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Activity Monitoring in Older Persons

- Methodology and Clinical Applications

Thesis for the degree of Philosophiae Doctor

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SAMMENFATNING (SUMMARY IN NORWEGIAN)

Fysisk aktivitet handler om hva du faktisk gjør i løpet av en dag. Fysisk aktivitet endres som følge av økt alder og funksjonsnivå, men også som følge av skader eller sykdom. For eldre er linken mellom fysisk aktivitet og funksjon viktig, og å være i aktivitet er viktig for å opprettholde selvstendighet i daglige aktiviteter. Eldre som har vansker med å forflytte seg er ofte inaktive, og risikoen for ytterligere funksjonsnedsettelser vil dermed også øke. For disse vil mobilisering være ekstra viktig etter perioder med sengeleie grunnet sykdom eller operasjoner.

Fysisk aktivitet over lengre perioder kan nå måles ved å benytte små, kroppsbårne, akselerometer-baserte aktivitetsmålere. Dette gjør det mulig å samle objektiv informasjon om hvor fysisk aktive eldre faktisk er i daglige aktiviteter. Slike akselerometer-baserte metoder har typisk blitt utviklet og validert på yngre og friskere personer. Derfor er det behov for å undersøke målesikkerheten og gyldigheten av slike metoder på eldre og de med forflytningsvansker, før man kan ta i bruk disse i klinisk forskning og praksis.

Avhandlingen inkluderer en litteraturgjennomgang, to metodestudier og en klinisk studie, hvor målsetningen består av fire deler, og er som følger:

1) å gå systematisk gjennom litteratur på hvilke fysisk aktivitetsvariabler som er utledet fra kroppsbårne sensorer gjennom langtidsmåling av friske eldre og eldre med ulik helseproblematikk;

2) å evaluere nøyaktigheten til en-aksete aktivitetsmålere basert på akselerometer til å gjenkjenne stillinger, forflytninger og steg, sammenlignet med videoopptak, i ulike eldre pasienter: i akuttfasen etter hjerneslag, etter hoftebrudd og sykehuspasienter fra geriatrisk avdeling, sammenlignet med friske yngre voksne;

3) å evaluere nøyaktigheten av ulike antall og kombinasjoner av dager med opptak for å estimere tid i oppreist stilling gjennom en dag hos hoftebruddpasienter; og

4) å evaluere om det er forskjell i tid i oppreist stilling fjerde postoperative dag hos hoftebruddpasienter behandlet med bred geriatrisk utredning og behandling eller ortopedisk behandling, og sekundert å evaluere forskjeller i antall forflytninger, funksjon i underekstremitetene og behov for hjelp ved forflytning.

Den systematiske litteraturgjennomgangen viste 134 studier som inkluderte ulike variabler fra aktivitetsmålere blant friske eldre og eldre pasientgrupper. Det er stor variasjon i hvilke aktivitetsvariabler som er brukt i de ulike studiene og også i metodene for aktivitetsmålingen, noe som gjør det vanskelig å sammenligne resultat mellom studier og ulike populasjoner.

Valideringsstudien på aktivitetsmåling blant eldre med forflytningsvansker viste stor nøyaktighet for variablene tid i oppreist stilling og antall forflytninger fra sittende til stående, samtidig var antall steg under gange unøyaktig spesielt på lave ganghastigheter. Videre fant vi at det blant hoftebruddpasienter er stor variasjon i tiden de er i oppreist stilling, både når det gjelder variasjonen mellom dager for enkeltpersoner og mellom personer. Basert på disse resultatene, foreslår vi at minimum fire dager med aktivitetsmåling bør gjennomføres for å få et nøyaktig estimat av tid i oppreist stilling gjennom en uke. Studien som evaluerte fysisk aktivitet tidlig etter hoftebrudd avslørte at pasienter behandlet med bred geriatrisk utredning og behandling i en geriatrisk sengepost tilbrakte mer tid i oppreist stilling og hadde bedre funksjon i underekstremitetene sammenlignet med de som fikk ortopedisk behandling i en ortopedisk sengepost. Dette viser at mobilisering bør inngå i en systematisk tilnærming overfor eldre etter hoftebrudd.

Denne avhandlingen gir ny kunnskap om fysisk aktivitet hos eldre, og særlig i forhold til eldre med forflytningsvansker. Det er behov for variabler som er pålitelige, noe som forutsetter evaluering for hver populasjon hvor metoden skal benyttes. Resultatet fra avhandlingen viser dessuten at fysisk aktivitet bør inngå som en del av ulike behandlingsmodeller. Basert på resultatet fra fysisk aktivitet tidlig etter operasjon for hoftebrudd, er forslaget at man bør ha fokus på å utnytte daglige aktiviteter til å være fysisk aktiv. Fysisk aktivitet hos eldre tidlig etter hoftebrudd vil være avhengig av omgivelsene, og utvikling av behandlingsmodeller med fysisk aktivitet som del av en systematisk tilnærming vil dermed være nødvendig.

Aktivitetsmåling er et relativt nytt forskningsfelt, hvor det er behov for enighet om metodevalg og hvilke variabler som bør benyttes ved aktivitetsmåling av eldre.

ABSTRACT

Physical activity refers to what you actually do during a day. Physical activity changes with increasing age and functional level, as following injuries or diseases. For older persons the link between physical activity and function is important, where living a physically active life will be important for independence in daily life activities. Older persons with mobility limitations could be at risk of further functional declines because of their low levels of physical activity. Thus, after periods of bed-rest caused by disease or surgeries, physical activity would be extra important.

Physical activity over longer periods can now be measured by use of small, wearable, accelerometer-based activity monitors. This enables collection of objective information about how physically active older persons actually are during their daily life. Activity monitors have typically been developed and validated in younger and healthy samples. Thus, before taken into use in older persons and older persons with mobility limitations both in clinical research and in practice, assessment of reliability and validity of these methods are needed.

The aim of this thesis, which includes one literature review, two method studies and one clinical study, was fourfold;

1) to systematically review the literature on physical activity variables derived from body-worn sensors during long term monitoring in healthy and in-care older persons;

2) to assess accuracy of single-axis accelerometer-based activity monitors in recognizing postures and transitions and counting steps compared to video recordings, in different samples of older patients: in the acute phase after a stroke, following a hip fracture, and in a geriatric hospital ward, compared to healthy younger adults;

3) to evaluate the precision of estimated upright time during the day in hip-fracture patients, using different numbers and combinations of recording days; and

4) to assess if there are differences in time in upright position the 4th day after surgery between hip-fracture patients treated with comprehensive geriatric care as compared to orthopedic care, and secondary to assess differences in upright events, lower extremity function, and need for help during ambulation.

The systematic literature search revealed 134 studies with different outcomes from activity monitoring for older healthy persons and patient groups. There were large inter-study variability in activity outcomes and great variety in activity monitoring methods, which makes it difficult to compare results across studies and populations.

