-moderate upright activity, respectively) were well detected by the Activ8 monitor at this location.

To further to evaluate the role of Activ8 positioning on detection of body P&M, non-parametric statistical analyses were completed, as the data were not normally distributed. Calculated Spearman Rho correlation coefficients between video observation and the Activ8 AM from each of the three leg positions are displayed in Table 6. Correlation coefficients range from -0.04 to 0.86 for the frontal thigh Activ8 position, from 0.49 to 0.99 for the lateral thigh Activ8 position, and from 0.14 to 0.79 for the pant pocket position.

Meng's tests were completed to compare correlated correlation coefficients and to evaluate whether the correlation coefficients between video observation and Activ8 measures differed among Activ8 leg positions. Results from Meng's tests can be found in

Table 7. Meng's tests revealed that the correlation coefficients from video/lateral thigh Activ8 position were greater than the correlation coefficients from video/front thigh Activ8 and video/pant pocket Activ8 for the P&M categories of sitting, basic standing, basic walking, and light-to-moderate upright activity ($p < .01$ for all). The correlation coefficients from video/Activ8 measures were not different among monitor leg positions for bicycling or running P&M categories. Comparison of correlation coefficients between video/frontal thigh Activ8 and video/pant pocket Activ8 revealed that data collected from the frontal thigh position had higher correlations with video observation than the pant pocket position for the sitting P&M category ($p=.015$)

Subsequently, Bland-Altman plots were generated to display individual intervals of agreement between video and Activ8 measurements from all 3 Activ8 leg positions (see Figure 4). The mean differences were smallest for basic walking (7.00, 95% CI = -10.6 to 24.6 sec) and bicycling (3.35, 95% CI = -17.4 to 24.1 sec) categories, while larger for sitting (-23.4, 95% CI = -40.1 to -6.67 sec), basic standing (7.72, 95% CI = -3.23 to 18.7), light-to-moderate upright activity (22.7, 95% CI = 5.97 to 39.4 sec), and running (-23, -35.9 to -10.1 sec). The upper and lower limits of agreement were 79.0 to -126 sec for sitting, 73.9 to -58.5 sec for basic standing, 115 to -101 sec for basic walking, 122 to -77.0 sec for light-to-moderate upright activity, 125 to -119 sec for bicycling, and 40.8 to -86.8 sec for running. Upon visual examination, it is apparent that the lateral thigh Activ8 monitor was most consistent in the correct categorization of activity time into P&M categories compared to the other two Activ8 monitor positions. Data collected from the frontal thigh Activ8 monitor location ranged from 276 to -165 second difference in time

compared to video observation, whereas data from the lateral thigh location ranged from 89 to -88 second difference. Activity data from the pant pocket Activ8 location regularly ranged from approximately 100 to -100 second difference for each P&M category, with exception to light-to-moderate upright activity (123 to -3 sec) and running (16 to -69 sec). These results support the notion that the frontal thigh and pant pocket are inferior Activ8 monitor locations compared to the lateral thigh, as detection of body P&M fluctuates greatly among individuals.

Wilcoxon Signed Rank tests (see Table 8) revealed a difference between video and lateral thigh Activ8 measures of basic standing time, despite the overestimation of standing time to be quite small for individual participants. Visual evaluation of the Bland-Altman plots shows existence of a bias for the measurement of basic standing by the lateral thigh Activ8. For this P&M category, the Activ8 underestimated the amount of standing time for 12 participants (total time difference = 50 sec) and agreed for two participants. A difference between video and frontal thigh Activ8 measures was found for the P&M categories of sitting, basic standing, and light-to-moderate upright activity ($p < .05$ for all). These results support the notion presented in section 3.1.2 regarding the inability of the frontal thigh Activ8 to properly distinguish between standing time and sitting time as well as walking and bicycling time in participants with a crouched stance or gait. Lastly, though detection of running time was only different between video and Activ8 measures for the pant pocket Activ8 location ($p=.041$), "running" time was overestimated by the Activ8 monitor at all attachment positions.

Table 4. Participant Characteristics

Participant No.	Age (years)	Gender	Activity Protocol Completed	Activ8 Monitors Worn				Limb Distribution	GMFCS-E&R Level
				Frontal Thigh	Lateral Thigh	Pant Pocket	Wheelchair Monitors		
1	23	F	Ambulatory	X	X	X		Hemiplegia	I
2	26	M	Ambulatory	X	X	X		Hemiplegia	I
3	28	F	Ambulatory and Wheelchair	X		X	X	Diplegia	III
4	23	M	Ambulatory	X	X	X		Hemiplegia	I
5	48	M	Ambulatory	X	X	X		Diplegia	II
6	46	M	Ambulatory and Wheelchair	X	X	X	X	Quadriplegia	III
7	55	M	Ambulatory	X	X	X		Hemiplegia	I
8	58	M	Ambulatory	X	X	X		Quadriplegia	II
9	21	F	Ambulatory	X	X	X		Hemiplegia	I
10	43	M	Ambulatory	X	X	X		Diplegia	II
11	24	F	Ambulatory	X	X	X		Diplegia	II
12	29	M	Ambulatory	X	X	X		Hemiplegia	II
13	27	M	Ambulatory	X	X	X		Hemiplegia	I
14	45	F	Ambulatory	X	X			Diplegia	III
15	50	M	Wheelchair				X	Quadriplegia	IV

Table 5. Total time within basic and complex activities, absolute time difference, and relative time difference between video observation and the Activ8 AM

	Video time (sec)		Activ8 time (sec)		Absolute Time Difference (sec)		Relative Time Difference (%)	
Frontal Thigh	**Median (Q1, Q3)**	**Simple sum (n=14)**	**Median (Q1, Q3)**	**Simple sum (n=14)**	**Median (Q1, Q3)**	**Total[c] (n=14)**	**Median (Q1, Q3)**	**Average[c]**
Basic Activities								
Sitting	242 (231, 259)	3474	245 (233, 300)	3722	0 (0, 0.75)	248	0.00 (0, 0.29)	7.14
Standing	79 (75, 84)	1139	75 (71, 78)	861	6 (1.5, 16)	278	7.30 (1.9, 21)	24.4
Walking	290 (278, 299)	3877	279 (250, 302)	3604	11 (1.8, 29)	273	3.68 (0.63, 14)	7.04
Bicycling	226 (222, 232)	2809	224 (208, 228)	2891	0 (0, 5.3)	82	0.00 (0, 2.7)	2.92
Running	63 (0, 74)	628	64 (0, 94)	847	2.5 (0, 22)	219	19.2 (5.3, 42)	34.9
MV Upright Activity[a]	289 (227, 305)	3437	299 (239, 329)	3738	6 (0.25, 26)	301	3.21 (0.32, 9.2)	8.76
Complex Activities								
LM Upright Activity[b]	498 (332, 568)	6277	470 (281, 566)	5795	5 (0, 19)	482	1.30 (0.39, 3.34)	7.68
Lateral Thigh	**Median (Q1, Q3)**	**Simple sum (n=13)**	**Median (Q1, Q3)**	**Simple sum (n=13)**	**Median (Q1, Q3)**	**Total[c] (n=13)**	**Median (Q1, Q3)**	**Average[c]**
Basic Activities								
Sitting	237 (232, 256)	3175	237 (232, 256)	3183	0 (0, 0)	8	0.00 (0, 0)	0.25
Standing	82 (73, 86)	1066	78 (74, 81)	1016	3 (2, 7)	50	4.00 (2.4, 8.0)	4.69
Walking	291 (268, 302)	3706	286 (261, 311)	3615	4 (3, 8)	91	1.26 (1.0, 3.0)	2.46
Bicycling	229 (221, 232)	2598	229 (155, 232)	2515	0 (0, 7)	83	0.43 (0, 10)	3.19
Running	69 (0, 72)	622	68 (3, 83)	837	5 (0, 16)	215	16.9 (8.8, 47)	34.6
MV Upright Activity[a]	289 (229, 304)	3220	296 (233, 308)	3352	5 (2, 12)	132	1.66 (0.6, 3.9)	4.10

Complex Activities								
LM Upright Activity[b]	460 (348, 544)	6072	463 (347, 544)	5953	1 (0, 9.5)	119	0.30 (0, 2.7)	1.96

Pant Pocket	**Median (Q1, Q3)**	**Simple sum (n=13)**	**Median (Q1, Q3)**	**Simple sum (n=13)**	**Median (Q1, Q3)**	**Total[c] (n=13)**	**Median (Q1, Q3)**	**Average[c]**
Basic Activities								
Sitting	241 (232, 257)	3207	236 (223, 261)	3194	0 (0, 1)	13	0.00 (0, 0.6)	0.41
Standing	79 (74, 86)	990	80 (75, 85)	1015	7 (1, 10)	25	8.33 (1.3, 57)	2.53
Walking	288 (252, 307)	3532	278 (244, 330)	3614	35 (7, 49)	82	11.2 (2.5, 34)	2.32
Bicycling	230 (223, 231)	2608	230 (107, 231)	2292	1 (0, 69)	316	5.75 (0, 44)	12.1
Running	71 (0, 75)	624	65 (5, 95)	845	9 (0, 20)	221	26.7 (17, 66)	35.4
MV Upright Activity[a]	299 (230, 307)	3232	295 (181, 313)	3137	23 (8.3, 63)	95	9.85 (3.0, 42)	2.94
Complex Activities								
LM Upright Activity[b]	506 (242, 584)	6023	482 (223, 559)	5762	3 (0, 23)	261	2.01 (0.4, 6.4)	4.33

a. Moderate-to-vigorous Upright Activity; the sum of Bicycling and Running categories
b. Light-to-moderate Upright Activity; the sum of Standing, Standing with Movement, and Walking categories
c. Based on simple sum values

Table 6. Correlation coefficients between Activ8 positions (frontal thigh, lateral thigh, and pocket position) and video observation

	Sitting			Basic Standing			Basic Walking		
	Video	Frontal	Lateral	Video	Frontal	Lateral	Video	Frontal	Lateral
Video	-			-			-		
Frontal	0.86***	-		-0.04	-		0.59*	-	
Lateral	0.98***	0.85***	-	0.93***	-0.07	-	0.94***	0.63*	-
Pocket	0.48	0.70**	0.43	0.14	0.25	0.45	0.37	0.55	0.36
	Light-to-Moderate Upright Activity			Bicycling			Running		
	Video	Frontal	Lateral	Video	Frontal	Lateral	Video	Frontal	Lateral
Video	-			-			-		
Frontal	0.72**	-		0.35	-		0.77**	-	
Lateral	0.99***	0.72**	-	0.49	0.28	-	0.73**	0.99***	-
Pocket	0.79**	0.94***	0.80**	0.39	0.53	0.33	0.74**	0.99***	0.99***

* p< .05
** p< .01
*** p< .001

Table 7. Comparison of Spearman Rho correlation coefficients using Meng's method of analysis

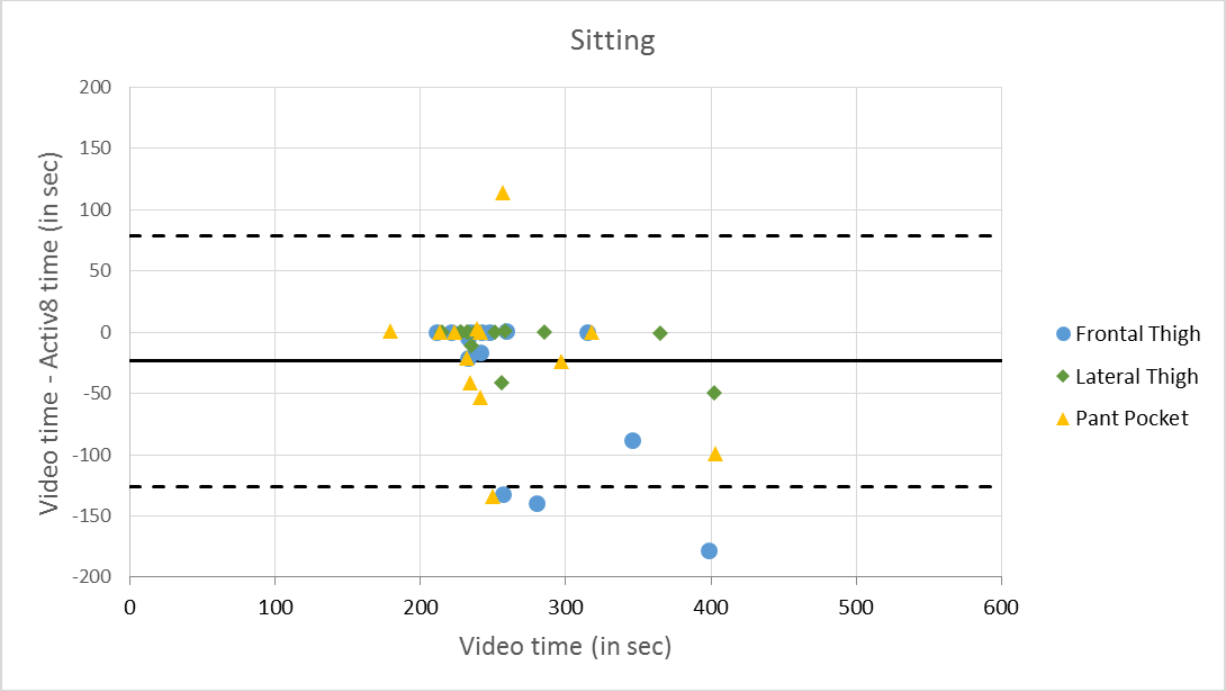
	Sitting	Basic Standing	Basic Walking	Upright Activity[a]	Bicycling	Running
r_1	0.86	-0.04	0.59	0.72	0.35	0.77
r_2	0.98	0.93	0.94	0.99	0.49	0.73
Z-score	2.96	3.60	2.88	4.82	0.42	1.36
***p*-value**	.003*	< .001*	.004*	< .001*	.672	.174

	Sitting	Basic Standing	Basic Walking	Upright Activity[a]	Bicycling	Running
r_1	0.86	-0.04	0.59	0.72	0.35	0.77
r_3	0.48	0.14	0.37	0.79	0.39	0.74
Z-score	2.44	0.46	0.87	1.00	0.14	1.03
***p*-value**	.015*	.642	.384	.318	.886	.304

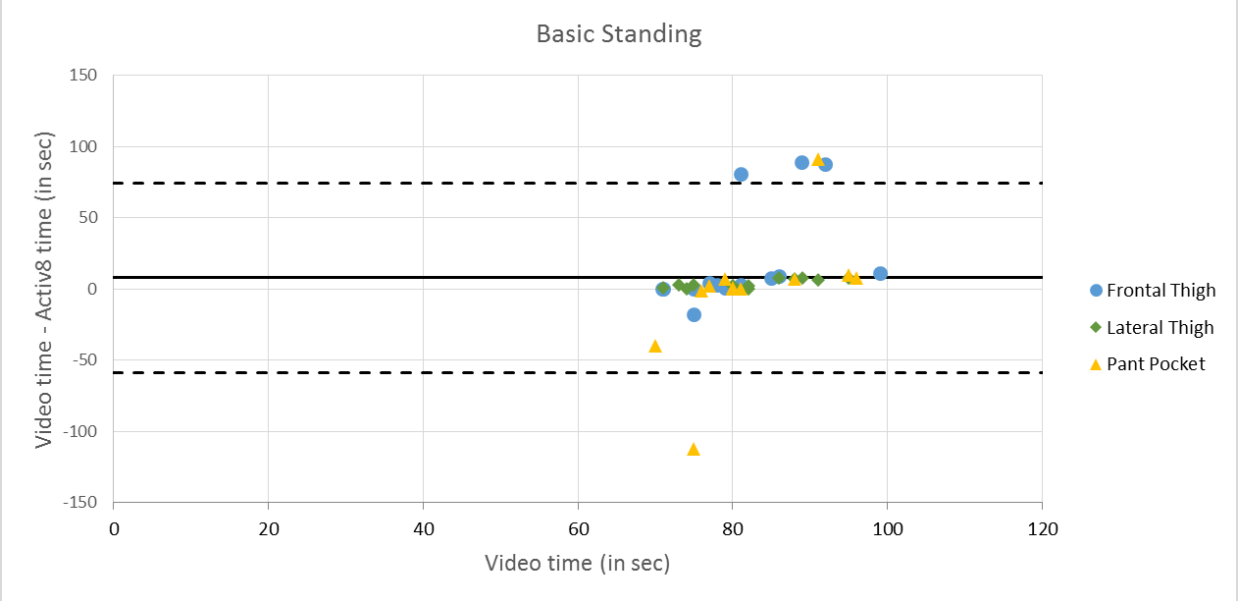
	Sitting	Basic Standing	Basic Walking	Upright Activity[a]	Bicycling	Running
r_2	0.98	0.93	0.94	0.99	0.49	0.73
r_3	0.48	0.14	0.37	0.79	0.39	0.74
Z-score	4.16	3.66	3.07	4.31	0.31	0.30
***p*-value**	< .001*	< .001*	.002*	< .001*	.754	.763

r_1: correlation coefficient for video/frontal thigh Activ8; r_2: correlation coefficient for video/lateral thigh Activ8;
r_3: correlation coefficient for video/pant pocket Activ8
a. Light-to-moderate Upright Activity
* p< .05

A


Sitting
Video time - Activ8 time (in sec)
200
150
100
50
0
-50
-100
-150
-200
0
100
200
300
400
500
600
Video time (in sec)
Frontal Thigh
Lateral Thigh
Pant Pocket

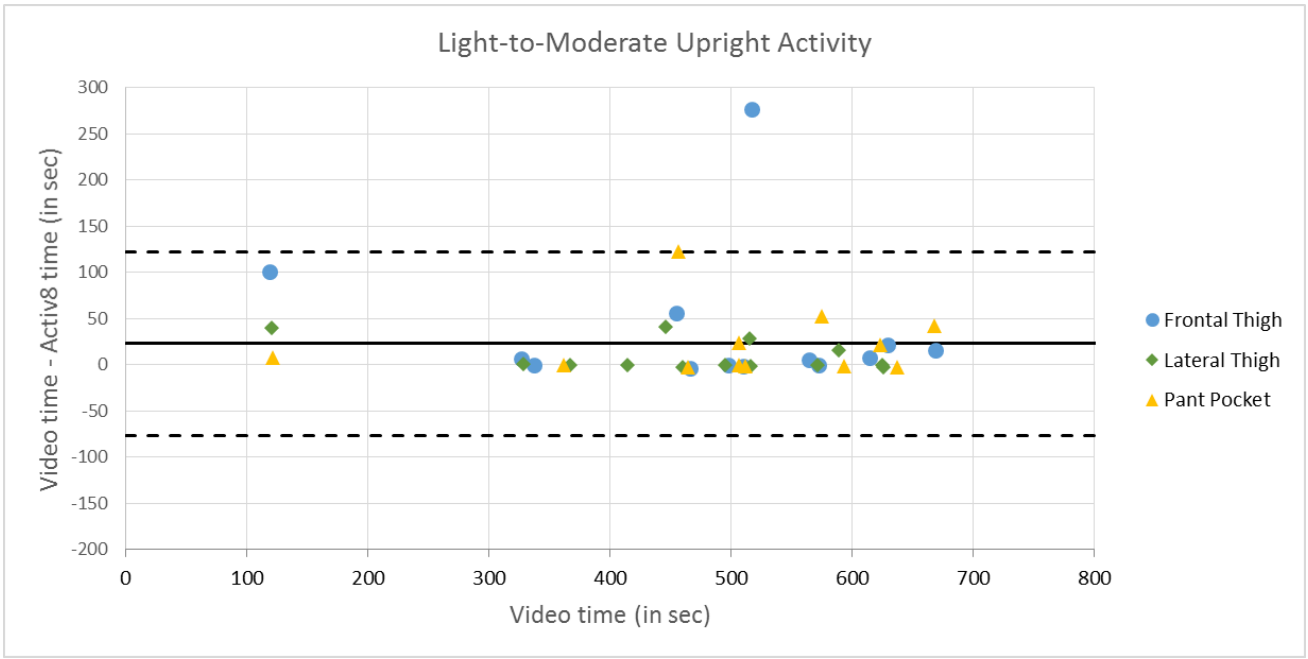
B


Basic Standing
Video time - Activ8 time (in sec)
150
100
50
0
-50
-100
-150
0
20
40
60
80
100
120
Video time (in sec)
Frontal Thigh
Lateral Thigh
Pant Pocket

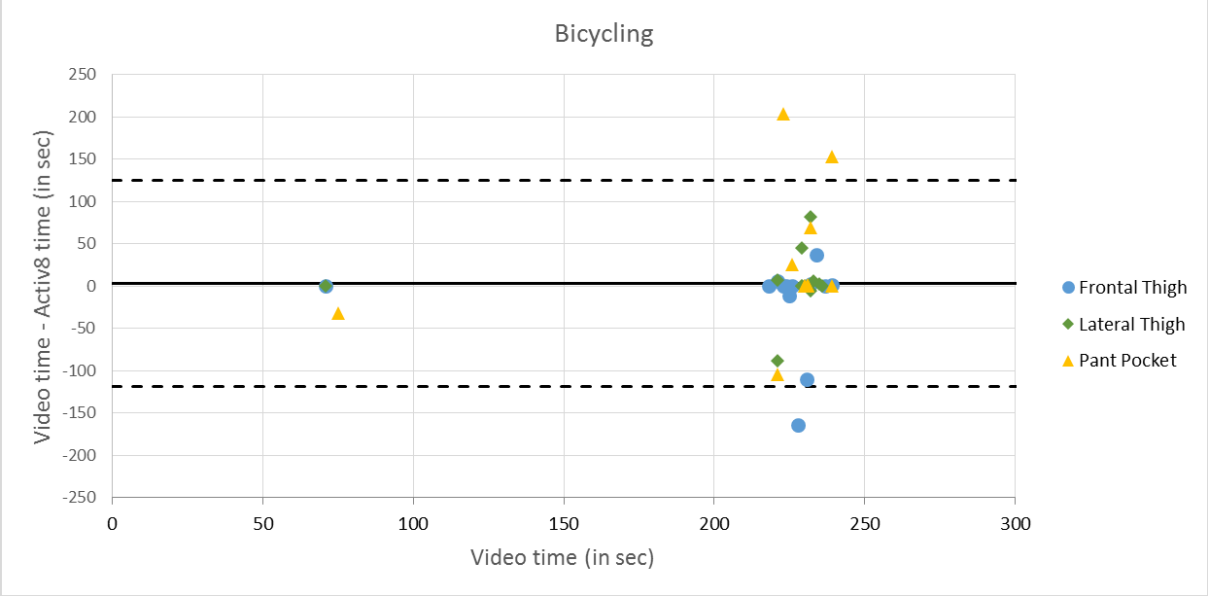
C


Basic Walking
Video time - Activ8 time (in sec)
Video time (in sec)
250
200
150
100
50
0
-50
-100
-150
-200
-250
0
50
100
150
200
250
300
350
400
Frontal Thigh
Lateral Thigh
Pant Pocket

D


Light-to-Moderate Upright Activity
Video time - Activ8 time (in sec)
Video time (in sec)
300
250
200
150
100
50
0
-50
-100
-150
-200
0
100
200
300
400
500
600
700
800
Frontal Thigh
Lateral Thigh
Pant Pocket

E



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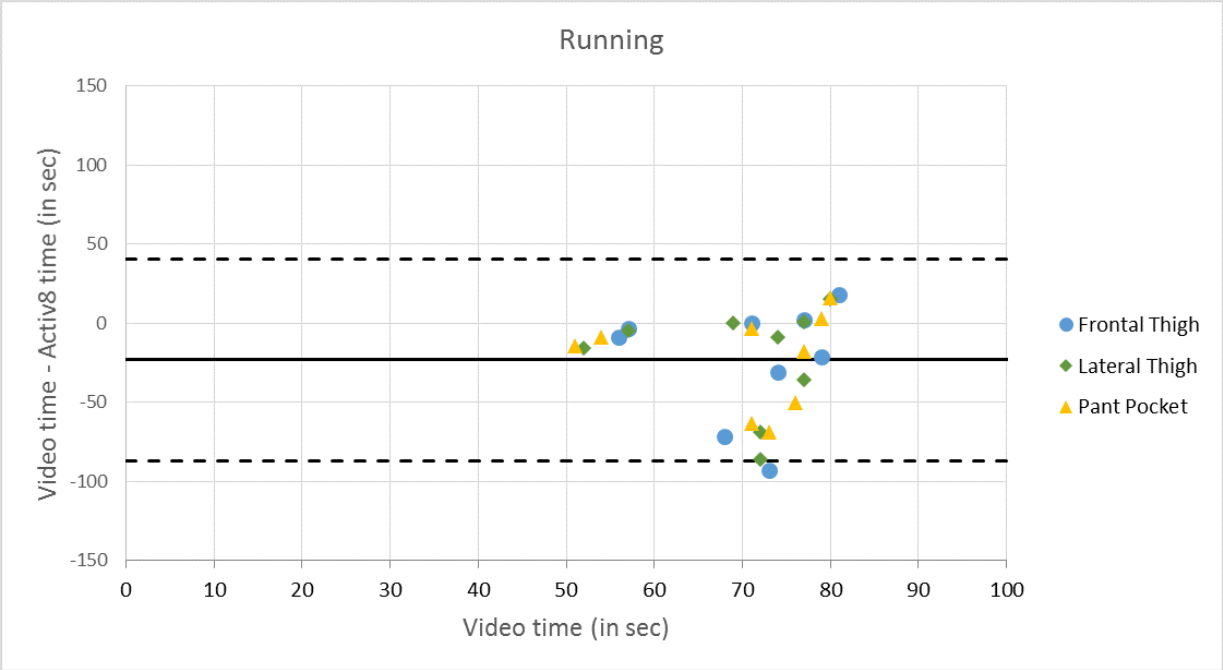


Figure 4. Bland-Altman plots between video observation and Activ8 measurement tools using Krouwer's method (201), comparing detected time within the P&M categories of

A) Sitting; B) Basic Standing; C) Basic Walking; D) Light-to-moderate Upright Activity; E) Bicycling; and F) Running. The middle solid line represents the mean difference between methods and the wide dashed lines represent the upper and lower limits of agreement.

Table 8. Wilcoxon signed-rank test comparing video time and Activ8 time for each P&M activity category

	Activ8 Leg Positions					
	Frontal Thigh		Lateral Thigh		Pant Pocket	
P&M Category	Z-score	*p*-value	Z-score	*p*-value	Z-score	*p*-value
Sitting	-2.30	.021*	-1.45	.146	-1.25	.213
Basic Standing	2.43	.015*	3.09	.002*	1.16	.247
Basic Walking	1.01	.314	0.14	.889	0.63	.529
Light-to-moderate Upright Activity	2.33	.020*	1.05	.294	1.45	.148
Bicycling	0.03	.973	1.00	.317	1.11	.266
Running	-1.84	.066	-1.89	.059	-2.05	.041*

P&M: Posture and movement
* p< .05

3.2 Results & Interpretation – OBJECTIVE 2

3.2.1 Participants

The characteristics of the fourteen adults (participant number 1 to 14) participating in this objective are displayed in Table 4. Please refer to section 3.1.1 for more details about participant characteristics.

3.2.2 Validity of the VitaMove Activity Monitor – Objective 2A

Absolute and relative differences in time between video observation and VitaMove AM for detection of body P&M are displayed in Table 9. Average relative time differences ranged from 1.69 to 23.8% among P&M categories for basic activities (median differences ranged from 0.00 to 7.02%). The combined category light-to-moderate upright activity was best detected, with an average relative difference of 0.91% between video and VitaMove measures. In addition to light-to-moderate upright activity, the VitaMove was able to adequately detect sitting, walking, and bicycling time (relative time difference <10%). Unlike the Activ8, the VitaMove overestimated standing time during basic activities (average relative time difference = 12.3%), despite having a median time difference of 3.57%. Bland-Altman plot analysis reveals that ninety of the 140 misclassified seconds resulted from one participant with a particularly slow walking speed (0.5 steps/sec, approximately 0.33m/sec); this slow walking time was categorized as standing by the VitaMove system. Another contrast with the Activ8 is the detection of running time, with a median time difference of only 7.02%. The larger average time difference is due to the VitaMove misclassifing 66 seconds of running as bicycling for

one participant with a crouched running gait and another 100 seconds of running misclassified as “move”, a subcategory of walking.

Lastly, though it is not displayed in the table, the VitaMove wrongly detected 484 seconds of sitting time as lying. To remain consistent with the analysis completed in section 3.1.1 and to allow for comparison between VitaMove and Activ8 activity monitors, lying time was added to the sitting P&M category. The angular position of the VitaMove monitor located on the trunk/chest allows differentiation between sitting and lying. However, slight deviation from the center plane, for example when a participant was leaning forward over a computer, led to the misclassification of sitting as lying. VitaScore users have the ability to increase this default angular threshold during kinematic analysis, but for the purpose of this paper all activity categorizations were left unmodified.

3.2.3 Comparison of VitaMove & Activ8 Activity Monitors – Objective 2B

Comparison of average relative time differences between video observation and AM measures reveal the Activ8 better detected the body P&M categories of sitting (0.25 vs 1.69% for Activ8 and VitaMove, respectively), standing (4.69 vs 12.3%), walking (2.46 vs 4.84%), and bicycling (3.19 vs 9.76%) during basic activities. The average relative time differences for running and light-to-moderate upright activity were lower for the VitaMove (23.8% and 0.91%, respectively) than the Activ8 (34.6% and 1.96%, respectively).

Data were not normally distributed. Therefore, non-parametric statistical tests were completed. Activity data collected from the Activ8 at the lateral thigh location was used when comparing video, VitaMove, and Activ8 measures, as this location yielded the best detection of body P&M. Spearman Rho correlation coefficients were calculated for each P&M category for video/Activ8, video/VitaMove, and Activ8/VitaMove relationships (see Table 10). Correlation coefficients range from 0.55 to 0.97 for video/VitaMove and from 0.59 to 0.99 for video/Activ8.

Results from subsequent Meng's tests, comparing Spearman Rho correlation coefficients, are displayed in Table 11. The Activ8 was significantly better correlated with video observation for the detection of basic walking (p=.009) and light-to-moderate upright activity (p=.002) than the VitaMove AM. Though the correlation coefficients between video/Activ8 were larger than video/VitaMove for all P&M categories, there was no statistical difference between coefficients for sitting, basic standing, bicycling, and running.

Bland-Altman plots comparing detected activity time by video observation, Activ8, and VitaMove measures are illustrated in Figure 5. The mean difference (95% CI) was 1.61 seconds (-6.56 to 9.77 sec) for sitting, -3.93 seconds (-11.5 to 3.6 sec) for basic standing, 10.5 seconds (-4.59 to 25.6 sec) for basic walking, 6.69 seconds (-4.43 to 17.8 sec) for light-to-moderate upright activity, -14.8 seconds (-38.4 to 8.85 sec) for bicycling, and -2.72 seconds (-21.9 to 16.4 sec) for running. The tightest limits of agreement were seen for sitting and standing P&M categories with the upper and lower limits of agreement

being 42.9 and -39.7 seconds for sitting and 34.1 and -42.0 seconds for standing. Visual examination of the plots revealed a potential bias in the measurement of sitting and running time, whereby the VitaMove frequently underestimates activity time within these P&M categories and the Activ8 marginally overestimates activity time. The trend was reversed with the detection of standing and bicycling time.

Wilcoxon Signed Rank tests reveal a significant difference between video observation and VitaMove measures of sitting ($p=.035$) and bicycling ($p=.026$) time. Sitting while completing activities such as donning and doffing a jacket or folding laundry was incorrectly classified as "move", a subcategory of walking, due to the increased movement of the trunk. Bicycling was largely overestimated in 3 participants (>50 seconds difference), all with a crouched gait. While completing activities such as stair climbing and mopping, walking time was misclassified as bicycling. The results of these Bland-Altman plots and Wilcoxon Signed Rank tests contrast the results presented in Table 9, indicating that although sitting and bicycling were well detected on a group level (relative differences of 1.7 and 9.7%, respectively), they were poorly detected on an individual basis (time differences ranged from 0 to 76 seconds for sitting time and from 0 to 172 seconds for bicycling time across individuals). Lastly, Wilcoxon Signed Rank tests also reveal a significant difference between video observation and Activ8 measures of basic standing time ($p=.02$, see Table 12), but no significant difference for other P&M categories.

Table 9. Total time within basic and complex activities, absolute time difference, and relative time difference between video observation and the VitaMove AM

	Video time (sec)		VitaMove time (sec)		Absolute Time Difference (sec)		Relative Time Difference (%)	
	Median (Q1, Q3)	Simple sum (n=14)	Median (Q1, Q3)	Simple sum (n=14)	Median (Q1, Q3)	Total[c] (n=14)	Median (Q1, Q3)	Average[c]
Basic Activities								
Sitting	237 (232, 258)	3490	237 (232, 256)	3431	0 (0, 0.8)	59	0.00 (0, 0.3)	1.69
Standing	81 (74, 86)	1141	83 (76, 92)	1281	3 (0.3, 9.3)	140	3.57 (0.3, 11)	12.3
Walking	290 (258, 300)	3822	283 (250, 300)	3637	16 (2, 39)	185	5.12 (0.7, 15)	4.84
Bicycling	229 (221, 232)	2598	231 (224, 235)	2850	0 (0, 0.8)	252	0.00 (0, 1.5)	9.70
Running	63 (0, 72)	622	24 (0, 71)	474	0 (0, 17)	148	7.02 (0, 51)	23.8
MV Upright Activity[a]	289 (223, 303)	3220	283 (229, 307)	3324	2 (0, 32)	104	0.65 (0, 11)	3.23
Complex Activities								
LM Upright Activity[b]	460 (348, 544)	6072	446 (386, 542)	6017	0 (0, 3)	55	0.39 (0, 0.8)	0.91

a. Moderate-to-vigorous Upright Activity; the sum of Bicycling and Running categories
b. Light-to-moderate Upright Activity; the sum of Standing, Standing with Movement, and Walking categories
c. Based on simple sum values

Table 10. Correlation coefficients between video observation, Activ8, and VitaMove activity measurements

	Sitting			Basic Standing			Basic Walking		
	Video	Activ8	VitaMove	Video	Activ8	VitaMove	Video	Activ8	VitaMove
Video	-			-			-		
Activ8	0.98***	-		0.71**	-		0.95***	-	
VitaMove	0.97***	0.93***	-	0.64*	0.93***	-	0.78**	0.81***	-
	Light-to-Moderate Upright Activity			Bicycling			Running		
	Video	Activ8	VitaMove	Video	Activ8	VitaMove	Video	Activ8	VitaMove
Video	-			-			-		
Activ8	0.99***	-		0.59*	-		0.77**	-	
VitaMove	0.94***	0.95***	-	0.55*	0.61*	-	0.66*	0.77**	-

* p< .05
** p< .01
*** p< .001

Table 11. Comparison of dependent Spearman Rho correlation coefficients (video-Activ8 vs video-VitaMove) using Meng's method of analysis