The studies on validation of physical activity monitoring in older people with mobility limitations demonstrated very good accuracy for the outcomes upright time and number of transitions from sitting to standing, but inaccuracy for step counts during walking, especially at low gait speeds. Furthermore, we found upright time in older hip-fracture patients to vary largely between persons and days. Based on the results, we suggest that activity monitoring should be performed for a minimum of four days in order to give a valid estimate of upright time during a week. Studying physical activity early after a hip fracture, we found more upright time and better physical function in patients treated with comprehensive geriatric care in a geriatric ward compared to orthopedic care in an orthopedic ward, suggesting that mobilization should be part of a systematic approach when treating older persons after hip fracture.

This thesis provides new knowledge about physical activity in older persons, particularly in older persons with mobility limitations. It pinpoints the need for reliable outcomes and that reliability needs to be assessed in this particular population. Results from this thesis also highlight that physical activity should be included in caring models. Based on the results of physical activity in hip fracture patients early after surgery, the suggestion is to make the most out of daily life activities in order to increase physical activity. Physical activity in older persons early after hip fracture is dependent of the settings where it is being performed. Development of treatment models where systematical approaches for physical activity are included in treatment procedures is therefore warranted.

Activity monitoring is a relative new field of research. The results from this thesis demonstrate the need for consensus on methodological aspects related to activity monitoring, including outcome measures when used in older persons.

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Contents

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ABBREVIATIONS

BBS	Berg Balance Scale
BI	Barthel Index
CAS	Cumulated Ambulation Score
CGC	Comprehensive Geriatric Care
MET	Metabolic Equivalent
MMSE	Mini Mental State Examination
mRS	modified Rankin Scale
MVPA	Moderate to Vigorous intensity Physical Activities
NE-ADL	Nottingham Extended Activities of Daily Living Scale Index
OC	Orthopedic Care
PA	Physical Activity
RCT	Randomized Controlled Trial
SB	Sedentary behaviour
SPPB	Short Physical Performance Battery
TUG	Timed Up-and-Go

CLARIFICATION OF CONCEPTS

Definitions and clarifications of some central concepts used in this thesis are presented here.

Activity monitoring:
Activity monitoring is defined as assessment of physical activity (PA) by use of small, wearable sensor systems that enables objective, continuous, and long-term collection of information on what a person actually does during a day (type, amount, frequency, intensity, and duration of activity).

Activity monitor:
An instrument that collects data on type, amount, frequency, intensity, and duration of activity. Accelerometers are the most used instrument embedded into activity monitors. Accelerometer-based activity monitors are therefore highlighted in this thesis.

Outcomes of PA derived from activity monitoring:
Outcomes are the different variables that can be derived from activity monitoring. The outcomes to be derived are dependent on placement site of the instrument on the body, the instruments embedded into the activity monitors as well as algorithms in the software systems.

Activity monitor used in Paper II, III and IV:
Single axis accelerometer-based *activ*PAL activity monitors from PAL Technologies (activPAL, PAL Technologies ltd., Glasgow, UK) attached at participants' thigh. In this thesis, this activity monitor is referred to as *activ*PAL.

Main outcome of PA in Paper III and IV:
Time in upright position, including both standing and walking, expressed as averaged minutes per day (Paper III) or total minutes per day (Paper IV).

In-care or healthy older persons in Paper I:
In-care older persons include persons with specific medical diagnoses or conditions as well as inpatients or long-term residents in continuing care facilities. Healthy older persons included samples of community-dwellers, without specifically reported diseases.

PAPERS

Paper I *Physical activity monitoring by use of accelerometer-based body-worn sensors in older adults: a systematic literature review of current knowledge and applications*

Taraldsen K, Chastin SF, Riphagen II, Vereijken B, Helbostad JL.
Maturitas 2012 Jan;71(1):13-9. Epub 2011 Nov 30.

Paper II *Evaluation of a body-worn sensor system to measure physical activity in older people with impaired function*

Taraldsen K, Askim T, Sletvold O, Einarsen EK, Bjåstad KG, Indredavik B, Helbostad JL.
Physical Therapy 2011 Feb; 91(2):277-85. Epub 2011 Jan 6.

Paper III *Multiple days of monitoring are needed to obtain a reliable estimate of physical activity in hip fracture patients*

Taraldsen K, Vereijken B, Thingstad P, Sletvold O, and Helbostad JL.
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Paper IV *Physical behaviour and function early after hip fracture surgery in patients receiving comprehensive geriatric care or orthopedic care. -A Randomized Controlled Trial*

Taraldsen K, Sletvold O, Thingstad P, Saltvedt I, Granat MH, Lydersen S, Helbostad JL.
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1. INTRODUCTION

To be able to walk and be physically active is taken for granted by many people, but for many older persons this is not that obvious. Getting up from the bed or a chair and walking to the toilet represent important daily life activities that are crucial for independent living. Physical activity during the day is a factor that can affect maintenance of independence in daily life and is also important when trying to regain physical functions after diseases or injury.

The first study focusing on the importance of physical activity performed as part of daily routines was performed in London in 1949, where conductors of double-decker buses who climbed the stairs repeatedly during a working day experienced lower rates of cardiovascular disease as compared to the drivers of the buses (1). Physical activity literature has later, to a large degree, focused on effects of physical exercise. Being physically active as part of daily routines may have important health benefits and be important for physical function, and physical activity therefore needs more attention. Recent technological developments have made it possible to monitor activity throughout the day. Using such methods may give new insight into the role of daily physical activity level and pattern on health and physical function in different populations, and is of extra relevance for older persons who are at risk of functional decline and dependence in daily life activities.

The topic of this thesis is monitoring of physical activity and daily physical activity in older persons, with a special focus on older persons with mobility limitations. The thesis highlights methodological concerns we meet when using wearable, accelerometer-based activity monitors in older persons, and clinical results derived from activity monitoring in hip fracture patients.

1.1 PHYSICAL ACTIVITY AS CONCEPT

1.1.1 Framework

The term physical activity is used to describe amount, type, frequency, intensity and duration of what a person does during a day. The exact definition of **physical activity (PA)** is ”any bodily movement produced by skeletal muscles that requires energy expenditure” (2). The use of the term has been dictated by how it has been defined and often also by the measurement device that has been available (3). Thus, much focus has been on energy expenditure (4).

The link between the terms PA and energy expenditure is so close, that many people automatically understand PA in relation to this aspect. The term PA in this thesis will be used related to activity monitoring with a wider understanding in terms of including all aspects of PA that together represent the complex nature of what a person does during a day, including amount, type, frequency, intensity and duration of activities. Furthermore, based on these aspects one can also describe a persons' **activity pattern**, in terms of time and frequency of activities during a certain time period.

Some other terms related to PA should also be introduced to get a complete framework for this thesis. **Exercise** is when activity becomes more targeted, repetitive, planned and structured, often aiming to affect one or more components of physical fitness (5).

Physical function can be defined as a persons' experience of ability to perform, or what he/she actually is able to physically perform (6, 7).

Physical fitness is a set of components a person has or achieves that is related to the ability to perform activities (2). Physical fitness is both skill and health-related, and includes skill performance of motor tasks related to daily life or sports (speed, agility, balance, coordination, power, reaction time), or important health-related aspects such as body composition, flexibility, muscular strength and endurance, and cardiorespiratory endurance.

Today, we have ample opportunity to have highly inactive lifestyles, and the serious negative effects of inactivity have caused researchers to extend their focus not only on PA but also on **sedentary behaviour (SB)**. SB is defined as activities that do not increase energy expenditure substantially above the resting level (8). Some have argued that SB is an independent behaviour distinct from PA, and not just the lower end when looking at different intensities of PA (9). Sitting is associated with negative effects because of muscle unloading as compared to quiet standing where postural muscles and leg muscles are activated (10), suggesting that SB should be used when non-upright postures are described (11).

PA has often been categorized related to the context where it has been performed, such as leisure time PA (for example walking, dancing or gardening), transportation (for example walking or cycling), household (for example cleaning), play, games, sports or exercise, or occupational for those still engaged in work (12).

In this thesis, PA will be used as all possible aspects of PA one can collected and derive from activity monitoring.

1.1.2 Why focus on PA in older persons?

PA is associated with health gain, including a lower risk of diseases, higher levels of cognitive function, better psychosocial well-being and independence in daily life (13). Thus the promotion of PA is of high importance, because the typical lifestyle is characterized by low levels of PA. The evidence of the health gains from PA is overwhelming, and increasing PA in the general population is a major public priority. To be able to increase peoples' levels of PA, people need to see and want the benefits and the environment should support people in more active lifestyles (13).

The preservation of independence in daily life is a major priority for many older persons (14, 15). Age-related changes in physical functions may affect level of independence, and these changes will be affected both by the persons' genetics, pathology, and lifestyle. Older persons are a heterogeneous group where age itself often says little about an individual's physical function, but where regular PA will be one important factor. As compared to genetics and chronic diseases, PA is actually a factor one can modify also in older age.

Researchers have often wondered about the recipe for living a long and healthy life, and evidence includes PA as one important aspect. One example is the HALE project including eleven European countries and 2339 older persons (70-90 years), that showed that adherence to a Mediterranean diet, nonsmoking, moderate alcohol use, and moderate to high levels of PA were associated with more than 50% lower rate of all-cause and cause-specific mortality (16).

Promotion of PA often includes leisure time activities such as participation in exercise classes as well as daily tasks like shopping and visiting friends (17) although the majority of activities for older persons are low intensity activities performed as part of their daily life activities in their homes (18). Furthermore, studies on age-related changes related to PA have often focused on effects of exercise alone, and not on non-exercise activities (19). There is a need for more knowledge about daily life PA because of the importance for health - but especially because of the close link to physical function.

1.2 ACTIVITIY MONITORING BY WEARABLE SENSORS

Several methods are available that can be used to collect data on PA. Questionnaires have most often been used, as a quick and relatively easy way to collect information about PA from large study populations. More recent technology has enabled long-term recordings of daily life PA by use of wearable activity monitors. There are both advantages and challenges of using data from such objective recordings, especially because this is a relatively new field of research where method development is far from completed.

1.2.1 Methods based on self-reports and observations

Retrospective methods like questionnaires or interviews have often been used when collecting data on PA. However, such methods have important limitations. For example, PA in older persons is mostly performed as part of daily life activities, and thus active time is mostly spent at lower intensity activities with little time being spent at higher intensity activities (20). To the extent that self-reported measures focus on activities at higher intensities, reports on PA may underestimate light and moderate intensity activities (21). For persons spending most of their active time at lower intensities, problems with recall could also be due to the fact that such activities are more routine and less remarkable or memorable (21).

Self-reported PA could also produce errors due to cognitive impairments or speech problems. Furthermore, older persons answering questions may also misinterpret questions or misunderstand terminology used in questionnaires (22). In addition, self-reports produce retrospective data on PA, and recalling PA from an average week for example could be difficult. It would also require dependable strategies to be found, to be able to report frequency and duration of different activities (23).

Behavioural mapping could be a solution for collection of real time, objective data (24). This is a time consuming method, and requires that a person is in the same room as the person being observed. Alternatively, observations can be performed by use of cameras, but this has severe issues of privacy, as well as limitations due to being stationary placed (25).

1.2.2 Activity monitoring

Small activity monitors are now available, that enables objective measures of different aspects of PA. PA in real life situations can therefore be captured, and outcomes of both leisure and daily activity can be derived.

The development of activity monitors from the start in 1970 and up till today has been revolutionary, from use of simple mechanical accelerometers (26) to smart-phone applications based on embedded accelerometers that further extend the possibilities and ease of use (27). Most activity monitors have become smaller and easier to use. At the same time increasingly more instruments have been embedded in activity monitors, more advanced algorithms for outcome variables have become available, and technological advances have enabled out-of-lab settings, wireless systems, and larger battery capacity, to name but a few. In addition, new activity monitors could also enable outcomes of more complex kinematics during gait in daily life settings (28).

Activity monitoring by use of wearable sensors has been, and is increasingly used as a method for collecting data on PA. There are several reasons for this: Activity monitors enable collection of quantitative data by use of simple, non-invasive and portable devices (29). Furthermore, data are objectively measured, and enable unsupervised collection of continuous data (29, 30). Activity monitors are also more and more used in older persons, although the potential for this use is not fully exploited.

Today, small activity monitors that are relatively easy to use are available at a relatively low cost, and can now be used in both clinical settings and free-living environments (29, 31). Activity monitors can collect data throughout the day, making it possible to evaluate a person's PA over the entire day (32). The rich variety of possible outcomes of PA one can derive from activity monitoring, enables other measures than those collected with more conventional methods for obtaining data on PA as well as for physical function (33). Activity monitoring derives information on what a person actually does, and therefore enables us to say something about PA under daily life situations. SB can also be evaluated, along with the possibility of looking at activity patterns across an entire day or during several days. One can therefore look at both the low-level PA and the fragmentation of activity in terms of when, how long and how often activities occur during the recording period (3, 34).

Despite the many advantages of using activity monitors instead of self-reports are highlighted here, activity monitoring is still a relatively new field of research where several questions related to methodology and interpretation of data need to be answered. Of all activity monitors that are available, few have been fully validated, especially when used in groups of older persons in general and in older persons with mobility limitations in particular.

1.2.3 Instruments embedded in activity monitors

Activity monitors may include different instruments, ranging from single-axis accelerometers to multi-axial accelerometers, gyroscopes, magnetometers or a combination of these instruments (33, 35, 36). However, most activity monitors are based on accelerometers.

Accelerometer-based activity monitors are therefore highlighted in this thesis. Sensor systems may include other instruments, but this are beyond the scope of this thesis.