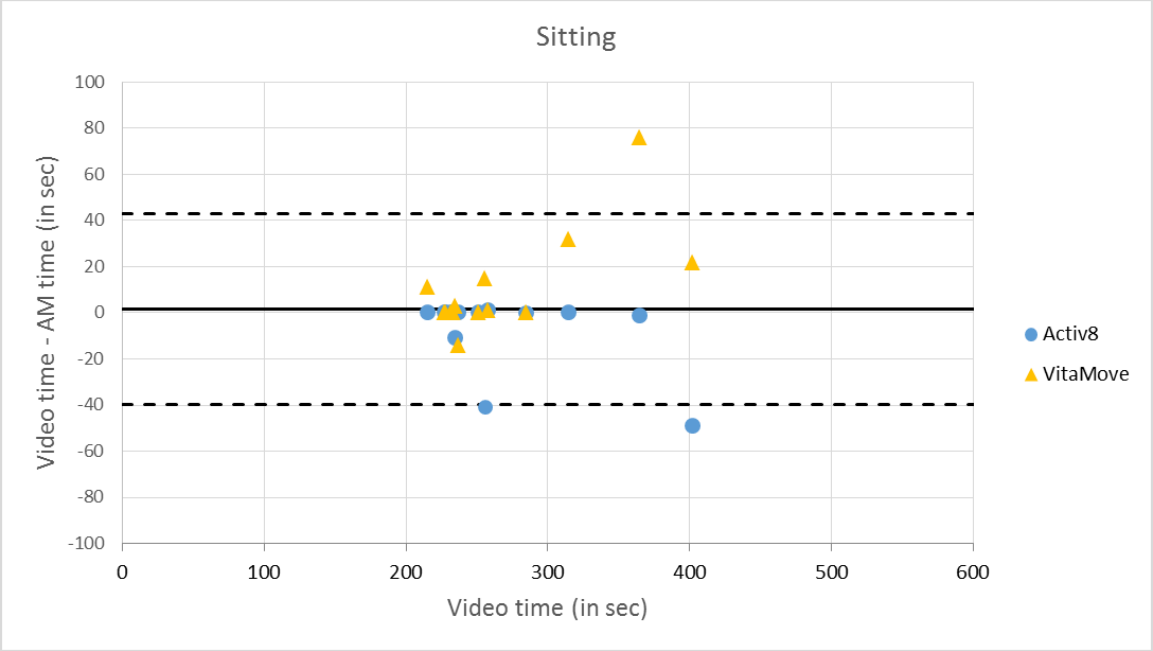
	Sitting	Basic Standing	Basic Walking	Upright Activity[a]	Bicycling	Running
r_1	0.98	0.71	0.95	0.99	0.59	0.78
r_2	0.97	0.64	0.78	0.94	0.55	0.66
Z-score	0.87	0.89	2.62	3.12	0.23	0.86
***p*-value**	.383	.373	.009*	.002*	.822	.391

r_1: correlation coefficient for video/Activ8; r_2: correlation coefficient for between video/VitaMove

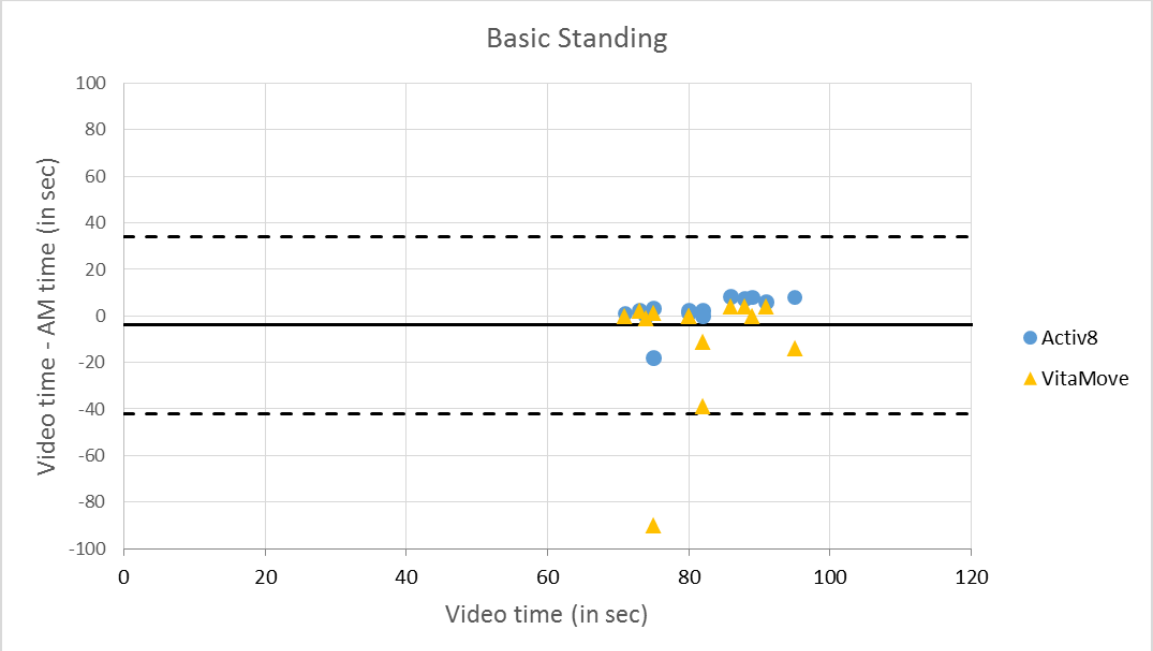
a. Light-to-moderate Upright Activity

* $p < .05$

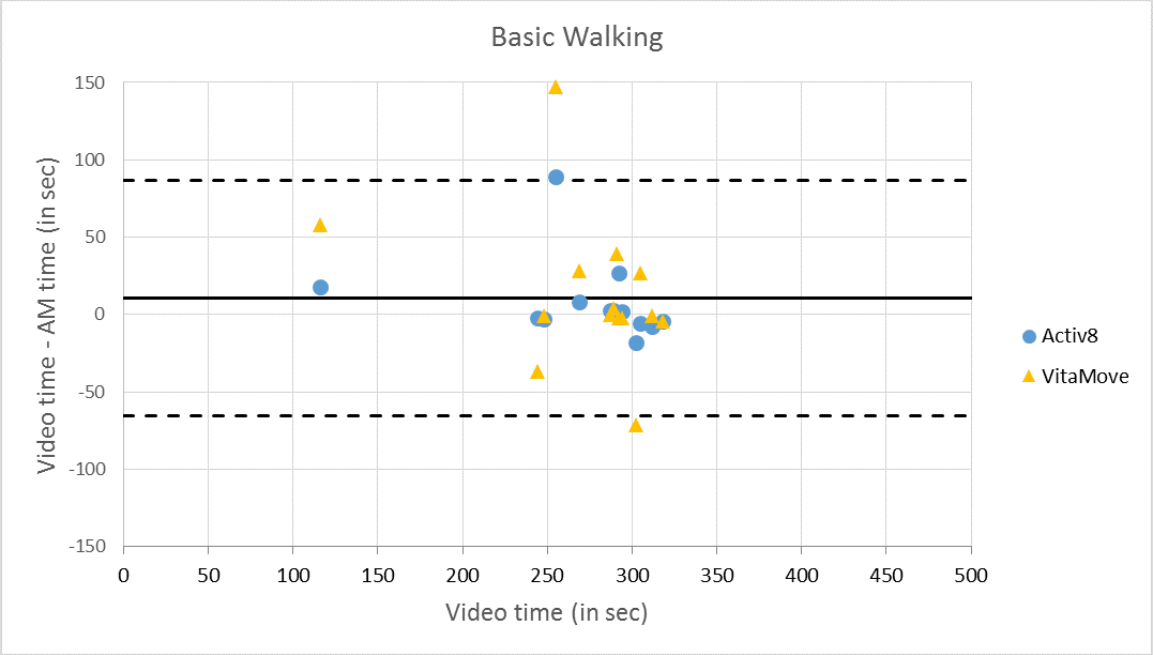
A


Sitting
Video time - AM time (in sec)
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
100
200
300
400
500
600
Video time (in sec)
Activ8
VitaMove

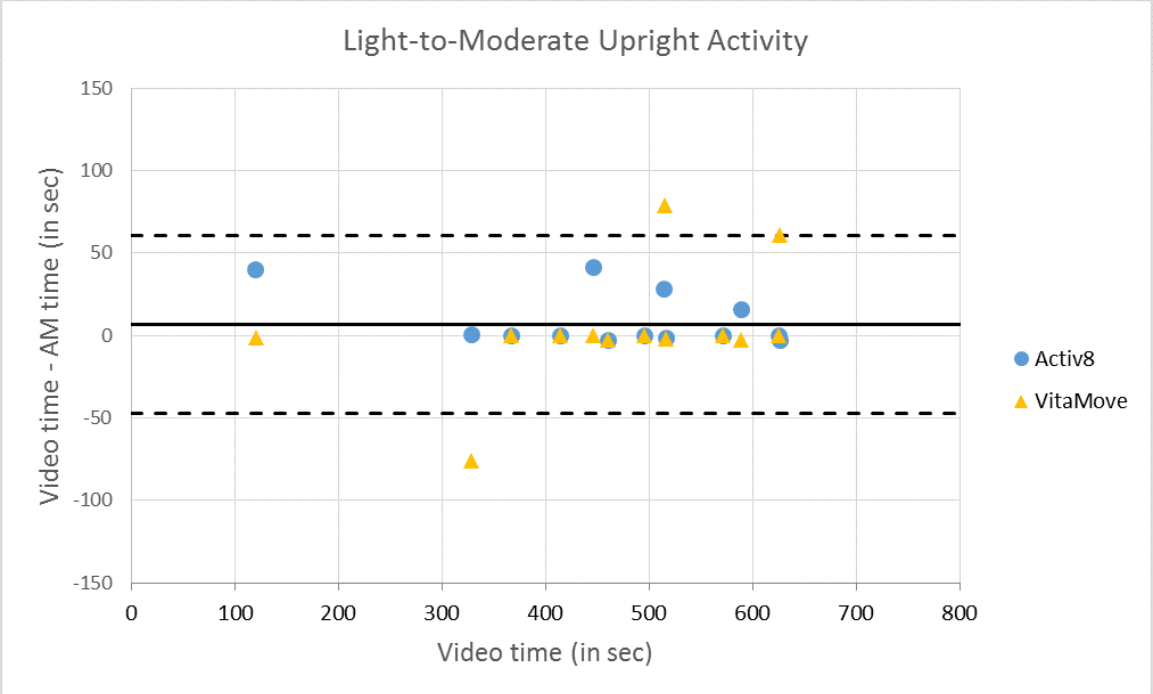
B


Basic Standing
Video time - AM time (in sec)
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
20
40
60
80
100
120
Video time (in sec)
Activ8
VitaMove

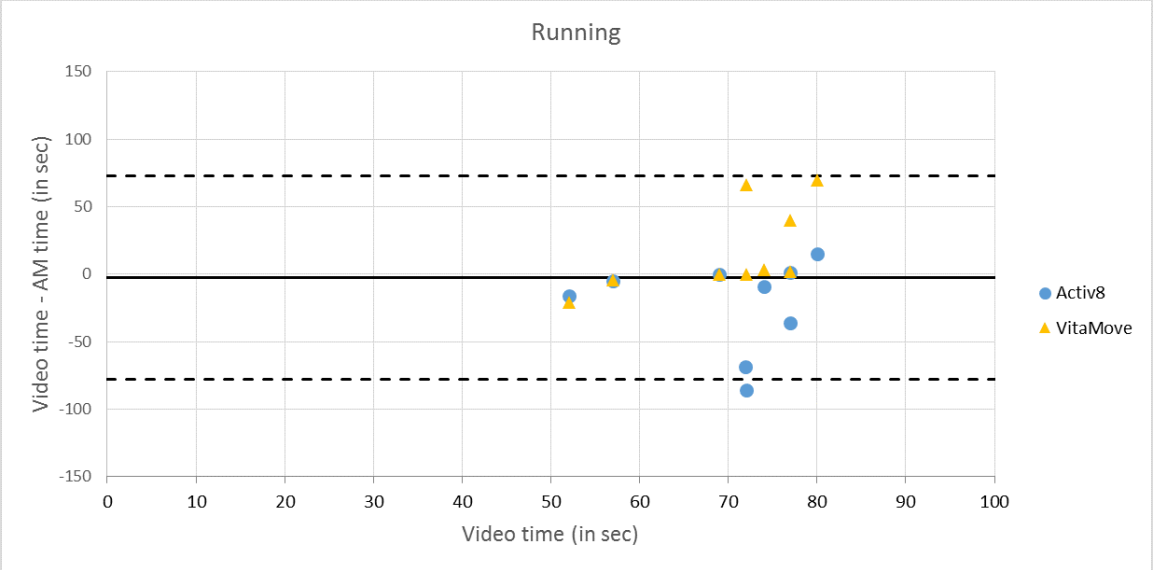
C


Basic Walking
Video time - AM time (in sec)
150
100
50
0
-50
-100
-150
0
50
100
150
200
250
300
350
400
450
500
Video time (in sec)
Activ8
VitaMove

D


Light-to-Moderate Upright Activity
Video time - AM time (in sec)
150
100
50
0
-50
-100
-150
0
100
200
300
400
500
600
700
800
Video time (in sec)
Activ8
VitaMove

E



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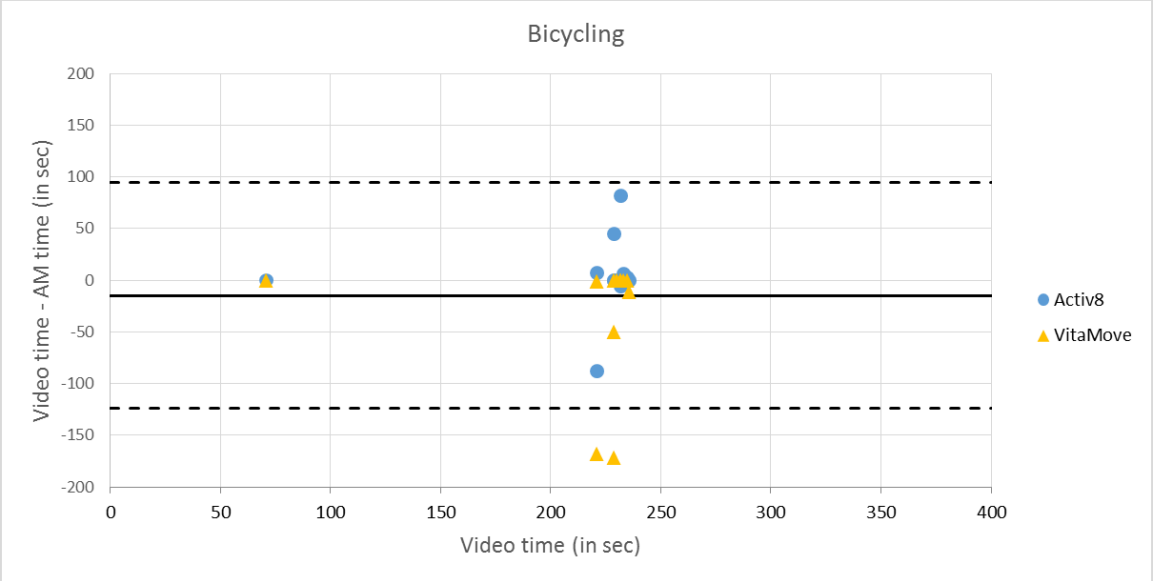


Figure 5. Bland-Altman plots between video observation and AM measurement tools (Activ8 and VitaMove AMs) using Krouwer's method (201), comparing detected activity time within the P&M categories of A) Sitting; B) Basic Standing; C) Basic Walking; D) Light-to-moderate Upright Activity; E) Bicycling; and F) Running. The middle solid line

represents the mean difference between methods and the wide dashed lines represent the upper and lower limits of agreement.

Table 12. Wilcoxon signed-rank test comparing video- and activity monitor-derived P&M activity time

	Activ8		VitaMove	
P&M Category	Z-score	*p*-value	Z-score	*p*-value
Sitting	-1.44	.149	2.11	.035*
Basic Standing	2.33	.020*	-0.51	.610
Basic Walking	0.54	.593	0.53	.593
Light-to-moderate Upright Activity	1.02	.308	-0.85	.398
Bicycling	1.01	.310	-2.22	.026*
Running	-1.87	.061	1.18	.237

P&M: Posture and movement
* p< .05

3.3 Results & Interpretation – OBJECTIVE 3

3.3.1 Participants

The characteristics of the three wheelchair users (participant number 3, 6, and 15) participating in this sub-study are displayed in Table 4. All three participants had bilateral spastic CP and were classified in GMFCS levels III (n=2) and IV (n=1). Two participants were partial wheelchair users, operating their wheelchair in community settings but ambulating with or without an assistive mobility device, such as a walker, in their own home. Participant 6 frequently used his wheelchair to patter (*trippelen* in Dutch), rather than drive his wheelchair, as both upper limbs were more severely affected by spasticity than his lower limbs. Therefore, the activity of pattering was added to the activity protocol during his assessment.

3.3.2 Comparison of Wheelchair Activ8 and VitaMove Activity Monitor

Absolute and relative time differences in the detection of sedentary and active upper body movement between video observation and each wheelchair AM are displayed in Table 13. Figure 6 contains two bar graphs that show total sedentary and active upper body movement time for each of the three participants. The Wheelchair Activ8 better detected these two P&M categories, with a relative time difference between video and Wheelchair Activ8 measures ranging from 1.85 to 16.5%. By comparison, the relative time difference between video and the VitaMove wheelchair monitor ranged from 8.61 to 95.9%. Wilcoxon Signed Rank tests revealed no significant difference between measures of sedentary or active upper body time (Table 14).

To estimate agreement between the Wheelchair Activ8 and video observation on an individual level for all possible wheelchair P&M categories, an adapted Bland-Altman plot (199,200) was created post-hoc (see Figure 7). From this plot as well as the data presented in Table 15, it is apparent that wheelchair driving time is overestimated and active upper body time is underestimated by the Wheelchair Activ8. Upon closer inspection of the video recordings, this classification discrepancy is due to minor rocking of the wheelchair during some active upper body activities, including ball sport exercises and folding laundry. Wilcoxon Signed Rank tests revealed no significant difference between video observation and Wheelchair Activ8 measurements of sedentary upper body ($z=0.272$), active upper body ($z=1.60$), wheelchair driving ($z=-1.60$), or assisted driving ($z=0.277$) in this small group of wheelchair users ($p>.05$ for all).

Table 13. Total time within sedentary and active upper body activity categories, absolute time difference, and relative time difference between video observation and the Wheelchair Activ8 (A) and video observation and VitaMove Wheelchair (B) AM

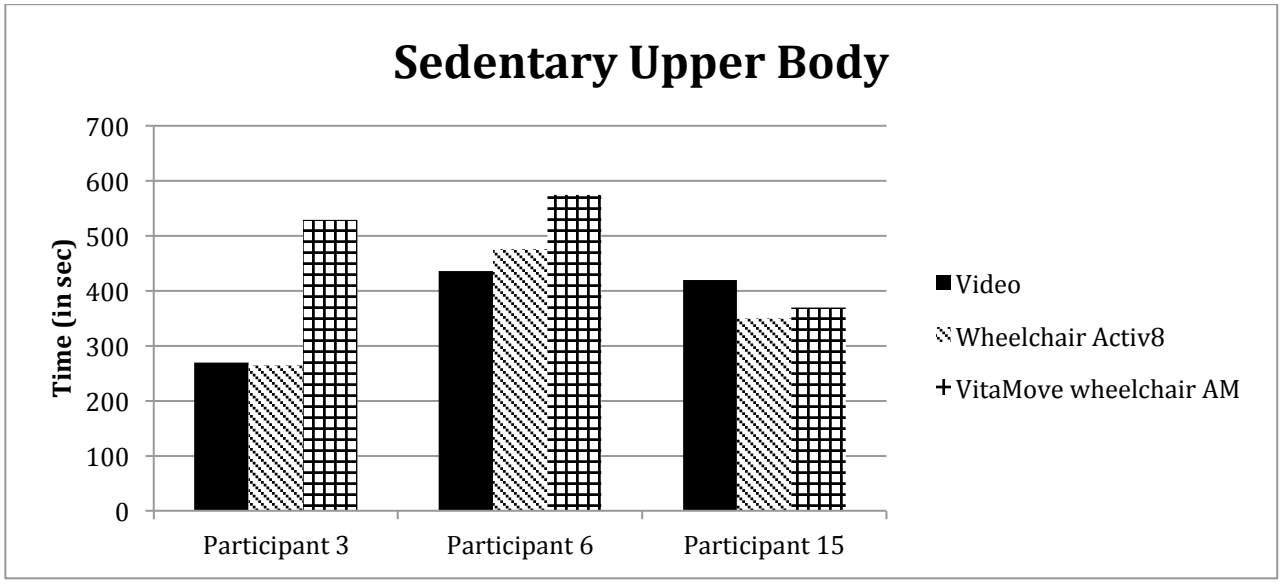
Table 13A

	Video time (sec)	Activ8 time (sec)	Absolute Time Difference (sec)	Relative Time Difference (%)
Sedentary Upper Body				
Participant 3	270	265	5	1.85
Participant 6	436	475	39	8.94
Participant 15	419	350	69	16.5
Active Upper Body				
Participant 3	470	475	5	1.06
Participant 6	354	315	39	11.0
Participant 15	581	650	69	11.9

Table 13B

	Video time (sec)	VitaMove time (sec)	Absolute Time Difference (sec)	Relative Time Difference (%)
Sedentary Upper Body				
Participant 3	270	529	259	95.9
Participant 6	436	574	138	31.7
Participant 15	419	369	50	11.9
Active Upper Body				
Participant 3	470	211	259	55.1
Participant 6	354	216	138	39.0
Participant 15	581	631	50	8.61

A



B

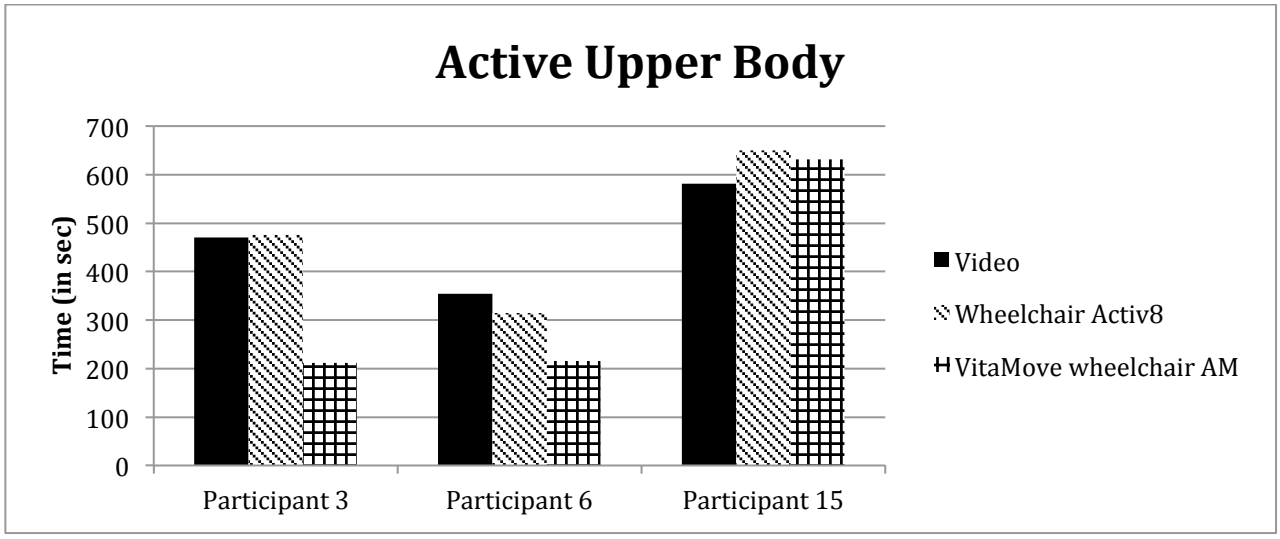


Figure 6. Sedentary upper body time (A) and active upper body time (B) across three participants as determined by video observation, the Wheelchair Activ8, and VitaMove wheelchair AM

Table 14. Wilcoxon signed-rank test comparing video- and activity monitor-derived sedentary upper body and active upper body time in wheelchair users

	Activ8		VitaMove	
Activity Category	Z-score	*p*-value	Z-score	*p*-value
Sedentary Upper Body	0.54	.593	-1.07	.285
Active Upper Body	-0.54	.593	1.07	.285

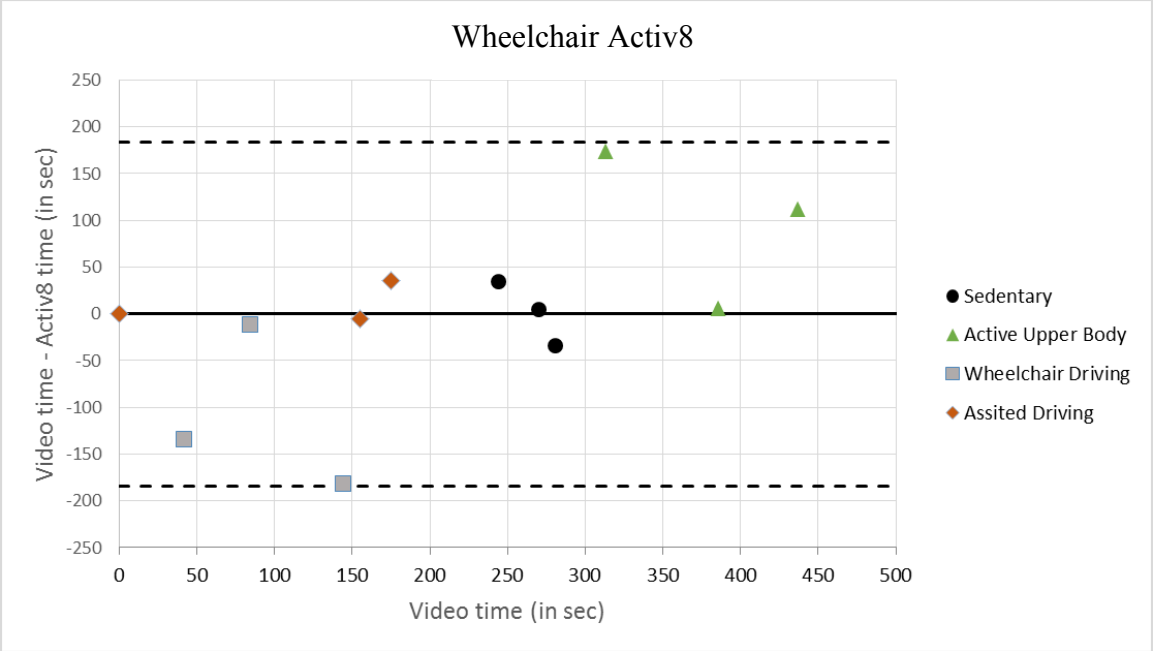


Figure 7. Bland Altman plot between detected wheelchair activity time from video observation and the wheelchair Activ8 AM using Krouwer's method (201). The middle solid line represents the mean difference between methods and the wide dashed lines represent the upper and lower limits of agreement.

Table 15. Total time within wheelchair activity categories, absolute time difference, and relative time difference between video observation and the Wheelchair Activ8

	Video time (sec)	**Activ8 time (sec)**	**Absolute Time Difference (sec)**	**Relative Time Difference (%)**
Sedentary				
Participant 3	270	265	5	1.85
Participant 6	281	315	34	12.1
Participant 15	244	210	34	13.9
Active Upper Body				
Participant 3	386	380	6	1.55
Participant 6	313	140	39	55.3
Participant 15	437	325	112	25.6
Wheelchair Driving[a]				
Participant 3	84	95	11	13.1
Participant 6	41	175	134	326
Participant 15	144	325	181	126
Assisted Driving				
Participant 3	0	0	0	-
Participant 6	155	160	5	3.23
Participant 15	175	140	35	20.0

a. Includes both maneuvering and wheelchair driving (all speeds)

CHAPTER 4 – GENERAL DISCUSSION

The first and second objective of this study evaluated the criterion validity of the Activ8 Physical AM and the VitaMove AM in the detection body P&M during fundamental daily life activities in ambulatory adults with spastic CP. The third objective provided proof for the concept of a Wheelchair Activ8 AM to detect activity in non-ambulatory, manual wheelchair users. Participating adults covered a range of ages and gross motor function; twelve participants were able to ambulate with or without the use of a mobility aide, two participants were partial ambulators and partial manual wheelchair users, and one participant was completely dependent on his wheelchair for mobility.

Overall, the Activ8 monitor demonstrated acceptable agreement with the reference method of video observation in the detection of body P&M in ambulatory adults with CP. The low absolute and relative time differences between video observation and AM methods of measurement suggest the Activ8 is an appropriate tool to detect free-living PA. As the Activ8 offers wearers an online user-interface for personal goal setting and coaching, but still can provide researchers and clinicians insight into raw activity data, it can be considered a hybrid between a research-grade and consumer-grade AM. When contrasting median and average relative time differences for the detection of each body P&M, it is evident that gross misclassification of activity time by AM measures is often only seen in one or two outliers. With a larger sample of adults, one could expect the average relative time difference to fall closer to the median, further supporting the validity of the Activ8 AM. Furthermore, the differences between median and average values draws attention to underlying issues regarding AM placement and classification

algorithm to be addressed. For example, by reviewing the gait patterns and characteristics of outliers, it became evident that the attachment position of the Activ8 on an individual's thigh substantially influences the detection of P&M. The positioning of the monitor is of particular importance for clinicians and researchers working with patients with hypertonicity, secondary musculoskeletal deformities and /or deviated gait pattern, such as persons with CP or survivors of stroke. Muscle spasticity and contractures across joints may lead to a crouched stance and/or crouched gait pattern (204,205). In this study, four participants with prominent crouched stances and a crouch gait pattern had standing frequently misclassified as sitting and walking misclassified as bicycling with the frontal thigh Activ8 location. As mentioned previously, the misclassification of a crouched stance and gait is the result of the P&M classification algorithm used by the Activ8, which considers both vector magnitude acceleration and the angular position (as determined by the z-axis accelerometer). During a crouched stance and gait, the knee does not fully extend, decreasing the angle of the thigh relative to the hip, leading to greater gravitational/accelerative forces detected by the z-axis accelerometer. Once the z-axis accelerative force surpasses a threshold, the Activ8 will categorize a posture as sitting and a movement as bicycling. Alternatively, positioning of the Activ8 monitor on the lateral thigh, compared with frontal thigh location, resulted in more accurate detection of sitting, basic standing, basic walking, and both pooled activity categories, light-to-moderate upright activity and moderate-to-vigorous upright activity, during basic and complex activities. At this lateral thigh location, gravitational/accelerative forces detected by the z-axis accelerometer are not as large as those detected by the frontal thigh monitor. For this reason, crouched stance and gait are properly categorized as standing and

walking. One of the disadvantages with the lateral thigh position is that it is more difficult to standardize. If the Activ8 were ever used for extended measurement periods (e.g. 7-days) and/or if patients were asked to place the monitor on their own thigh, instructions to attach the monitor to the frontal thigh, along the midline of the thigh, are much simpler than instructions to attach the monitor approximately 2 cm laterally from the midline. Future Activ8 algorithms and products should aim to resolve the inaccurate classification of crouched stance and gait when attached to the frontal thigh location.

Though the detection of P&M from the pocket position shows larger between-subject variability compared to the thigh positions, detection of body P&M was still acceptable (<10% difference) during basic and complex activities, with the exception of bicycling and running. The reasons as to why misclassification of bicycling and running time were observed have been discussed in section 3.1.2 and may be related to loose pant pockets allowing excessive monitor movement. For long-term, community-based lifestyle intervention programs, the utility, convenience, and practicality of the pocket position may increase user adherence and therefore should be considered. However, the results clearly indicate the lateral thigh Activ8 position has higher criterion validity.

The study results highlight several important considerations when using the Activ8 AM for detection of body P&M. The first important consideration is with regard to ambiguous movements and determining the most sensible way to categorize such movements. In particular, the distinction between standing and walking in the video was not always easy to make. In this study, movements that fell between standing and walking were given the

classification "standing with movement". Examples of these movements ranged from minor foot/leg movements when someone was standing restlessly to brief lunges such as when trying to reach a mop underneath a chair or table. During complex activities, the Activ8 overestimated walking time and underestimated standing time as a result of this ambiguous movement. To account for this, these P&M categories were merged, allowing more accurate comparison of light-to-moderate upright activity between the video observation and Activ8 measurement tools. The distinction between standing and walking requires the attention of Activ8 users. It should be noted that former validation studies using the DynaPort MiniMod AM also noted difficulties in distinguishing standing, shuffling, and walking in adults with Parkinson's disease due to the grey area movement characterized by quick alternations between these P&Ms (175). The clinical importance of the distinction between standing and walking should be discussed. A large percentage of "standing with movement" time was detected as walking by the Activ8, and perhaps appropriately so. The majority of these ambiguous movements were fairly vigorous in nature, and may require similar energy expenditure as walking. Additionally, research by Verschuren *et al*. has demonstrated that youth with CP have elevated energy expenditure during standing across all GMFCS levels, which reduces intervals of SB and contributes to the accumulation of light intensity PA (206). Researchers and clinicians have suggested that it is important to promote breaks from SB, in addition to increased PA, particularly for individuals with CP (8,207). Therefore, in terms of health benefits, the distinction between standing and walking may not always be necessary or pertinent information. The pooled category of "light-to-moderate upright activity" may be appropriate when analysing free-living physical behaviour patterns in adults with CP.

When compared to the VitaMove activity monitoring system, the Activ8 better detected several P&M including sitting, standing, walking, and bicycling. Furthermore, the Activ8 was significantly better correlated with video observation for the detection of light-to-moderate upright activity than the VitaMove. These surprising results are of particular importance because the VitaMove is considered a high-end, multi-sensor AM. It offers greater insight into physical behaviour: monitoring time can be categorized into more than twenty different body P&M; it providing continuous data regarding the angular position and accelerative force/motility of each monitor; and it provides a signal data for each axis (longitudinal, sagittal, and transverse) within each monitor. Due to the multiple sensors part of the monitoring system and the sophisticated data analysis software, the VitaMove is far more expensive; the VitaMove costs $1350 USD per ambulatory AM system (3 monitors), which excludes the software price, whereas the Activ8 costs $170 USD and software is free (93, www.activ8all.com). The results from this study suggest that without extensive data cleaning and processing, the default algorithms used in the VitaScore software may lead to inaccurate classification of activity time.

As an additional post-hoc analysis, median time differences were compared across gross motor function levels (GMFCS levels I vs II vs III). There were no significant differences between GMFCS levels for median time differences between video and Activ8 measures. However, Kruskal-Wallis tests revealed a significant difference between GMFCS levels for time differences between video and AM measures using VitaMove-derived activity time from sitting, walking, and light-to-moderate upright activity categories (see

Appendix D). Wilcoxon Ranked Sum tests show median time differences in sitting and walking time from participants in GMFCS level III were significantly different than for GMFCS level I and level II. With regard to light-to-moderate upright activity, median time differences from GMFCS level II were significantly different than GMFCS level I. Sitting and walking time from adults with GMFCS level III were significantly underestimated by the VitaMove AM. Furthermore, light-to-moderate upright time was also significantly underestimated in adults with GMFCS level II, but not GMFCS level III.