Accelerometers measure acceleration along one or more sensitive axes (31). Accelerometer-based activity monitors measure acceleration due to movement (dynamic) as well as gravitational (static) acceleration (31, 37). There is a range of different accelerometer-based activity monitors and techniques, but all use a variation of the spring mass system (31). When acceleration is applied to such a sensor system, the small mass responds by applying a force to a spring, causing it to stretch or compress, and the displacement is measured and used to calculate acceleration (31).

Output from accelerometer-based activity monitors depends on the position of the sensor in relation to gravity, its orientation relative to the participant wearing it, the posture of the participants and the activities being performed. If the participant is at rest, then the output from an accelerometer is determined by its orientation relative to gravity. If the placement site for the sensor is known, one can use the sensor to determine the orientation of the participant relative to the vertical (gravitational direction). The total measured acceleration will therefore include both the movement acceleration and the gravitational acceleration (31).

In a review from 2008 on activity monitoring in older persons, the physical placement and reports on use are presented for some activity monitors, showing different placement sites from shoe to different parts of the body, including ankle, thigh, waist, trunk, and sternum among others (33). Accelerometer-based activity monitors focusing on for example step counts or walking activities are typically attached on ankle (38), thigh (39), hip (40), or waist (41).

A combination of attachment sites can be used if one wants to detect transitions and positions of both the upper body and the lower limbs, where for example two single-axis accelerometers are attached at different sites, such as one worn on the thigh and one attached at the sternum, as in the study from White and colleagues (42). A study from Bussmann and colleagues (2001) showed that an activity monitor with four accelerometers attached to different parts of the body could distinguish up to twenty everyday positions and activities (43). However, a single placement site will probably help the acceptability of wearing an activity monitor for a prolonged period of time.

1.2.4 Measuring PA by use of activity monitors

Activity monitoring as method enables many possible uses and a wide range of possible outcomes. When using activity monitors, the categorization of PA is defined by the exact activity monitor that is being used, including the activity monitors' algorithms. For example, an actigraph activity monitor typically derive outputs based on activity counts (40) while other activity monitors are used as inclinometers to be able to derive outcomes of activity recognition (44).

Figure 1 presents an overview of constructs and examples of outcomes used to describe PA derived from raw acceleration signal data from activity monitoring. The figure also provides the framework of how PA is used in this thesis. A similar classification is suggested by others (3). Traditionally, raw data from accelerometer-based activity monitors have been used for the purpose of either activity recognition or activity counting, where the first focuses on recognition of positions and the other focuses on energy expenditure of PA.

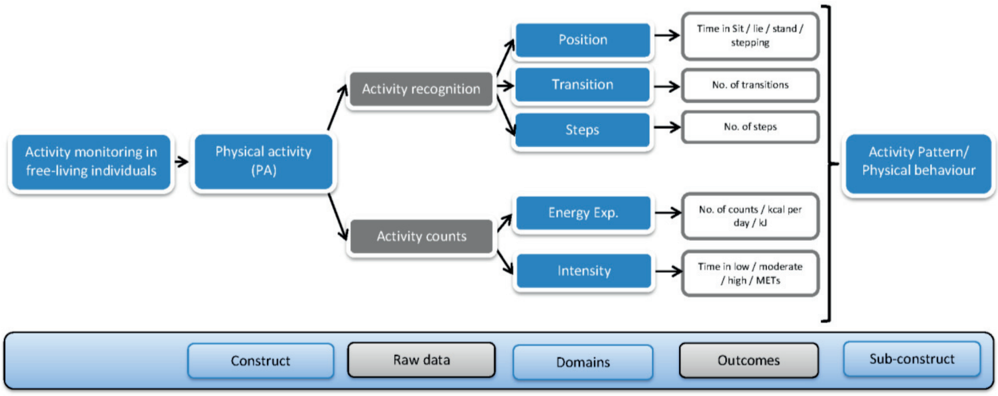

Figure 1. *Overview of constructs and examples of some outcomes used to describe PA derived from data collected by activity monitors.*

Activity counts are often used to express amplitude and frequency of raw acceleration data (45). The acceleration signal is divided into a set of time periods, often one minute. The value "counts" is calculated for each time period. More movement will provide higher value of the counts (46). To be able to interpret the dimensionless unit of activity counts, values of counts are often translated into units and related to energy expenditure or thresholds for particular intensities (45).

Large population-based studies from the U.S and Norway (40, 47) included “counts per minute” as outcome measure of PA. Activity counts can also be translated into caloric expenditures of energy expenditure such as “kcal per minute” (48). Activity counts are often used for estimation of Metabolic Equivalent (MET) values, to be able to interpret results related to particular intensity categories such as for example moderate and vigorous PA (MVPA) (48, 49) or duration of activity >3 METs (50).

The use of thresholds for a particular intensity could for example be, light intensity activities, that represents activities such as slow walking, sitting and writing, cooking, and washing dishes (8). Other thresholds could also include thresholds that distinguish SB from light intensity activities, where sedentary will be the lowest threshold of the activity counts (49). The use of thresholds or fixed cut-off values for activity counts has been discussed lately, especially for older persons where results could be dependent on the cut-off that is chosen (51). Although, cut-offs could be relevant for comparison of results across studies or when the focus is to assess PA related to guidelines, cut-offs are not related to the actual fitness level for each persons. For older persons where level of fitness is relatively low compared to younger populations, definitions of intensity levels based on adults could be problematic. Moderate intensity for normal adults defined by MET levels of 3.0 to 6.0 for example, could for older persons be either relatively vigorous or physiologically impossible to perform (52). Researchers have discussed and highlighted that energy expenditure is a complex construct to measure, and the use of thresholds for activity counts could therefore be relatively arbitrary (3).

Activity recognition is based on raw accelerometer data, but where the inclination of the activity monitor relative to the horizontal is at focus. The posture of the participants and the activities being performed along with the placement of the activity monitor therefore enables outputs of events of upright activities and sedentary activities. An event is a period where the person is spending a certain duration of time in one single position (3). Outcomes representing positions could for example be “upright time” (39). The raw accelerometer signal can also be used to derive outcomes representing steps taken during walking based on the vertical accelerations, enabling outcomes such as “step count” and/or “walking time” (53). For activity monitors where activity recognition is at focus, changes in position or events can be used to calculate number of transitions, providing outcomes such as “upright events” that are related to transitions from a sitting to a standing position. In comparison to the use of activity counts where sedentary is the lowest threshold, the recognition of sedentary will here be a period where a person is spending a certain duration of time in a sedentary position, such as for example sitting and lying.

Furthermore, the collection of continuous data provides possibilities for looking at **activity patterns** over a certain time period, where the aim is to describe a person's variation and complexity in PA in more detail (34). One example of such an outcome is the "length of events" during daytime presented in the study from Grant et al. (2010) (39). This could also involve more complex outcomes that enhance complex mathematical strategies (4, 34, 37, 38, 54). One example is the outcome called "ApEn" (approximate entropy) that represents activity patterns in terms of how complex the pattern of PA is (55). The major advantage of looking at activity patterns is the interpretation of data, where the pattern rather than an average or overall PA can be derived (37). Because activity patterns enable a wider understanding of a person's PA we have included "**physical behaviour"** in figure 1, where outcomes that describe activity pattern represent the physical behaviour of a person during a certain time period.

1.2.5 Considerations when using activity monitors

Activity monitoring is not a "one size fits all"-method (56), and a variety of activity monitors or sensor system are used (33). At present there is lack of consensus in terms of which sensor system and outcomes should be used (57).

Different manufacturers have their own recommendations for where to place the activity monitor and procedures for how to attach it. The activity monitor's size and weight, comfort of wearing it, attachment site on the body, attachment method, and whether the device is water-proof or not will affect how feasible it is for the participants to use the activity monitor (33). Problems with participants' memory could also affect compliance of wearing an activity monitor, especially for several days, and strategies for detecting non-wear time of the sensor system is important to consider to be able to collect reliable data (20).

Ensuring correct placement could also improve the accuracy of data collected. Attachment site of a single device on an affected versus a non-affected lower limb could for example be very important for data accuracy in terms of walking activity, such as detection of steps (58). Periods of non-wear time can bias results and researchers should try to get information about the compliance by participants wearing the accelerometers. Strategies that are suggested are for example log of wear time filled out by the participants, reminders, and careful education of participants (59). To overcome the challenges with non-wear time, some new generation accelerometers contain algorithms that distinguish between sedentary and non-wear time (37).

The typical number of recording days is between 3 and 7 (59). However, the length of data collection periods should be related to the reliability of the outcome at interest. Some studies mention that both weekend days and week days should be included to get reliable measures of PA (60). Furthermore, activity monitoring for longer periods should probably also consider seasonal variations related to PA, even if few studies report the time of the year when data is collected (49).

1.2.6 Interpretation of data from activity monitors

Activity monitoring is a relative new field of research and in addition to the obvious questions of how valid and reliable outcomes from activity monitors are, as well as how feasible the method is, other important factors should also be considered. First, it is important to know that manufacturers may change their devices and algorithms embedded in the sensor systems that could affect the outcomes derived from the activity monitor system. Such changes may challenge comparison of results even for the same sensor systems over time (61).

Comparison of outcomes derived from different activity monitors should also be performed with caution, because the same outcomes can be calculated differently (49). Furthermore, algorithms used to calculate outcome variables are often developed based on younger populations, and outcomes representing energy expenditure will not necessarily represent the actual energy expenditure of a person if the algorithms are based on thresholds and not actual physical fitness level (4). Outcomes of energy expenditure could therefore be inaccurate for older persons because of several age-related changes, such as for example declines in basal metabolic rate, that together will provide errors in calculations developed for younger samples (20). Algorithms and cut-points that are specific to older persons are therefore needed (62).

Acceleration in vertical direction increases with increasing gait speed (63). Some studies have found lower accuracy in detecting steps at lower gait speed compared to higher gait speed, which may be explained by the low acceleration amplitudes during slow walking (64). One should therefore know the accuracy for an accelerometer device in step detection at different gait speeds. One example is the single-axis sensor validated in a study from Ryan and colleagues (2006) on healthy younger adults, where the authors conclude that results of step counts were unaffected by walking speed (65). Nevertheless, one should question the implication of these results when used in an older population where gait speeds will be lower. However, a validation study from Grant (2008) showed accurate results also for community-dwelling older persons (66). Furthermore, in a paper from the same research group they briefly comment that some preliminary unpublished results from their study indicate problems with step detection in frailer older persons (39). The authors comment that the problems are not due to the device's ability to detect the accelerometer signals, but because the software did not manage to classify these signals as steps (39).

Commercially available accelerometer-based activity monitors are often delivered with software containing algorithms that are opaque to the users. When using these "black boxes" one should at least know the population that was included in the validation studies. Validation studies more typically include older persons that are healthy rather than older persons with mobility limitations. One can therefore not rely on the same accuracy for the measurements when for example the gait speeds are lower than what it was validated on. Furthermore, validation studies often are performed in in-lab settings, and validation in free-living settings might provide different results (67).

Different outcomes derived from activity monitoring may represent different aspects of PA. One example is the results from the population-based study in Norway, showing that men and women did not differ in their overall activity level in terms of counts per minute and steps per day (47). However, men did spend more minutes being sedentary and in MVPA compared with women, indicating differences if reporting these outcomes (47). Furthermore, when comparing overall results from this study with data from the National Health and Nutritional Examination Survey (NHANES study) from the U.S., Norwegians were more physically active. Nevertheless, authors of the report (68) speculate whether the explanation is not lower levels of overall activity, but a higher proportion spent at lower intensities in the U.S. population that will not be shown by the intensity-dependent outcome that was reported.

1.3 PA REPORTED FROM ACTIVITY MONITORING STUDIES

1.3.1 PA in older persons

Activity monitoring provides knowledge about PA from direct observations, which may provide new knowledge about PA in older persons compared to using questionnaires to assess PA. A population-based study from Norway, for example, monitored PA by accelerometer-based activity monitors in persons from 20-85 years of age over a week (68). A total of 3267 participants completed this assessment, and 282 out of them were older persons between 65 and 85 years. Results showed that overall activity (counts per minute) and number of steps taken per day decreased after the age of 65 years, while time in SB increased and time spent in lower intensity activities decreased (47). Furthermore, differences in PA between week and weekend days, with less upright time during weekend days, was found in this population as compared to younger adults (68).

Other population-based studies reported similar findings. The 2003-2004 National Health and Nutritional Examination Survey (NHANES) in the United States, reported that older persons (>70years, n=704) were among the least active part of the population, where only 3% met the current health recommendations (40). Regardless of cut points used, time spent in MVPA declined with advancing age. Furthermore, time spent in SB was longer among participants at 80 years or older as compared to younger groups of elderly (51).

The Nakanojo study from Japan included 170 older persons from 65 to 84 years of age, and collected activity monitoring data for one year. Outcomes of PA in this study were steps taken and duration of PA at >3 METs per day. The total sample spent on average 17.3 minutes in moderate or higher intensity activities (defined as > 3 METs) and took 6 574 steps per day. This study also reported declines in PA with advancing age when comparing two older age groups, where the oldest age group (75-84 years, n=54) spent on average 14.2 minutes in PA and took 5 482 steps per day as compared to the younger older group (65-74 years, n=116), who spent on average 20.1 minutes in PA and took 7 190 steps per day (50).

The study from Japan also showed a significant positive association between physical function and outcomes of PA (steps per day and time in PA >3 METs), especially for those at 75 years of age or older (50). This suggests that older persons who have better physical function also are more active. However, as this was a cross-sectional study it does not prove a cause-and-effect relationship. Gait speed was one of the measures of physical function in this study (50), and gait speed is shown to be an important predictor of functional independence (69).