The poor categorization of sitting among GMFCS level III participants is due to the trunk monitor, which is sensitive to chest movements. During the activity "don and doff a jacket", participants in GMFCS level III all chose to sit. Excess chest movement caused this time to be classified as "move", a subcategory of walking, even though the participants were sitting. Walking was underestimated among this same group of participants most likely as a result of their slower pace. The last difference, between GMFCS level I and II for detection of light-to-moderate upright activity, is due to misclassification of a crouched gait as bicycling. Regardless of the reasoning, all this evidence suggests the Activ8 is a superior and cheaper alternative for the measurement of physical behaviour in ambulatory adults with CP.

Compared to published studies validating another popular research-grade AM in adults with CP, the activPAL, the Activ8 demonstrated comparable if not slightly better validity in the detection of P&M (163,176). Furthermore, as the activPAL can only distinguish

between sitting, standing, and stepping time (163,173), the Activ8 provides greater insight into physical behaviour. Unfortunately, a common issue with both activPAL and Activ8 AMs is that neither monitor can distinguish between transient lying and sitting (173).

This study was the first ever evaluation of the Wheelchair Activ8 as a tool to detect wheelchair P&M in a clinical sample. The Wheelchair Activ8 configuration and custom-made MATLAB data analysis algorithm provide proof of concept. By attaching and synchronizing one accelerometer to the wrist and the other accelerometer to the spokes of the wheelchair, both arm and wheel movements can be measured simultaneously; this allows valid quantification of the amount of self-propelled wheelchair driving and maneuvering as well as engagement in other activities, including upper-limb activities, sitting in a wheelchair without arm movements, and assisted wheelchair driving such as being pushed. Compared to several other AMs used within wheelchair users, the Wheelchair Activ8 offers more insight into body P&M by classifying activity into numerous distinct categories. Some monitors used with wheelchair users merely distinguish between active and sedentary activity, either with regard to the upper body such as seen with the VitaMove (162) or with regard to wheelchair movement, regardless of propulsion technique (179,208). The majority of other AMs for wheelchair users provide estimates of energy expenditure, but have not been calibrated for, used with, or validated in persons with CP (181). Knowing the issues regarding heterogeneous estimates of energy expenditure with AMs in ambulatory individuals (93) as well as the fact that individuals with CP have different energy costs than other populations (92), the

Wheelchair Activ8 offers a great alternative for assessment of physical behaviour in adults with CP. However, with only three wheelchair users participating in this study, the validity of the Wheelchair Activ8 monitor needs to be evaluated in a larger clinical sample.

4.1 Clinical Relevance

In the current study, participants performed a series of activities in a simulated free-living environment. Daily life activities typically include a considerable amount of upper body movement, which may lead to misdetection of activity by the monitor (103). This is one of the strengths of this study; validation of the Activ8 while completing free-living activities may better reflect the true accuracy and future applicability of the monitor.

The results of the Wheelchair Activ8 are both promising and exciting. Once validated in a larger cohort of wheelchair uses, the Wheelchair Activ8 would be invaluable to allow to researchers to assess the physical behaviour of a broad range of functional abilities, including non-ambulatory adults with CP and adults with spinal cord injury.

An important clinical feature of the Activ8 is the ability to set goals and to offer feedback, allowing users to monitor their HPA from their personal computer or mobile device. Furthermore, clinicians and researchers can remotely monitor the HPA of their clients through the use of a coach dashboard feature. The features of goal setting and user feedback are also seen with a number of consumer-grade AMs, such as the Fitbit trackers (www.fitbit.com). The Activ8, however, is arguably better than Fitbit products or other

consumer-grade AMs for use in rehabilitation research. For one, Activ8 offers researchers access to raw data, which can be used to assess physical behaviour in greater detail. The Activ8 activity outcome, detection of body P&M, may be a more appropriate activity outcome in adults with CP than time within activity intensities (e.g. MVPA) and estimates of energy expenditure, as these have been calibrated in a healthy population. Furthermore, the heterogenous and inaccurate detection of MVPA and energy expenditure by consumer-grade AMs leave few valid outcome variables, namely step count (90,107). Ultimately, the Activ8, and the Wheelchair Activ8, appear to be better tools for researchers evaluating physical behaviour in this population.

As discussed briefly in Chapter 1, a number of studies have reported that AM user feedback was associated with beneficial health action and stimulated behaviour change (101,102). User feedback, through an online website or via a smart phone app, was associated with an increased likelihood to log >10,000 steps per day over a 90-day study period compared with those who did not receive this feedback (102). Wearable technologies using web or mobile platforms for goal setting and feedback have been shown to align with behaviour change theories (101). Furthermore, AMs like the Activ8 can be used to compare one's own progress against peers or a broader community of users, both of which are advantageous mediators to increasing overall PA (209). These features may provide the stimulus needed to promote change, fitting well into the Health Belief Model as a *cue to action* and may even help improve one's *self-efficacy*. This grand theory of behaviour change can be supplemented and informed by both control theory and CALO-RE taxonomy.

4.1.1 Control theory and CALO-RE taxonomy

Control theory purports that setting goals, self-monitoring, and interpreting feedback are important aspects of motivation and behaviour change (210,211). Formerly known as cybernetic control, control theory was originally developed as an approach to understanding self-regulating systems and has been applied to the fields of engineering, mathematics, economics and medicine (211). Carver and Scheier suggest that when one's current performance is discrepant from the standard or set goal, a negative feedback loop will minimize or remove the discrepancy (211). In the context of PA, if an individual becomes aware that their current level of PA falls below a set goal or target, the individual would re-evaluate their latest performance and be driven to increase their activity (210). Research evaluating the effect of control theory on health behaviour have noted that intervening on all aspects of the feedback loop (i.e. goal setting, self-monitoring, and feedback) leads to the greatest changes (210).

The Coventry, Aberdeen, and London – Refined (CALO-RE) taxonomy of behaviour change builds on former research that classified psychological techniques used in intervention to change behavior, but has a particular emphasis on physical activity and nutrition (212). CALO-RE identifies self-monitoring, in combination with the self-regulatory skills of goal setting and frequent behavioural feedback, as the most important theory-driven components of successful behaviour change (213).

Control theory and CALO-RE have both been used to inform research and evaluate behaviour change in the context of PA. This evidence provides the theoretical underpinnings to support the use of goal setting and feedback, integrated into an intervention or health promotion program. This is of particular importance for researchers and clinicians designing interventions that promote PA and a healthy lifestyle among patient groups with lower levels of habitual PA, such as persons with CP. Implementing a measurement tool that empowers the user, allowing the individual to self-regulate, to record and monitor set goals, as well as provide users with feedback, may promote HPA and sustain improved HPA after an exercise training intervention (210,213).

4.2 Limitations

This study was only able to evaluate the validity of the Activ8 in ambulatory adults with CP. Future research with a greater number of participants is warranted to establish the validity of the Wheelchair Activ8 for non-ambulatory, wheelchair users.

In this particular study, the recruitment success was lower than originally expected (n=30, as outlined in the consent letter). One should consider the feasibility of a validation study in non-ambulatory adults. Perhaps mobility limitations deter partly or completely dependent wheelchair users from attending a study assessment outside of their home setting. With this in mind, one may consider whether volunteer bias influenced the results of this study.

The structured activity protocol and simulated "home" environment within the occupational therapy unit of the rehabilitation department may not truly represent free-living activity in the home and community setting. The structured activity protocols most certainly missed a number of important activities of daily living, such as self-care (i.e. bathing), certain sport/leisure time activities (e.g. swimming), and mobility in the community (e.g. bicycling outdoors, public transportation, etc.). Aquatic-based therapy and PA are common among persons with CP (150,158,214). In fact, Usuba *et al*. stated that swimming was the third most common leisure time PA among adults with CP, with 54% of their sample reporting swimming participation (150). An issue is that common with most AMs is that they cannot be worn in water, as the water would damage the electrical components of the device. If researchers can determine an effective way of waterproofing the AMs, this would enhance the utility of "wearable" technology in rehabilitation research.

A major limitation of this work is the fact that only one rater coded video recordings. Previously validation studies using video (or direct) observation as criterion measures have used two or more raters to ensure the most appropriate body P&M classification is used for each 1-second frame by comparing the scores of the raters and determining the inter-rater reliability (162,163,176,178,215). In this manner, any inconsistent video scores will be highlighted, improper scores/mistakes rectified, and ambiguous data can be discussed and resolved. However, in this study, ambiguous video was highlighted and discussed with a researcher experienced in video coding, in order to minimize potential bias.

Currently, there are two minor issues with the Activ8 as a result of cheaper hardware. The first is that there is a 21-second delay between real-time recorded activity and the activity data displayed in the CSV output file. The second issue is more complicated: the Activ8's hardwired 32-sample FIFO buffer does not synchronize well with the 12.5Hz sample rate. As a result, activity data presented in the CSV data output is misaligned. At a 12.5Hz sampling rate, and only 32 samples allowed in each FIFO buffer, 2.54 seconds of activity data will fill a single buffer. However, with a 5-second epoch, two FIFO buffers is slightly too much activity data (2 buffers = 5.08 seconds of data). When the majority of a sampled second spills over into a new buffer, the data output will squeeze 6-seconds into a single row. Both of these issues are not damaging and do not result in missing data, but are confusing and require special attention. Until the Activ8 developers resolve these problems by changing the sampling frequency or type of FIFO buffer, researchers need to be aware of these issues, especially when using data from small time intervals.

4.3 Future Directions

To date, the inter-device reliability of the Activ8 AM has not been evaluated. Establishing the parameters of the device, including reliability, is essential before extending its use in large intervention trials.

In addition to some of the changes mentioned in the Limitations section, the name of the categories "lying" and "running" also need to be changed by the Activ8 developers. Since

"lying" is only detected if the device is still for 5 consecutive minutes, this first category would be better represented with the name "non-wear". Furthermore, the current Activ8 classification algorithm categorizes all movement with a high vector magnitude as running, regardless of the unit's angular position. The category name "running" is misleading and should be changed to "vigorous movement" or "high intensity activity" to more appropriately depict movement categorized as such.

In addition to evaluating the validity of the Wheelchair Activ8 with a larger sample, the current classification algorithm may need to be fine-tuned and tested. In this study, two participants did not have their wheelchair wheels fixed or locked in a break position during active upper body activities, such as folding laundry. As a result, the Wheelchair Activ8 overestimated maneuvering and wheelchair driving time, while underestimating active upper body time. By increasing the wheel monitor threshold (currently 31 vector magnitude counts) by a factor of 1.5, the wheel monitor will be less sensitive to minor rocking movements and would better classify active upper body activity while sitting.

The integrated feedback and coaching features further support the use of the Activ8 as a support tool in lifestyle intervention studies and may supplement lifestyle programs, like the lifestyle program evaluated in the Learn to Move program described by Slaman and colleagues (21), by allowing participants to receive on-going feedback and remotely interact with a coach/therapist through an online dashboard. Future research should aim to assess the goal setting and feedback features of the Activ8, assessing whether these components promote HPA and/or help sustain the beneficial effects of an exercise or

lifestyle intervention program. Going a step further, would be to add a heart rate monitor to future Activ8 models, perhaps by using the same technology as high-end consumer-grade AMs (known as photopleysmography). Not only could this provide insight into patient heart rate and energy expenditure, but it would also allow researchers to determine whether the AM is being worn (i.e. adherence) and could provide a minute-by-minute (even second-by-second) report of wear time (90). While not reviewed here, researchers do need to consider ethical issues related to privacy and security when using shared data through online or mobile dashboards (216).

4.4 Conclusion

The Activ8 is a suitable direct and objective measurement tool to assess HPA and SB, through detection of body P&M, in ambulatory adults with spastic CP. The Activ8 has demonstrated good criterion validity (<10% relative time difference) in the measurement of physical behaviour during both basic and complex activities in a simulated home environment. Attachment of the device to the lateral thigh led to the most accurate detection of physical behaviour compared to frontal thigh and pant pocket positions. However, the pant pocket Activ8 demonstrated adequate validity. Given the utility and practicality of the pant pocket position, researchers and clinicians should consider the use of this location in future practice. Comparison of the Activ8 with the VitaMove, a high-end, research-grade AM, revealed the Activ8 better detected body P&M in this population. Furthermore, the Wheelchair Activ8 has shown great promise, providing the research field with a valuable objective measure to assess physical behaviour in wheelchair users.

The use of the Activ8 in larger clinical studies, inpatient, or outpatient settings should be explored further. It would provide vital insight into changes after lifestyle interventions or involvement in community programs aimed at promoting HPA participation and decreasing SB.

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APPENDIX A

Activ8 activity time relative to video observation for the ***frontal thigh*** Activ8 position

		Activ8 Value / Video Value x 100%							
Participant No.	**Time of Observation (sec)**	**Sitting Time**	**Basic Standing Time**	**Basic Walking Time**	**Upright Activity Time[a]**	**Bicycling Time**	**Running Time**	**Mean**	**SD**
1	1392	100	100	100.4	100.4	99.6	97.4	99.6	1.1
2	1596	106.6	94.8	101.3	97.6	100	100	100.1	4.0
3	506	100	124	84.5	-	-	-	102.8	20
4	1519	109	89.5	100	96.7	100	116.1	101.9	9.4
5	1465	150	100	84.2	46.6	148.1	205.9	122.5	57
6	1087	144.9	0	38.5	16.0	172.4	-	74.3	79
7	1486	100	98.7	80.4	100	84.2	227.4	115.1	56
8	1352	100	90.6	101.5	100	100	-	98.4	4.4
9	1399	99.6	96.2	95.3	100.9	97.3	126.9	102.6	12
10	1180	151.8	5.43	102.6	87.9	100	-	89.5	53
11	1218	100	100	90.0	100	98.7	141.9	105.1	18
12	1558	100	88.9	108.9	98.7	104.9	77.8	96.5	11
13	1428	101.7	96.3	100.4	99.1	100	105.3	100.5	3.0
14	1270	125.4	0	100	97.9	100	-	84.7	49

a. Light-to-moderate upright activity time is the summed time of standing (video and Activ8), walking (video and Activ8), and standing with movement (video only) during complex activities

APPENDIX B

Activ8 activity time relative to video observation for ***lateral thigh*** Activ8 position

		Activ8 Value / Video Value x 100%							
Participant No.	**Time of Observation (sec)**	**Sitting Time**	**Basic Standing Time**	**Basic Walking Time**	**Upright Activity Time[a]**	**Bicycling Time**	**Running Time**	**Mean**	**SD**
1	1397	100	100	100.8	100.2	99.1	98.7	99.8	0.76
2	1034	100	96.0	101.2	100	-	100	99.4	2.0
3	506[b]	100	124	84.5	-	-	-	102.8	20
4	1501	100	90.7	97.0	100	100	130.8	103.1	14
5	1477	100	98.6	102.0	94.6	79.9	195.8	111.8	42
6	1087	112.2	91.0	65.1	66.7	123.1	-	91.6	26
7	1474	100	98.8	99.0	100	64.7	219.4	113.6	54
8	1358	100	92.0	101.3	100	100	-	98.7	3.7
9	1380	99.6	97.3	99.3	100.7	96.8	112.2	101	5.7
10	1180	116	91.6	102.6	90.8	100	-	100.2	10
11	1266	100	97.6	90.8	100	97.4	147.8	105.4	21
12	1565	100	93.4	106.0	100.5	100	81.3	96.8	8.6
13	1482	104.7	97.5	99.0	97.3	102.6	108.8	101.6	4.6
14	1295	100.3	100	100	99.7	100	-	100	0.20

a. Light-to-moderate upright activity time is the summed time of standing (video and Activ8), walking (video and Activ8), and standing with movement (video only) during complex activities

b. Frontal thigh position (did not wear monitor on lateral thigh)

APPENDIX C

VitaMove activity time relative to video observation

		VitaMove Value / Video Value x 100%							
Participant No.	**Time of Observation (sec)**	**Sitting Time**	**Basic Standing Time**	**Basic Walking Time**	**Upright Activity Time[a]**	**Bicycling Time**	**Running Time**	**Mean**	**SD**
1	1397	100	101.4	115.2	100.4	100	48.1	94.2	23
2	1034	100	98.7	100.4	100	-	100	99.8	0.66
3	506	89.8	220	50	-	-	-	119.9	89
4	1501	100	95.3	89.6	100	104.7	140.4	105	18
5	1477	100	100	91.1	84.7	175.1	8.33	93.2	53
6	1087	94.5	100	42.4	100.8	176	-	102.7	48
7	1474	100	100	100	100	100	100	100	0
8	1358	100	95.5	101.3	100	100	-	99.3	2.2
9	1380	99.6	97.3	100.7	100.7	100.5	95.9	99.1	2.0
10	1180	94.1	114.7	100.3	100	100	-	101.8	7.7
11	1266	94.9	113.4	100.7	100	100	97.4	101.1	6.4
12	1565	105.9	95.6	123.5	90.3	121.8	12.5	91.6	41
13	1482	98.7	100	98.6	100.5	100	107	100.8	3.1
14	1295	79.2	147.6	86.6	123.2	100	-	107.3	28