A review from Bento et al. (2012) presents the most reported activity monitoring outcomes from studies in healthy adults. Large variety across studies were reported, although few reports were shown for older persons PA (49). The average count per minute per day was the most reported outcome of PA found in this review. Another review from 2008 showed that overall measures of PA or estimations of energy expenditure is commonly reported, whereas few studies use outcomes of transitions or time spent in different positions (33).

Activity monitoring enables us to collect data on PA as it occurs, including non-structured activities in daily life settings (20), and new knowledge about an older person's PA can be evaluated. Some persons may be more predictable in their PA with less arbitrariness in their activity patterns (34). It has also been suggested that outcomes of activity patterns, such as the number of ambulation per day or number of "bouts" per day, could be particularly sensitive to detect differences in PA between healthy younger and older persons (38), where for example number of steps or minutes of PA could be similar between the two, while the number of bouts in older persons is reduced. This could suggest that activity patterns will become more predictable with advancing age, where initiating of ambulation could become difficult (38).

1.3.2 PA in older persons with mobility limitations

Some older persons with functional limitations have limited spare capacity and will function close above the thresholds needed to perform daily functions, where for example a minor illness can be enough for them to become dependent in daily life activities (70). In this thesis this group of older persons is described as older persons with mobility limitations. The mobility limitations are typically characterized by short walking distances, low gait speed, and limited PA, and where the risk of experiencing loss of independence, falls and injuries are increased (71-74).

Knowledge from studies collecting objective data on PA in groups with mobility limitations is expanding (56), and can be important to better understand the PA performed in their daily life environment. For example, a study on older stroke patients showed a sample with low levels of PA both in terms of total activity counts per day (mean 53 075, SD 83 476) and total energy expenditure per day (kcal) (mean 155.9, SD 140.7) (75). Participants in this study also showed low between-day variability in their PA, both in terms of activity counts and energy expenditure, that could be caused by routine activities each day (75).

It has been suggested that how predictable a person's activity pattern is, can be related to the ability of performing mobility activities such as for example walking. For example, outdoor walking could require more of a person as compared to walking in a more controlled setting, and the ability to walk outdoors is shown to be more difficult to maintain with age or with compromised health (76, 77). Nevertheless, factors affecting PA are highly complex, and studies trying to explain a certain behaviour such as PA, should examine several subcomponents of the task being studied, because several factors do affect and explain a persons' behaviour (78).

Another suggestion is that because older persons with mobility limitations use a higher percentage of their total capacity when walking, this could influence their overall PA level (79). One study tried to link improvements in function following an intervention to changes in PA, suggesting that a reduced energy cost of walking could result in spending more time being active (80). Results showed marginally larger improvements in activity counts for those that reduced their energy cost during walking (81). However, walking requires improvements in more than just the components of physical function in the person, and the authors suggest that improving motor control aspects of walking may also reduce costs of walking thereby making walking easier as well. Furthermore, the same argument has also been suggested as the explanation for why exercise has shown positive effects on reducing falls (82). Although interventions aimed at reducing falls may not cause improvements in components of physical function in the person, positive effects of being more physically active could be seen on for example cognitive function and executive function (82).

1.3.3 PA in hip-fracture patients

Every year more than 9000 persons suffer from a hip fracture in Norway (83). Every fifth women aged 80 years and almost every second woman aged 90 years, will have a hip fracture (84). The risk for experiencing major negative effects on lifestyle and wellbeing following a hip fracture is high (85). A hip fracture may lead to dependence on walking aids, loss of independence and restriction in activities of daily living, and loss of independence in outdoor walking (85). A review from 2011 showed that 42% of older persons with a hip fracture had not regained pre-fracture mobility level one year after the fracture, 35% were unable to walk independently, and 14% were not able to climb stairs independently (86). Hip-fracture patients therefore **represent a major group of older persons with mobility limitations** at risk for permanent loss of mobility.

The lack of regain in function is a serious consequence of a hip fracture, and perhaps more serious than it should be. A study on older persons after a hip fracture reported that little time was spent being physically active, only 70.4 activity minutes per day and only 1.8 of these minutes per day spent on MVPA (87). The study also demonstrated that most of the PA was performed as part of routine daily living activities such as early morning bathing, dressing, and toileting during the middle of the night (87). Therefore, in order to increase PA, the authors argue for making most out of daily life routines in these persons.

Treatment offered to older persons after hip fractures have traditionally included exercise with focus on components of physical function, such as balance and strength. PA following a hip fracture will be influenced by several factors, for example how treatment or care is offered (88, 89). Furthermore, the hospital setting could also be important and should ensure interesting destinations in the environment so that persons admitted to the hospital who have the ability to walk, will spend more time being physically active (89).

1.3.4 PA Guidelines

The Norwegian recommendations for PA are in line with international recommendations, where 30 minutes of moderate intensity activities per day is recommended to gain an effect on health (90). Older persons are also recommended to follow this guideline. The national and international recommendations for health benefits have focused on MVPA (91), and report extensive benefits such as reduced risk for cardiovascular disease, stroke, hypertension, type 2 diabetes mellitus, osteoporosis, obesity, colon cancer, breast cancer, anxiety, and depression (52). For older persons some important additional benefits would include lower incidence of developing new diseases, reduction of fall risk, and prevention of functional decline (52, 92).

A population-based study from Norway using PA questionnaires has previously shown that 60% of the participants (n=4500, age 19-91 years) followed the PA guidelines (93). However, when using objective activity monitors, a study showed that only 20% of participants were found to meet the recommendations of 30 minutes of moderate intensity activities per day (68). For those over 70 years of age, only 11% of women and 17% of men met the recommendations (68). For comparison, in the U.S. only 3% of older persons meet the same health recommendations (40).

The difference in PA measured by questionnaires and activity monitoring may have several explanations. Activity monitoring may provide estimates that are closer to the truth, thus indicating that self-reports tend to provide greatly overestimated measures of PA. It has also been suggested that responders may misclassify their PA, such as in a study on sedentary adults using a self-administered activity log where results showed overestimation of the intensity of their PA, specifically for moderate intensity activities (94).

To achieve the recommended levels of PA, older persons can take a stepwise approach towards reaching the goal of meeting the PA guideline (52). Furthermore, spending time being physically active also below the recommended level will be important for health, especially because a large number of persons spend much time in SB (52). Changing from sedentary to light activity could be an especially important contributor to health (8), as PA and SB are suggested as two important factors that are independently related to overall functional fitness (95). Pate (2008) provided a good illustration of this by comparing two persons with very different activity patterns during one day (8). The first person was classified as sedentary because the 30 minutes of MVPA recommendations were not met. However, when looking at the activity pattern, this person was not sedentary for more than 25% of total monitoring time, while 75% of time was spent performing light activities. In contrast, the second person met the recommendations with one hour of MVPA although SB accounted for 70% of total time and light activity for 23% of time for this person (8). To be able to meet the challenges with SB, it has been suggested to include SB in national recommendations for PA (96).

1.3.5 Consequences of immobility or low levels of upright activity

The physical environments humans live in have changed dramatically, and we can function well in daily life without being physically active. Today, there are ample opportunities for living sedentary lifestyles. A highly sedentary day could for example be: using the escalator instead of the stairs, go by car or public transportation instead of walking or cycling, having a sedentary occupation during the day, and spending all evening watching television or in front of a computer. A lifestyle similar to this will have a potential serious negative impact on health. Studies could for example evaluate television (TV) viewing time, such as in a study on older persons (65-74 years of age) where less time watching TV was associated with lower risk of being overweight or obese, independent of meeting PA recommendations (97).

Bed-rest would illustrate a total sedentary lifestyle, and a study on healthy older persons showed that 10 days of bed-rest affected lower extremity muscle strength, power, and aerobic capacity (98, 99). Participation in the study was the reason for the bed-rest. However, despite the great loss of lower extremity strength and power, participants did not experience a decrease in their overall lower extremity function (98). This could be due to additional spare capacity, and that although the participants experienced loss in strength and power, they did function above the thresholds needed to perform the tests on lower extremity function.

Similar studies on older persons with mobility limitations have not been performed, so one can only speculate about results from such studies. Older persons who are bedridden in a hospital will have conditions that probably already have affected their physical functions negatively prior to the bed-rest. The bed-rest could therefore cause loss of strength and power as well as the ability to perform certain daily functions, because of limited capacity already prior to the bed-rest.

Although measurements of daily PA during hospitalization rarely have been included in previous research (100), Kortebein (2008) made a comment about studies looking at effects of hospitalization, where inactivity during hospital stay could be an explanation of the functional declines seen. A study investigating the association between episodes of bed-rest and functional declines during 18-months in a sample of 680 older persons over the age of 70 years, concluded that episodes of bed-rest could have an important impact on several important factors of physical function as for example decline in instrumental activities of daily living (101).

1.3.6 The role of environmental factors for PA

PA as part of daily life activities could be very important for health, where for example one study found that housework and climbing stairs could reduce the mortality risk (102). Other examples of non-exercise studies have included activities such as walking and stair climbing as part of daily routines, where one study found improvement in capacity in obese women (103), and one found improved physical function and reduced bodily pain in recent breast cancer survivors (104). These studies suggest that in addition to the traditional focus on effects of exercise interventions, similar effects can be found in interventions that focus on daily life PA.

Physical function is often an important factor that is highlighted when describing or explaining PA. Nevertheless, because long-term PA includes free-living activities, a range of factors will together explain a person's PA. Interventions trying to increase PA could therefore benefit from a wider focus, where for example improving physical function and improving factors in the environment that could stimulate persons to be more physically active are but two examples.

The Norwegian survey from 2009 found that people living in neighborhoods with possibilities for being physically active, particular opportunities for exercise and PA, and short walking distances to the shops, actually spent more time being active as compared to those that did not report that they had these possibilities (68). Another study also came to the same conclusion, showing that so called "high-walkable" neighborhoods with close and easy access to nonresidential destinations can influence PA in older persons (4). However, the Norwegian survey showed that fewer of the persons over the age of 70 reported that they had possibilities in their neighborhoods to be physically active as compared to those under the age of 70 years. Furthermore, a lower percentage of those over 70 years agreed that there were several arrangements for exercise and PA in their neighborhoods as compared to those being younger (68).

For hip-fracture patients, early ambulation after surgery may prevent postoperative complications and length of hospital stay (105). A study from Denmark found that need for help during mobilization the first days following hip fracture surgery could predict short-term outcomes such as length of hospitalization, time to discharge, mortality (30-day), and medical complications after surgery (106). The philosophy of an acute hospital setting could therefore be important for PA in older persons with mobility limitations (107), and perhaps a systematic focus on mobilization as part of the treatment regime is needed (108). It could also be important to be aware of the barriers to mobility. A qualitative interview study where older persons, nurses and physicians participated highlighted symptoms like weakness, pain and fatigue, having an intravenous line or urinary catheter, and being concerned about falls as the most frequent barriers to mobility, concluded that such knowledge would be the first step to improve hospital treatment (88). Nevertheless, evaluations of what hip-fracture patients actually do during their hospital stay and how it is influenced by environmental factors like mobilization regime is not evaluated with objective measures, and knowledge about PA is at present lacking.

1.4 RATIONALE FOR THESIS

Although activity monitoring in terms of accelerometer-based sensor systems is typically presented as a simple and easy way to collect information about PA, some methodological considerations should be highlighted. Outcomes derived should be of high accuracy, the activity monitor should be validated on the population at interest, and considerations about its feasibility should be raised. One should use an activity monitor that measures the aspects of PA of interest, and one should know that the practicality of wearing the device will affect compliance. So far, most studies that exist on older persons include healthy older persons, and not older persons with mobility limitations. Hip-fracture patients represent a major group of older persons with mobility limitations, where PA is an important factor to consider following the fracture.

Activity monitoring is a research field that changes rapidly. The focus on PA collected by activity monitors is important because it can capture the activity that is actually performed during the day. Furthermore, it represents several new possibilities that are not limited to only higher intensity activities or lack of activity (immobility) but can focus on the overall PA as well as the activity pattern. This thesis is one such contribution that sets a special focus on older persons and older persons with mobility limitations in particular.

2. AIMS OF THE THESIS

The overall aim of this thesis is to assess the methodology and clinical application of activity monitoring in older persons, with a special focus on older persons with mobility limitations. The work consists of four papers: one retrospective systematic review and three prospective studies of which two are method studies and one is a randomized controlled trial (RCT).

The specific aims were as follows:

I. To identify variables of PA derived from body-worn accelerometer-based sensors used for long-term monitoring in older persons and to describe amount and pattern of PA in different groups (healthy and in-care) of older persons (109).

II. To evaluate the concurrent validity of the *activ*PAL Professional single-axis accelerometer-based activity monitor against video observations in recognizing postures (sitting or lying, standing, and walking) and transitions and step counts in people with acute stroke, older inpatients, and people three months after hip-fracture surgery as well as a healthy adult reference group. Furthermore, to assess whether step counts were affected by placement of a sensor on the affected limb versus the non-affected limb in people with hip fracture and acute stroke, and finally to assess the possibility of distinguishing between sitting and lying position by use of two sensors (110).

III. To investigate the precision of objectively estimated upright time during one week using different numbers and combinations of consecutive recording days in hip-fracture patients (111).

IV. To assess whether there were differences in time in upright position the 4th day after surgery between hip-fracture patients receiving comprehensive geriatric care in a geriatric ward as compared to orthopedic care in an orthopedic ward, and secondary to assess differences in upright events, need for help during ambulation, and lower extremity function (112).