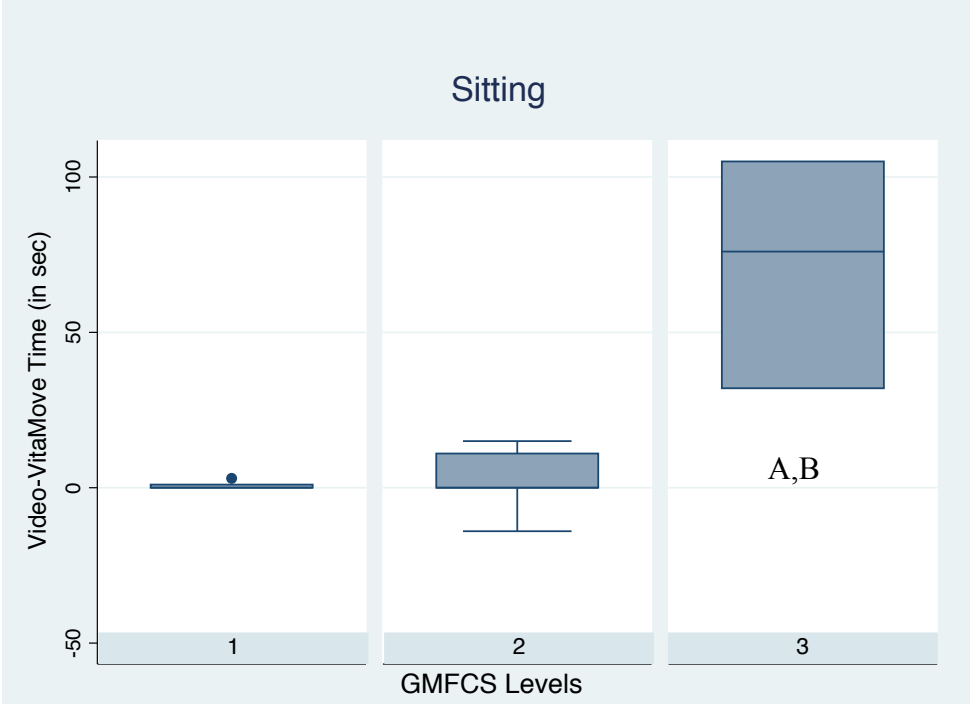
a. Light-to-moderate upright activity time is the summed time of standing (video and VitaMove), walking (video and VitaMove), and standing with movement (video only) during complex activities

APPENDIX D

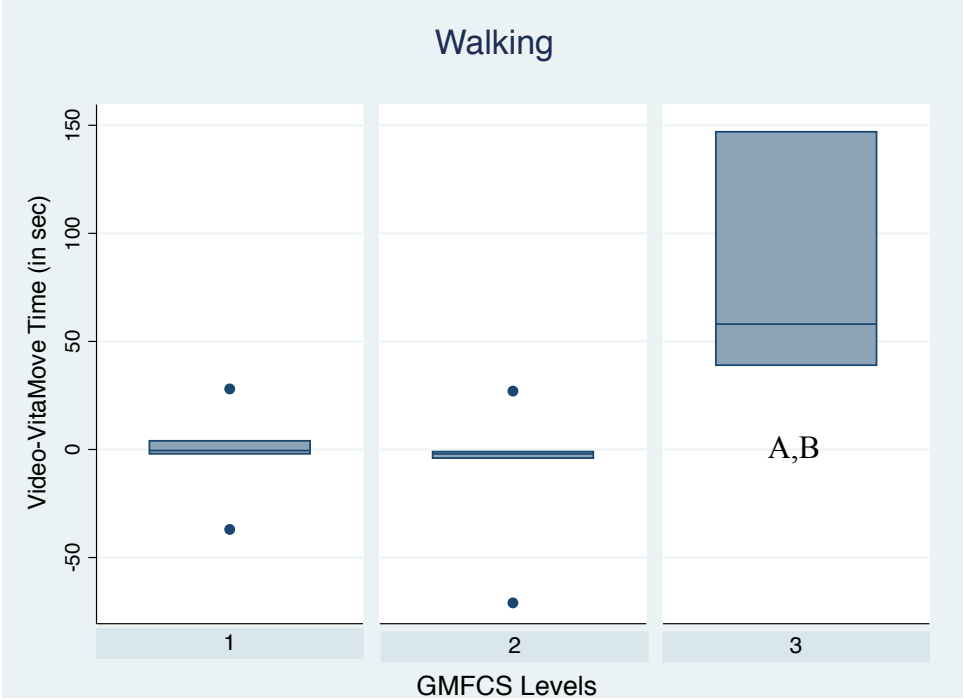
Kruskal-Wallis test comparing GMFCS level I (n=6), level II (n=5), and level III (n=3) using the time differences (video-activity monitor time, in sec) calculated for each P&M category

	Video-Activ8[a]		Video-VitaMove	
P&M Category	χ^2	*p*-value	χ^2	*p*-value
Sitting	2.70	.259	7.17	.028*
Basic Standing	1.49	.475	3.73	.155
Basic Walking	4.67	.097	7.16	.028*
Light-to-moderate Upright Activity	2.16	.340	6.35	.042*
Bicycling	2.50	.287	0.404	.817
Running	1.51	.471	2.70	.260

a: Activ8 monitor from the lateral thigh position
P&M: Posture and movement
* p< .05



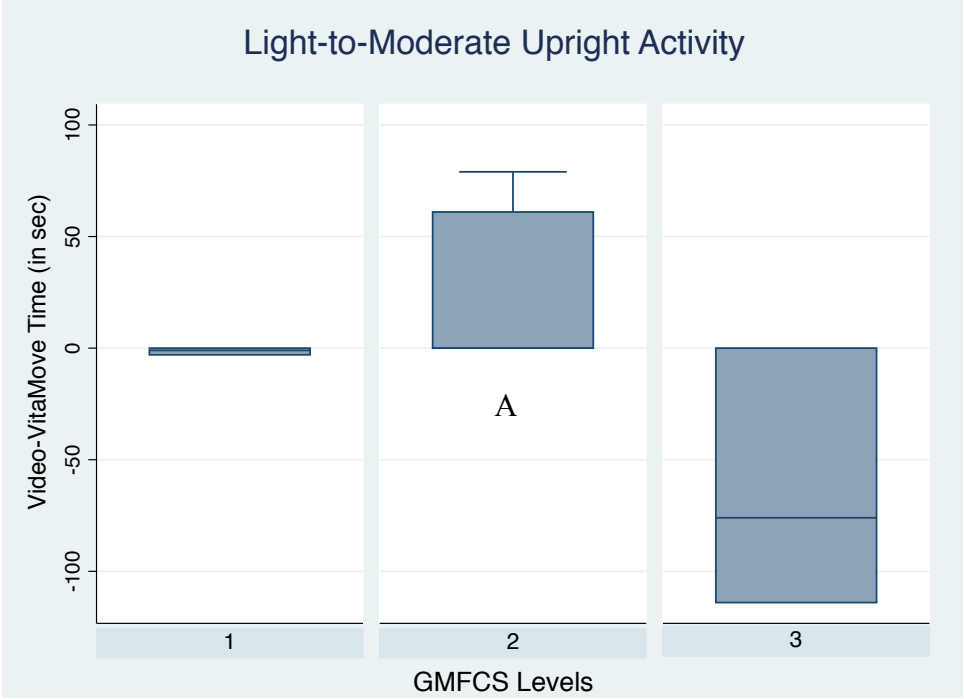
Wilcoxon Rank-Sum (Mann-Whitney) test between GMFCS levels revealed:
A) statistical difference between GMFCS levels I and III (z=-2.43, p=.015)
B) statistical difference between GMFCS levels II and III (z=-2.25, p=.025)



Wilcoxon Rank-Sum (Mann-Whitney) test between GMFCS levels revealed:

A) statistical difference between GMFCS levels I and III (z=-2.32, p=.020)

B) statistical difference between GMFCS levels II and III (z=-2.24, p=.025)



Wilcoxon Rank-Sum (Mann-Whitney) test between GMFCS levels revealed:

A) statistical difference between GMFCS levels I and II (z=-2.10, p=.036)

APPENDIX E
Participant Information Letter and Consent (Dutch)

Onderzoek naar de nauwkeurigheid van een activiteiten monitor voor het bepalen van beweeggedrag bij mensen met Cerebrale Parese

Geachte heer/mevrouw,

Wij vragen u vriendelijk om mee te doen aan een medisch-wetenschappelijk onderzoek naar de nauwkeurigheid van een activiteiten monitor voor het bepalen van beweeggedrag. U beslist zelf of u wilt meedoen. Voordat u de beslissing neemt, is het belangrijk om meer te weten over het onderzoek. Lees deze informatiebrief rustig door. Bespreek het met partner, vrienden of familie. Ook is er een onafhankelijk persoon, die veel weet van het onderzoek (zie punt 14). Hebt u na het lezen van de informatie nog vragen? Dan kunt u terecht bij de projectleider. Op bladzijde 5 vindt u haar contactgegevens.

1. Waarom contacteren we u?
We hebben uw contact informatie via revalidatiecentrum Rijndam en/of het Erasmus MC verkregen. Als een revalidant en/of voormalig deelnemer aan een onderzoeksproject benaderen we u voor deelname aan wetenschappelijk revalidatieonderzoek.

2. Wat is het doel van het onderzoek?
Mensen met een lichamelijke aandoening hebben vaak moeite met het uitvoeren van dagelijkse activiteiten. Hierdoor is het risico op het ontwikkelen van een inactieve

leefstijl groot. Omdat inactiviteit negatieve gevolgen kan hebben voor het dagelijks functioneren en de gezondheid, wordt mensen met een lichamelijke aandoening een zo actief mogelijke leefstijl geadviseerd. Om dit te kunnen bereiken is het belangrijk dat dagelijkse houdingen, bewegingen en activiteiten, oftewel beweeggedrag, nauwkeurig bepaald kunnen worden.
Onlangs is er een klein, eenvoudig, en gebruiksvriendelijk apparaat op de markt gekomen, de Activ8 activiteiten monitor. Het is echter nog niet goed bekend hoe nauwkeurig deze

activiteiten monitor beweeggedrag kan meten. Daarom is het van belang om onderzoek hier naar te doen, zowel bij mensen zonder lichamelijke aandoening als bij mensen met een lichamelijke aandoening.

3. Welk product wordt onderzocht?

In dit onderzoek wordt een activiteiten monitor, de Activ8 (zie foto), onderzocht. De Activ8 is een apparaat dat bestaat uit een kastje van 3x3x1 cm, met daarin een sensor die houdingen, bewegingen en activiteiten kan onderscheiden en registreren in het dagelijks leven.

4. Hoe wordt het onderzoek uitgevoerd?

Voor het onderzoek zijn we op zoek naar 30 mensen met Cerebrale Parese. U wordt gevraagd om eenmalig een aantal houdingen, bewegingen en activiteiten uit te voeren. Deze houdingen, bewegingen en activiteiten zijn grotendeels onderdeel van uw normaal, alledaags beweeggedrag. De bewegingen en activiteiten zijn niet intensief en u kan altijd tussentijds stoppen of een pauze nemen wanneer u dat wilt.
Tijdens het uitvoeren van de houdingen, bewegingen en activiteiten draagt u één of meer Activ8 monitoren. De Activ8's zullen gedragen worden op uw bovenbeen en in uw (broek)zak. Deze monitoren worden met huidvriendelijke folie bevestigd. Mensen die zich in een rolstoel voortbewegen dragen (ook) een Activ8 op hun pols en op het rolstoelwiel.

Tijdens het onderzoek draagt u ook een meer complexe activiteiten monitor, de VitaMove. De VitaMove wordt veel gebruikt in wetenschappelijk onderzoek, maar is minder geschikt om op grotere schaal in het dagelijks leven te gebruiken. De sensoren van dit systeem worden met behulp van bandjes bevestigd op bovenbeen, romp en eventueel op de polsen (3 of 5 monitoren in totaal). Door het gelijktijdig dragen van de Activ8 en VitaMove is het voor ons mogelijk om beide systemen met elkaar te vergelijken.

Tijdens het uitvoeren van de verschillende houdingen, bewegingen en activiteiten wordt er een video-opname gemaakt; deze video-opname is belangrijk om na te kunnen gaan of houdingen, bewegingen en activiteiten goed worden herkend en gemeten door de Activ8. Het dragen van de Activ8 zal op geen enkele manier pijnlijk of hinderlijk zijn.

U zal gevraagd worden om de meting in een laboratorium en op de ergotherapie afdeling in het Erasmus Medisch Centrum uit te voeren. Over de locatie van de meting zal u specifiek en uitgebreid worden geïnformeerd.
Na afloop van de metingen zullen de resultaten van de Activ8 worden vergeleken met de werkelijke, gefilmde houdingen, bewegingen en activiteiten en met de resultaten van de VitaMove. Uiteindelijk zal worden bepaald of de Activ8 nauwkeurig genoeg is om ingezet te kunnen worden in leefstijlprogramma's en/of wetenschappelijk onderzoek rondom beweeggedrag.

5. Wat wordt er van u verwacht?

Wij vragen u om eenmalig de Activ8 en de VitaMove activiteiten monitoren te dragen en een aantal dagelijkse houdingen, bewegingen, en activiteiten uit te voeren. Elke houding, beweging of activiteit duurt ongeveer 80 seconden en in totaal duurt de meting 45 tot 60 minuten. Tijdens de meting wordt u gefilmd. Ook willen we u vragen om comfortabele schoenen en een broek met zakken aan te trekken. U hoeft verder niks te doen of laten voor dit onderzoek. Het onderzoek zal geen gevolgen hebben voor uw gezondheid.

6. Welke bijwerkingen kunt u verwachten?

Er worden geen bijwerkingen van deelname aan dit onderzoek verwacht.

7. Wat zijn mogelijke voor- en nadelen van deelname aan dit onderzoek?

U heeft zelf geen voordeel van deelname aan dit onderzoek. Voor de toekomst kan het onderzoek wel nuttige gegevens opleveren.
Een nadeel van deelname aan dit onderzoek is dat het enige tijdsinvestering van u vraagt.

8. Wat gebeurt er als u niet wenst deel te nemen aan dit onderzoek?

U beslist zelf of u meedoet aan het onderzoek. Deelname is vrijwillig. Als u besluit niet mee te doen, hoeft u verder niets te doen. U hoeft niets te tekenen. U hoeft ook niet te zeggen waarom u niet wilt meedoen. U krijgt gewoon de behandeling die u anders ook zou krijgen. Als u wel meedoet, kunt u zich altijd bedenken en toch stoppen. Ook tijdens het onderzoek.

9. Wat gebeurt er als het onderzoek is afgelopen?

Als u de metingen heeft voltooid of als u tussentijds bent gestopt zullen uw gegevens beveiligd worden opgeslagen. Uw gegevens zullen worden geanalyseerd en worden verwerkt in een wetenschappelijk artikel. U hoeft na het uitvoeren van de metingen verder niks meer te doen.

10. Zijn er extra kosten/is er een vergoeding wanneer u besluit aan dit onderzoek mee te doen?

Voor deelname aan dit onderzoek bieden wij u een reiskostenvergoeding aan. Ook zal er koffie/thee voor u beschikbaar zijn tijdens de metingen.

11. Welke medisch-ethische toetsingscommissie heeft dit onderzoek goedgekeurd?

De Medisch Ethische Toetsings Commissie Erasmus MC [MEC-2015-211] heeft dit onderzoek goedgekeurd.

12. Wilt u verder nog iets weten?

U kunt zich te allen tijde bedenken. Dit betekent dat u zich zowel in de aanloop naar de metingen als ook tijdens de metingen kan bedenken en af kan zien van deelname.
Wilt u graag een onafhankelijk advies over meedoen aan dit onderzoek? Dan kunt u terecht bij een onafhankelijk deskundige (zie contactgegevens onder punt 14).

13. Worden de gegevens anoniem verwerkt?

Persoonsgegevens die tijdens deze studie worden verzameld, zullen worden vervangen door een codenummer. Alleen dat nummer zal worden gebruikt voor studiedocumentatie, in rapporten of publicaties over dit onderzoek. Slechts degene die de sleutel van de code heeft (de projectleider en de onderzoeker) weet wie de persoon achter het codenummer is. De gegevens worden 15 jaar bewaard, dit is wettelijk verplicht. Tot uw persoon herleidbare gegevens kunnen slechts met uw toestemming door daartoe bevoegde personen worden ingezien. Deze personen zijn medewerkers van het onderzoeksteam, bevoegde medewerkers van de Inspectie voor de Gezondheidszorg en leden van de Medisch Ethische Toetsings Commissie van het Erasmus MC. Inzage kan nodig zijn om de betrouwbaarheid en kwaliteit van het onderzoek na te gaan. Onderzoeksgegevens zullen worden gehanteerd met inachtneming van de Wet Bescherming Persoonsgegevens en het privacyreglement van het Erasmus MC.

14. Contactgegevens

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Met vriendelijke groet, mede namens
Dr. W. van der Slot
en Dr. Rita van den Berg-Emons

Toestemmingsformulier

Onderzoek naar de nauwkeurigheid van een activiteiten monitor voor het bepalen van beweeggedrag bij mensen met Cerebrale Parese
Protocol versie: 1 d.d. ***07 maart*** 2016

Ik heb de informatiebrief voor de proefpersoon gelezen en kon aanvullende vragen stellen. Mijn vragen zijn afdoende beantwoord. Ik had genoeg tijd om te beslissen of ik meedoe.

Ik weet dat meedoen helemaal vrijwillig is en dat ik op ieder moment kan beslissen om toch niet meer mee te doen. Daarvoor hoef ik geen reden te geven.

Ik geef toestemming om mijn gegevens te gebruiken, voor de doelen die in de informatiebrief staan.

Ik geef toestemming om mijn onderzoeksgegevens 15 jaar na afloop van dit onderzoek te bewaren.

Ik wil meedoen aan dit onderzoek.

Naam proefpersoon:
Handtekening: Datum : __ / __ / __

Geslacht: Man / Vrouw
Geboortedatum: _____ - _____ - _____ (dd-mm-jjjj)

Proefpersoon nummer: _____

Ik verklaar hierbij dat ik deze proefpersoon volledig heb geïnformeerd over het genoemde onderzoek.

Als er tijdens het onderzoek informatie bekend wordt die de toestemming van de proefpersoon zou kunnen beïnvloeden, dan breng ik hem/haar daarvan tijdig op de hoogte.

Naam onderzoeker (of diens vertegenwoordiger):
Handtekening: Datum: __ / __ / __

Aanvullende informatie is gegeven door (indien van toepassing):
Naam:
Functie:
Handtekening: Datum: __ / __ / __

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* Doorhalen wat niet van toepassing is.

APPENDIX F

MEASUREMENT PROTOCOL

Validation of an accelerometry-based activity monitor in adults with spastic cerebral palsy

Everett Claridge, MSc-RS Candidate

This research project was supported by the Canadian Institutes of Health Research (www.cihr-irsc.gc.ca).

Table of Contents

1. General

a. Inclusion Criteria

- ≥18 years of age
- Definitive clinical diagnosis of spastic cerebral palsy (CP)
- Physically able to perform the activities in the assessment protocol
- For wheelchair users, ability to propel oneself using the rim of the wheelchair, with either one or both hands

i.e. Gross Motor Functioning Classification System [GMFCS] level I to IV

b. Exclusion Criteria

- Disabilities other than CP that affect daily physical activity
- Severe cognitive disorder or insufficient comprehension of either English or Dutch
- Orthopaedic surgery within the past 6 months

c. Recruitment Strategies

Participants will be recruited through a patient list from Erasmus MC and Rijndam Rehabilitation in Rotterdam, the Netherlands. Participants of past research studies at Rijndam and Erasmus MC who had indicated they were interested in learning more about future research studies will be contacted (N=30; 13 unilateral, 17 bilateral spastic CP). Furthermore, eligible out-patients of Rijndam Rehabilitation will be contacted for participation by Dr. van der Slot. All eligible persons will be sent an information letter and invitation to participate by mail or in person. Those interested in participation will be contacted by telephone to confirm their eligibility and set an assessment date.

d. Sample Size

- 10 adults who are able to walk with or without assistive devices
- 10 adults who can walk with assistive devices **and** are partly wheelchair dependent
- 10 adults who are strictly wheelchair dependent

*Sample size based on comparable studies evaluating the validity of an activity monitor in both children and adults with and without disability (Nooijen et al. 2015; Postma et al. 2005; Horemans et al. (n.d.))

e. Adverse Events

Adverse events (AE) are undesirable incidents that occur during the course of the investigation, whether or not related to this research study (injuries, illness, etc.). All AEs that are reported by a participant or are seen by the investigator(s) will be listed on the AE form apart of the Participant's Report file.

Follow-up will occur for all participants who experience an AE until it has resolved or stabilized.

2. Study Timeline

Week	Week Start Date (Monday)	Broad Project Tasks	Notes
1	16-01-11	Introductions	
2	16-01-18	Literature search & begin development of measurement protocol	
3	16-01-25	Continue development of measurement protocol & create patient information letter	meet with Nick van der Stam (NOTE: Nick is a 4th year undergraduate student who will be assisting me with recruitment and assessment - major asset to overcome language barrier)
4	16-02-01	Development of measurement protocol	
5	16-02-08	Protocol rehearsal (incl. equipment check and preparing assessment space) & edit measurement protocol	Nick van der Stam is not available from Feb 9th until Feb 17th; Dr. Rita van den Berg-Emons is not available from Feb 8th until Feb. 17th
6	16-02-15	Prepare participant contact list, protocol rehearsal with Nick	Meet with Dr. Wilma van der Slot?
7	16-02-22		Everett is away

8	16-02-29	Meet with Ergotherapie (OT) staff, protocol rehearsal	
9	16-03-07	Protocol rehearsal with supervision (Rita or Herwin?); begin recruitment (send information letters)	Note: complete a test measurement with Rita and/or Herwin supervision (this week or next)
10	16-03-14	Meet with thesis committee; finalize measurement protocol; continue participant recruitment	
11	16-03-21	Recruitment; begin participant assessments	
12	16-03-28	Recruitment; participant assessments	
13	16-04-04	Recruitment; participant assessments	
14	16-04-11	Recruitment; participant assessments	
15	16-04-18	Recruitment; participant assessments	
16	16-04-25	Recruitment; participant assessments	
17	16-05-02		Everett is away (May 2-12)
18	16-05-09	Participant assessments, data analysis & formal write-up	Aim: manuscript
19	16-05-16	Participant assessments, data analysis & formal write-up	
20	16-05-23	Participant assessments, data analysis & formal write-up	
21	16-05-30	Formal write-up & participant follow-up (if necessary)	
22	16-06-06	Tie up any loose ends	
23	16-06-13	Tie up any loose ends	

3. Participant Report – Instructions

- Participant information will remain anonymous. All participants will be given a study participant number at the time of recruitment. Participant name and other personal identifying information as well as the participant's associated number will be stored in a secure location (with Dr. Rita van den Berg-Emons).

- Information will be coded in the following manner:
    - Participants will be given a number according to their recruitment order (e.g. the fourth participant will be given 04; the eleventh participant will be given 11)
    - Depending on the ambulation status and monitor set-up, participants will have the following digit added to the end of their participant number:
        - Ambulatory participants 1
        - Partly wheelchair dependent 2
        - Completely wheelchair dependent 3

Example. The fourth recruited participant who is partly wheelchair dependent will be given the participant number 042

- Populate all fields. If information is missing, provide reasoning why.
- Completed Participant Reports will be signed by the researcher who has populated the form.
- All Participant Reports will be numbered, filed, and stored in a secure location within Erasmus MC.
- Digital data will be void of personal and identifying information. Study data will be stored on the Klinisch Bewegings Laboratorium (KBL) network drive.

3. Postures and Movements – Definitions

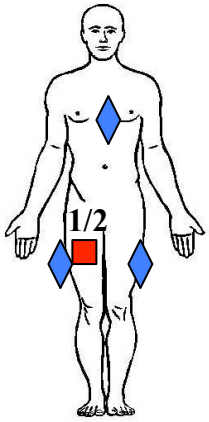
The Activ8 monitor can distinguish the following postures/movements: lying/non-wear (0 counts for >5min); sitting; standing; walking; running; bicycling; assistive wheelchair driving; active wheelchair use; handcycling.
Therefore, in order to have proper comparison between direct observation/video recordings, various postures and movements need to be defined.

The following definitions are based on former research studies evaluating the validity of an activity monitor in individuals with CP and/or individuals who are wheelchair-dependent.
Lying: The torso of a participant is resting in contact with a surface with weight relief from the legs (>5 minutes), in either a supine, prone, or lateral position.

Sitting: A participant is resting in contact with a surface with weight relief from the legs, including times when sitting on the edge of a seat/chair.
Standing: A participant is bearing their weight on the lower limbs (perhaps with the use of a walking aid in contact with the arms or holding hands with an assistant).
Walking: Forward progression of the lower limbs, from one foot strike to the next, characterised by a transient double support phase in between strides.
Running: Forward progression of the lower limbs, from one foot-strike to the next, characterised by a transient "flight" phase during which neither limb touches the ground.
Bicycling: Rhythmic, cyclical movement of lower limbs while seated on a bicycle (incl. stationary bicycle).
Sedentary – Active upper body: Repeated extension and/or flexion of one or both elbow joints, causing the hand to move at approximately 0.25m/s or more, while the wheelchair is stationary
Assistive driving: Forward movement of the wheelchair while the participant is seated, pushed forward by someone other than the participant
Active Wheelchair Use (incl. manoeuvring and wheelchair driving): Self-propulsion of the manual wheelchair.
Handcycling: Rhythmic, cyclical movement of upper limbs while seated (incl. own wheelchair).
Transfer: The distinct **transition** from a stable sitting position to a stable standing position (sit-to-stand), from a stable standing position to a stable sitting position (stand-to-sit), or from a stable sitting position to another sitting position (sit-to-sit; e.g. wheelchair to office chair). The sit-to-sit transfer is further characterized by a transient "standing" phase between both stable sitting positions.

Miscellaneous activities of daily living: may be a combination of the above-mentioned postures/movements. Since the time resolution will be 1-second for the video recording, complex ADLs can be broken down into 1-sec postures/movements. For example, vacuuming may be observed as a combination of standing and walking, which may also be recorded by the Activ8, but may be difficult to analyse.

4. Equipment Set-up



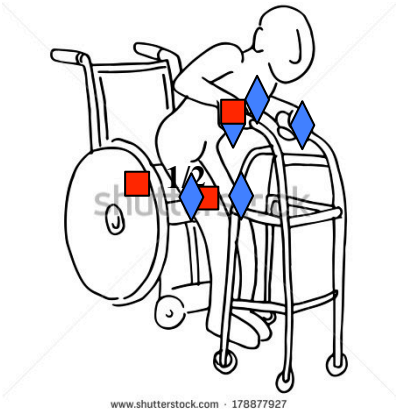
Place Activ8 leg monitors and both Activ8 and VitaMove wrist/wheel monitors **on least impaired leg** and/or **wrist**. This configuration is expected to be most commonly used in daily practice and will result in the most valid measurements.

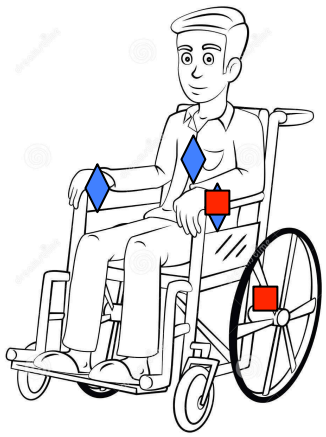
Ambulatory participants

- Two (2) Activ8 monitors (**red**), three (3) VitaMove monitors (**blue**)
    - Activ8 monitor worn **in the pant pocket** and **strapped/taped on the thigh of the same leg (frontal side of thigh)**
    - VitaMove monitors: **chest, right thigh, left thigh (lateral side of thighs)**

Partly wheelchair dependent

- Four (4) Activ8 monitors (**red**), five (5) VitaMove monitors (**blue**)
    - Activ8 monitors: **in the pant pocket, strapped on the thigh of the same leg (frontal side of thigh), wrist,** and **wheel (spokes of wheelchair)**
    - VitaMove monitors: **chest, right thigh, left thigh (lateral side of thighs), right wrist,** and **left wrist**





Completely wheelchair dependent

- Two (2) Activ8 monitors (**red**), three (3) VitaMove monitors (**blue**)
    - Activ8 monitors: **wrist** and **wheel (spokes of wheelchair)**
    - VitaMove monitors: **chest, right wrist,** and **left wrist**

NOTE: The Activ8 monitors should be attached directly ON TOP of the VitaMove monitos for **wrist** location (see picture for example). Please make note of the initialization order in the patient report.

Location of VitaMove monitors according to colour

The ***BLUE*** VitaMove monitor must be located on the **CHEST**. It must go either directly on the skin or over a t-shirt, but cannot be worn above any other clothing, as it may be subject to shifting.

ORANGE VitaMove monitor goes on the **RIGHT LEG.**

YELLOW VitaMove monitor goes on the **LEFT LEG.**

**leg monitors must be placed in middle of the thigh and on laterally.

GREEN VitaMove monitor goes on the **RIGHT WRIST**.

RED VitaMove monitor goes on the **LEFT WRIST** of the wheelchair.

**Make a note in the patient report at what time the whole activity monitoring system (both Activ8 and VitaMove) is properly fastened

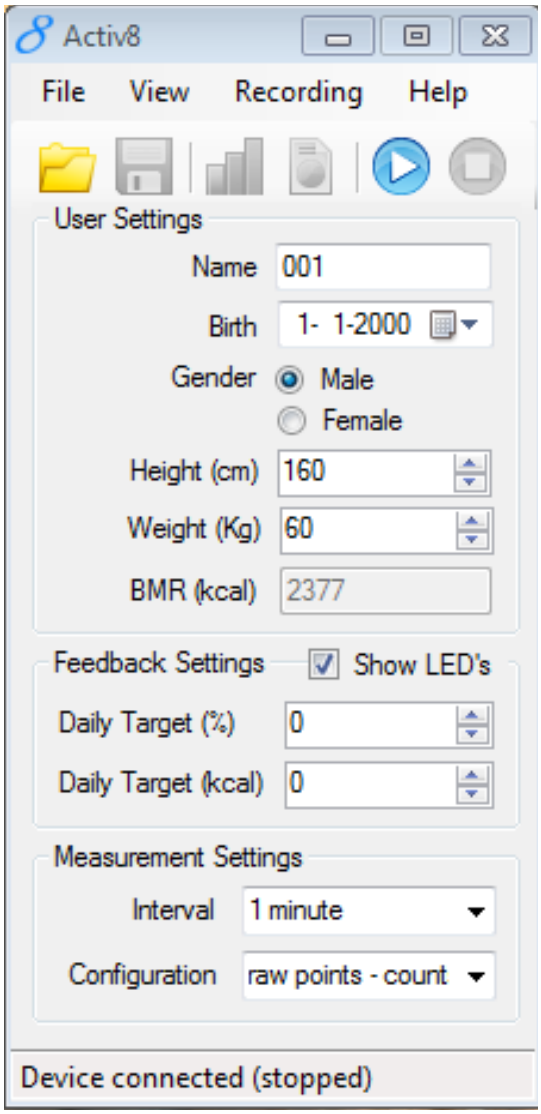
NOTE: Sync external clock (phone) with computer time display prior to the initialization of activity monitors and activity recording. Therefore, as you run through the assessment protocol, all monitor-recorded times will match appropriate verbal cues recorded on the video recorder.

5. Activ8 Monitor

a. Initializing the Activ8 Monitor

1. Choose the appropriate number of monitors (dependent on assessment protocol). Note the number of these devices in the Participant Report, as well as where this device will be placed on the participants body.

2. Plug in the Activ8 monitors, one at a time, into the study computer using the appropriate USB cable.
3. Open the Activ8 program found on the Desktop.
4. Enter the participant number, date of birth, gender. Height=999 and weight=999
5. Turn off "Feedback Settings"
   - Leave "Daily Target (%)" and "Daily Target (kcal)" at 0
6. Set "Interval" (epoch) to **5 seconds**
7. Set "Configuration" to **raw points-counts**
   a. On the "Recording" drop-down menu, also click on **Raw Values**
8. Press the blue play button to begin recording



To ensure the device has been properly initialized, open the *Activ8 Removable Hardware* by clicking on My Computer→Devices with Removable Storage to see whether a CSV file has been created. If not, the device has NOT been properly initialized.

9. Unplug the device. **Record this time**. When the device is removed from the computer this will be the start time of the data collection.

ATTENTION: Ensure that the USB is properly ejected by choosing the "Safely eject device" option in the bottom right corner of the menu bar.

10. All devices need to be calibrated/synchronized after their initialization. To do this, lightly shake all devices at the same time for 10 seconds.

b. Downloading data from the Activ8 Monitor

1. Plug in the Activ8 monitors, one at a time, into the study computer using the appropriate USB cable.

2. Open the Activ8 program
3. You will be prompted with the following message: "Load measurement from device?" Click **Yes**. You will then be redirected back to the program.
4. Then click **Stop**. You will then be required to save the collected data file. Save under the title of "Participant number – Start time of measurement – Date of measurement"

Other notes:

- The Activ8 will start recording the moment it is **EJECTED** from the computer.
- Only one Activ8 monitor can be initialized at a time. Monitors can be synchronized afterwards, on the basis of the "Time Column" in the data collection. When using multiple monitors for one participant, start each successive Activ8 monitor (i.e. pull it out of the computer) exactly 60 seconds after the previous.

6. Video Recorder

- Prior to each participant assessment, ensure that the video camera is fully charged (note: a full charging takes at least 45 minutes)
- You should also complete a screen/recording test prior to each assessment to ensure the device is working properly
- Begin recording prior to the activation of both the Activ8 monitor(s) and the VitaMove monitors. Film the activation of all devices and provide a verbal cue/announcement of their start time.
- Verbally announce the start time of each assessment task and write this time on the assessment form
- Verbally announce the end time of each assessment task and write this time on the assessment form

7. VitaMove Monitor

a. Initializing the VitaMove Monitors

Ensure all monitors being used (3 to 5, depending on the protocol set-up) are fully charged

1. Turn **on** all monitors. The ON/OFF button found on the right side of each monitor is in the **up position** (towards the light). Leave monitors **on** at all times.
2. Remove/dismount the SD/memory card from each monitor BEFORE they are plugged in.
3. Plug in all sensors (3 to 5) into the appropriate charging unit using the USB cable.
    - Note: Orange LED light = charging; Green LED light = fully charged
4. Once all are charged, remove from charging unit.
5. Take all required SD/memory cards and insert into the computer/laptop. Put in the ***BLUE*** SD card first.
6. Open the VitaMove program found on the computer desktop.
7. Click on "File" then "New"
    - If there is an error, click "View" then "Options" and ensure the monitor is plugged into the correct USB port
8. Select "New Patient" and populate the following fields:
    - Personal ID: Enter participant ID (see above for numbering procedure)
    - Height = 999
    - Weight = 999
9. For "Set-up" select: "Activity" for participants in the **ambulatory** group
   "Upper limbs" for participants in the **partly wheelchair-dependent** group
   "Wheelchair" for participants in the **completely wheelchair-dependent** group
10. Once completed, click "OK". **Record this time**. Note that all participant information is stored on the *blue* card, but all cards will be ready for data collection.
11. Remove the SD/memory card from the computer. *Remove full USB containing the SD card, rather than just the SD card.
12. Insert the SD card back into the blue monitor (copper side up). **Record this time**. Try to insert this SD card exactly 60 sec after clicking "OK" in the VitaMove program. The LED light should be alternately flashing green and orange, indicating that it is reading the card.

13. Insert all other SD cards back into their monitors.
14. Ensure all monitors are flashing green simultaneously every 3 seconds.
15. Attach monitors to appropriate positions/locations on the participant.
16. Once secured, hold down the button on the top of the ***BLUE*** sensor for approximately 5 seconds. The LED light will flash green/orange 5 times before turning solid green for 2 seconds. Then let the button go to **start the measurement**.

    Note this time on the Assessment Report as well.

    - The LED lights will flash green to indicate that measurement/activity recording has started. All monitors will flash synchronously.

DO NOT turn a monitor off or remove a SD card during an assessment.

Possible Errors

1. The LED light flashes orange, and only once. The measurement has NOT started. Try the above procedure once again before beginning the measurement protocol.
2. The LED light flashes orange *rapidly*. There is an error. Turn off the sensor using the switch on the right side, wait 30 seconds, then turn it back on again.

If there are further issues, contact Dr. Emiel Sneekes or Dr. Herwin Horeman (e.sneekes@erasmusmc.nl and h.l.d.horemans@erasmusmc.nl, respectively)

b. Downloading data from the VitaMove system

1. To STOP the measurement, hold down the button on the top of the ***BLUE*** sensor for approximately 5 seconds. The LED light will flash green/orange 5 times before turning solid green for 2 seconds. Hold down the button on the ***BLUE*** sensor **a second time within 1 minute**. This will stop the measurement recording.
    - If one of the LED lights does not flash, this may be due to loss of battery. The activity recording for that particular monitor will have stopped automatically.
2. Once data collection has stopped, remove all monitors and attachment bands/tape.
3. Remove all 5 SD/memory card from the monitors

4. On the VitaMove computer/laptop, create a new folder, on the desktop/My Documents (Activ8 Validation CP→Participants), labelled with the participant number. You need to create sub-folders within the participant folder: one per monitor.
5. Insert all monitor SD/memory cards.
6. Copy the files from each SD card to the location you have just created.
   i.e. Copy the **S**, **CAL**, and **DAT**-files for the ***BLUE*** card and the **CAL** and **DAT**-file for **all other** monitors to the computer hard drive.
   - Always remove all files from previous measurements from the C-drive, except the file labelled "VITAMOVE" (this should **always** remain there)
   - Check the activity recording by opening the VitaMove program. Double click the patient's file (view an activity graph in the lower half). Click "Download recording" and "OK". Look to see if the measurements were recorded synchronously.
   - Make a second secure file for each participant on the NAS network drive in the appropriate folder within "Everett Claridge". The data may remain on the SD cards, but it will automatically overwrite this information for each new participant.
7. Clean the monitors and straps with disinfectant prior to the following assessment.

8. Assessment Procedures

There are three (3) separate standard protocols to be completed, depending on ambulation status. All activities will be explained to the participants prior to assessment. Any activity that the participant feels they cannot complete safely, or that they do not ever complete in daily life, will be removed from that particular assessment. Prior to assessment, participants are also asked to add any meaningful daily activity(ies) that are missing from the standard protocol to the personalized protocol list (e.g. basketball – dribbling), within reason. The **start time** and **ending time** of each activity will be recorded via verbal announcement (to be heard on the video recording) as well as written on the assessment report.

Participants are asked to perform the activities using their own mobility aids at their own pace, unless otherwise specified.

Protocol for ambulant adults

Activity	**Minimum Time**
Sit	80 sec
Read a newspaper/magazine (flip through pages)	80 sec
Stand	80 sec
Walk - At **comfortable** pace (between pylons, 10m apart) - At a pace **slower** than what you consider comfortable - At a **faster**/**brisk** pace	80 sec 80 sec 80 sec
Running (jog/sprint between pylons, 10m apart)	80 sec
Stationary bicycle - At **comfortable** pace - At a pace **slower** than what you consider comfortable - At a **faster**/**brisk** pace	80 sec 80 sec 80 sec
Stair climb – walking **up** a flight of stairs - walking **down** a flight of stairs	N/A N/A
Walk down hall, open door, walk across threshold, close door, continue walking	N/A
Vacuuming (in OT area)	80 sec
Unpacking a grocery bag (in OT area) - Moving objects from bag to table-top. When finished repack the bag.	N/A
Wash dishes (in OT area) OR Loading/Unloading a dishwasher	80 sec
Office work - copy a written passage by pen and paper OR - type out the written passage on a computer	80 sec
Folding laundry then carrying it across the room (in OT area)	N/A

Don a jacket/coat then taking it off	N/A
Transfers - incl. chair-to-chair, chair-to-bed (and back) *Integrated in protocol	N/A
Sports - Dribbling a basketball OR – Ball toss (throw and catch)	80 sec
Additional Activities – if appropriate, other personalized activities can be added here	

Approximate total time: 45 minutes

Protocol for partly wheelchair-dependent adults

Activity	**Time**
Sit	80 sec
Read a newspaper/magazine (flip through pages)	80 sec
Stand	80 sec
Walk - At **comfortable** pace (between pylons, 10m apart) - At a pace **slower** than what you consider comfortable - At a **faster**/**brisk** pace	80 sec 80 sec 80 sec
Stationary bicycle - At **comfortable** pace - At a pace **slower** than what you consider comfortable - At a **fast** pace	80 sec 80 sec 80 sec
Stair climb – walking **up** a flight of stairs - walking **down** a flight of stairs **only if safe to do so**	N/A N/A
Wheelchair driving – At a **comfortable** pace (between pylons) - At a pace **slower** than what you consider comfortable - At a **fast** pace	80 sec 80 sec 80 sec
Being pushed without any arm movement	80 sec
Being pushed while using mobile phone or rummaging through	80 sec

bag/purse	
Handcycling (with own handbike) – At **comfortable** pace - At a pace **slower** than what you consider comfortable - At a **fast** pace	80 sec 80 sec 80 sec
Wheel down hallway, open door, drive through, close door, continue driving forward	N/A
Unpacking a grocery bag (in OT area) - Moving objects from bag to table-top. When finished repack the bag.	N/A
Wash dishes (in OT area) OR Loading/Unloading a dishwasher	80 sec
Office work - copy a written passage by pen and paper OR - type out the written passage on a computer	80 sec
Folding laundry then carrying it across the room (in OT area)	N/A
Don a jacket/coat then taking it off	N/A
Transfers - incl. wheelchair-to-chair (and back), wheelchair-to-bed (and back) *Integrated in activity protocol	N/A
Additional Activities – if appropriate, other personalized activities can be added here	

Approximate total time: 60 minutes

Protocol for wheelchair-dependent adults

Activity	**Time**
Sit	80 sec
Read a newspaper/magazine (flip through pages)	80 sec

Wheelchair driving – At a **comfortable** pace (between pylons) - At a **slow** pace - At a **fast** pace	80 sec 80 sec 80 sec
Being pushed without any arm movement	80 sec
Being pushed while using mobile phone or rummaging through bag/purse	80 sec
Handcycling – At **comfortable** pace - At a pace **slower** than what you consider comfortable - At a **fast** pace	
Wheel down hallway, open door, drive through, close door, continue driving forward	N/A
Unpacking a grocery bag (in OT area) - Moving objects from bag to table-top. When finished repack the bag.	N/A
Wash dishes (in OT area) OR Loading/Unloading a dishwasher	80 sec
Office work - copy a written passage by pen and paper OR - type out the written passage on a computer	80 sec
Folding laundry then carrying it across the room (in OT area)	N/A
Don a jacket/coat then taking it off	N/A
Transfers - incl. wheelchair-to-chair (and back), wheelchair-to-bed (and back) *Integrated in activity protocol	N/A
Additional Activities – if appropriate, other personalized activities can be added here	

Approximate total time: 45 minutes

Other possible activities to add/include:

food preparation; self-grooming/using a bathroom; other sports activities

9. Appendices

a. Assessment Checklist

- Activ8 Monitors (4)
- Video Camera
- VitaMove Monitors (5)
- Laptop computer (for installation and analysis)
- Protocol laptop (for office work/typing)
- Tape (appropriate for skin) and scissors
- Patient information letter and Consent forms
- Blank assessment report
- Pens and pencils
- Assessment protocol (activity order and times)
- Watch/phone
- Stationary bike
- Plates, cups, cutlery (at OT kitchen)
- Vacuum
- Pylons (2)
- Declaration form

b. Participant Report – Template

Subject Number: ……..……..

Assessment Date: ……..... - …… - ……

Classification

Number of limbs affected: ……

Which limbs are affected? ……

Topographical distribution: Unilateral / Bilateral

Gross Motor Function Classification System

GMFCS Level: ……

Protocol to be used (circle one):

Ambulatory / Partly Wheelchair-dependent / Wheelchair-dependent

Activ8

Device number: …… Location on patient: …….

Initialization time (when removed from computer): ……..

Device number: …… Location on patient: …….

Initialization time (when removed from computer): ……..

Device number: …… Location on patient: …….

Initialization time (when removed from computer): ……..

Device number: …… Location on patient: …….

Initialization time (when removed from computer): ……..

VitaMove

Selected setup: Activity / Upper limbs / Wheelchair

Initialization time (Click "OK" in VitaMove software): ……..

Time blue SD card inserted into monitor: ……

Try to insert blue SD card exactly 60 seconds after clicking "OK" in the VitaMove software

Monitors Attached on Patient

Time all monitors secured: ……

Press button on ***Blue* VitaMove for 5 seconds Time: …….

For proper calibration, complete the following activities FIRST, each for 60 seconds.

SIT → STAND → WALK

Stop Time

Press button on ***Blue* VitaMove for 5 seconds

Within 60 seconds, press and hold the button on the ***Blue*** VitaMove **a second** time.

Time (2nd occurrence when button was held): …….

Time all monitors removed: …….

Start Time	**End Time**	**Activity**

APPENDIX G

Video Coding and Activ8 Data Scoring

Video Observation – Coding and Scoring

It is recommended to complete the video coding and scoring with two PC screens. Therefore, 1 screen can be used solely to analyze the video while inputting the second-by-second code/score into an excel file on the second PC screen.

The video file is first to be converted from a .MTS to a .avi format (quality of 640*480) with *Freemake Video Converter* (program found on KBL laptop). Afterwards, the video file can be played using *VLC*. Users are able to move through the video at exactly 1-sec frames.

Note: Under "Tools" → "Preferences" you will be able to see a list of beneficial keyboard shortcuts.

The video scoring excel file will contain the following 5 columns:

Video time (note: the beginning of each recording starts at 0:00); Real time; Code; Activity; Comments

Code for the various Postures and Movements (P&M):

1. **Non-wear**: The device is NOT secured to the participant.
2. **Lying**: The torso and lower-body of a participant is resting in contact with a horizontal surface with weight relief from the legs, in either a supine, prone, or lateral position.
3. **Sitting**: A participant's buttocks and thighs are resting in contact with a horizontal surface with weight relief from the legs, including times when sitting on the edge of a seat/chair.

4. **Standing**: A participant is bearing their weight on the lower limbs (perhaps with the use of a walking aid in contact with the arms or holding hands with an assistant).
5. **Standing with Movement**: Ambiguous movement that falls between standing still and walking
6. **Walking**: Continuous forward progression of the lower limbs, from one foot strike to the next, characterised by a transient double support phase in between strides. This category also includes **shuffling**, the continuous forward progression of the lower limbs without either foot being completely lifted off the ground/walking surface.
7. **Running**: Forward progression of the lower limbs, from one foot-strike to the next, characterised by a transient "flight" phase during which neither lower limb touches the ground.
8. **Bicycling**: Rhythmic, cyclical movement of lower limbs while seated on a bicycle (incl. stationary bicycle). The thigh is moving between horizontal and vertical positions.

   Note: When seated on a bike without pedalling, this is considered sitting. When standing on the pedals of a bike without pedalling, this is considered standing.
9. **Assistive driving/Passive Wheelchair Use:** Forward movement of the wheelchair while the participant is seated, pushed forward by someone other than the participant.
10. **Active Wheelchair Use (incl. manoeuvring and wheelchair driving):** Self-propulsion of a manual wheelchair, characterized by the hand(s) holding onto the rims of the wheels and rotating the wheel (forwards or backwards).
11. **Handcycling**: Rhythmic, cyclical movement of upper limbs while seated in a hand bicycle (may incl. own wheelchair).
12. **Transfer**: The distinct **transition** from a stable sitting position to a stable standing position (sit-to-stand), from a stable standing position to a stable sitting position (stand-to-sit), or from a stable sitting position to another sitting position (sit-to-sit; e.g. wheelchair to office chair). The sit-to-sit transfer is further

characterized by a transient "standing" phase between both stable sitting positions.

13. **Sedentary – Active upper body**: Repeated extension and/or flexion of one or both elbow joints, causing the hand to move at approximately 0.25m/s or more, while the wheelchair is stationary

0:12:45	4	Vacuum
0:12:46	4	Vacuum
0:12:47	5	Vacuum
0:12:48	5	Vacuum
0:12:49	4	
0:12:50	4	
0:12:51	4	
0:12:52	5	
0:12:53	5	
0:12:54	5	
0:12:55	5	
0:12:56	5	
0:12:57	5	
0:12:58	5	
0:12:59	5	
0:13:00	4	Wash dishes
0:13:01	4	Wash dishes

Here, a listed activity from the protocol is not being carried out, but the participant would be moving into position to start the next activity.

0:13:02	4	Wash dishes
0:13:03	4	Wash dishes

Activ8 Data Scoring

Copy the contents of the Activ8 CSV file into the "Activ8 Data Outlook – Template" excel file.

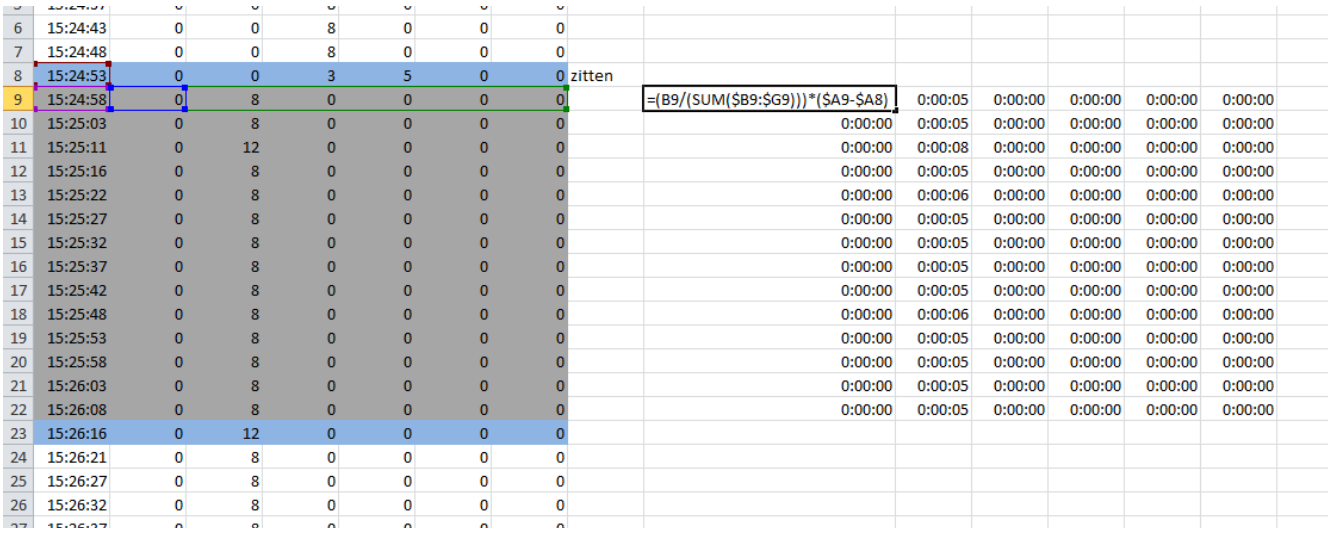
This template has the formulas for converting the Activ8 ***raw points*** awarded to each activity category (8 or 12 points for every 5-second interval/each row) into actual ***seconds***. This template will also provide a New Time, accounting for the 20-second delay associated with the Activ8 monitor.

Refer to the start and end times of each activity, as recorded in the participant assessment. Highlight the associated rows in the new Activ8 data excel file, according to the new Activ8 time for each activity (synchronized with the video observation).

The first and last row of each "activity" segment should be highlighted a different colour/shade and should not be used in the analysis. As each row accounts for a total of 5-seconds, there is the strong possibility that the actual start of an activity would not perfectly align with the start of that row's 5-second "epoch".

See the example below:

Sitting (or labeled here in Dutch as ***Zitten***) started at 15:24:52. The start time of the activity falls within the 5-second interval seen in Row 8. Here, it has been highlighted blue. The end time of the activity is 15:26:12, which falls within Row 23. It also has been highlighted blue. The rest of the rows in between have been highlighted light gray. These light gray rows will be used for analysis.



6	15:24:43	0	0	8	0	0	0									
7	15:24:48	0	0	8	0	0	0									
8	15:24:53	0	0	3	5	0	0	zitten								
9	15:24:58	0	8	0	0	0	0		=(B9/(SUM($B9:$G9)))*($A9-$A8)	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	
10	15:25:03	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
11	15:25:11	0	12	0	0	0	0		0:00:00	0:00:08	0:00:00	0:00:00	0:00:00	0:00:00		
12	15:25:16	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
13	15:25:22	0	8	0	0	0	0		0:00:00	0:00:06	0:00:00	0:00:00	0:00:00	0:00:00		
14	15:25:27	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
15	15:25:32	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
16	15:25:37	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
17	15:25:42	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
18	15:25:48	0	8	0	0	0	0		0:00:00	0:00:06	0:00:00	0:00:00	0:00:00	0:00:00		
19	15:25:53	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
20	15:25:58	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
21	15:26:03	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
22	15:26:08	0	8	0	0	0	0		0:00:00	0:00:05	0:00:00	0:00:00	0:00:00	0:00:00		
23	15:26:16	0	12	0	0	0	0									
24	15:26:21	0	8	0	0	0	0									
25	15:26:27	0	8	0	0	0	0									
26	15:26:32	0	8	0	0	0	0									

NOTE: The time listed for each row is the exact time at the END of that epoch/storage interval. For example, in the above example, the actual start and end time of the gray "analysis" period is **15:24:53** and **15:26:08**. You will notice that the **Start time** is really the time label from **ROW 8**, not ROW 9.

Compare only the duration of time in the gray highlighted area between video and Activ8. Therefore, a few seconds of coded P&M from the video observation will also have to be removed from analysis.