3. METHODS

All studies in this thesis were carried out at the Department of Neuroscience at the Norwegian University of Science and Technology and St. Olav's University Hospital in Trondheim, Norway. Papers included in the systematic review (Paper I) were searched for in PubMed up till March 8th 2011, the data in Paper II were collected between September 2007 and March 2008, the data in Paper III were collected between March 2007 and September 2007, and the data in Paper IV were collected between April 2008 and January 2011.

3.1 STUDY DESIGN

The four papers in the thesis focus on activity monitoring in older persons. An overview of design and study populations for the Papers is presented in Table 1.

Table 1. *Study design and patient groups included in Papers I, II, III and IV*

Paper	Design	Population	N included (analysed)
I	Systematic literature review	Older persons (>65 years) with and without mobility limitations, classified into two groups; incare or healthy	
II	Cross-sectional method study	3 sub-groups of older persons with mobility limitations; acute stroke patients, older inpatients at a Geriatric Ward, and hip-fracture patients 3 months after surgery	36 (36)
III	Cross-sectional method study	Older persons 3 months after surgery for hip fracture	47 (31)
IV	RCT	Older persons early after surgery for hip fracture	397 (317)

Abbrevation: RCT=Randomized Controlled Trial. The 134 papers included in the systematic review included a total of 17684 participants.

3.2 DATA FROM LARGER HIP-FRACTURE STUDIES

Data on hip-fracture patients presented in the thesis are collected through two different studies: 1) **The Hip Fracture Observational Study** included a total of 277 hip fracture patients from St.Olav's University Hospital in Trondheim, Ullevål University Hospital in Oslo, and the Diakonhjemmet Hospital in Oslo, Norway. This study included community-dwellers at 65 years of age or older with a hip fracture, where the final examination was three months after the hip-fracture surgery (113). Participants from this study treated at St.Olav's University Hospital in Trondheim, were included as participants both for the study presented in Paper II and Paper III. Those included were able to walk with or without assistance from a walking aid or another person. Participants were asked on their final examination 3 months after hip-fracture if they wanted to participate in a method study (Paper II), and those who volunteered returned to the hospital for assessment on another day than the final examination. For Paper III, participants were asked at the final examination to wear activity monitors from this day, and the activity monitors were collected in the participants' home after one week.

Paper IV was part of a second study on hip-fracture patients, 2) **The Trondheim Hip Fracture Trial** (114). This RCT included patients over 70 years of age with acute hip fracture that were home-dwelling in the country of Sør-Trøndelag and previously able to walk 10 meters. Patients with pathological fractures and fracture caused by trauma, and patients with short life expectancy and those not suitable to be treated in the two intervention wards in this trial for medical reasons, were excluded from participation. The major groups of hip-fracture patients excluded were long-term care residents and those under the age limit of 70 years.

The primary end point in this study was lower limb function measured by the Short Physical Performance Battery (SPPB) four months after hip fracture. Sample size was calculated based on this primary end point. The overall hypothesis for the RCT was that hip-fracture patients would benefit from comprehensive geriatric care (CGC) in a geriatric ward. Participants in the intervention group received CGC during the pre- and post-surgery hospital stay. Controls were randomised to receive conventional orthopedic care (OC) in an orthopedic ward. The design of the study and the full intervention protocol are described elsewhere (108, 114). In Paper IV in this thesis, activity monitoring results from the acute phase post-surgery in the hospital were evaluated.

3.3 STUDY SAMPLE CHARACTERISTICS

The literature review reported in Paper I included studies where both older persons with and without mobility limitations had participated. Paper II included different groups of older persons with mobility limitations and a healthy adult reference group as participants, and Papers III and IV older persons with a hip fracture.

Paper I (109) used the PRISMA guidelines (115), an evidence-based guide for how to report systematic reviews, to improve the reporting of results from the literature review. Paper I was a systematic review of a total of 134 articles. Inclusion criteria for age were mean or median age at or above 65 years. PA was reported for 213 samples of older persons. Samples with specific medical diagnoses (for example Parkinson's Disease) or conditions (for example post hip fracture), inpatients or long-term residents in continuing care facilities were categorized as in-care older persons, while healthy older persons included community-dwelling or older adults described both as sedative or more active, but without any specific reported disease.

One hundred samples (n=7405) were included among those categorized as in-care older persons, along with 113 samples of healthy older persons (n=10279).

Paper II (110) included a convenience sample of 36 persons with mobility limitations recruited among three sub-groups, acute stroke patients from a stroke unit (n=14), older inpatients at a Department of Geriatrics (n=14), and hip-fracture patients 3 months after surgery (n=8) at the end of their participation in the observation study described in the previous chapter (see 3.2 for further details). In addition, 10 healthy women who were employees at the hospital or the university were recruited as a reference group in this study. See Paper II for details on the reference group (110).

Paper III (111) included 47 participants at the end of their participation in the same observational study as the sub-group of hip-fracture patients included in Paper II (see section 3.2 for further details). A sample of 47 persons agreed to participate, of which 31 completed one week of activity registrations that were included in the analysis for this cross-sectional method study.

Paper IV (112) consists of data from the 397 participants included in the Trondheim Hip Fracture Trial (see section 3.2 for further details). Of the 361 participants who wore activity monitors, 317 completed the activity registrations the 4th day post-surgery. Three participants included in the analyses were discharged from the hospital at day four, all others were in-hospital patients when data were collected. Activity registrations from respectively 175 and 142 participants treated in the two hospital wards were included in the final analysis in this paper. Sample characteristics for Papers II, III, and IV are presented in Table 2.

Table 2. *Sample characteristics for Papers II, III and IV (mean, ± SD)*

	Paper II		**Paper III**	**Paper IV**
	Mobility limitation	References	Hip fracture	Hip fracture
Analysed data on n=	36	10	31	317
Female gender in %	61%	100%	77.4%	74.4%
Age in years	79.7 ±7.3	46.3 ±9.0	81.8 ±5.3	83.1 ±6.0
BI score	15.8 ±3.7	20 ±0	18.1 ±2.6	18.4 ±2.4
NE-ADL score			37.8 ±18.1	43.1 ±17.3
Gait speed, m/s	0.46 ±0.2	0.84 ±0.10	0.59 ±0.25	0.35 ±0.16

Abbrevations: BI= Barthel Index; NE-ADL=Nottingham Extended ADL Index, Paper IV reports the pre-fracture BI and NE-ADL scores.

3.4 ETHICAL APPROVAL

Papers II, III, and IV had ethical approval prior to study start. The Regional Committees for Medical and Health Research Ethics (REC), Central Norway, and the Norwegian Social Science Data Services approved the study protocol for Paper II (4.2007.1301). REC approved the study in Paper III (4.2006.1059). The Trondheim Hip Fracture Trial (Paper IV) has approval from REC and has been registered in clinical.trials.gov (4.2008.335 and ClinicalTrials.gov NCT00667914).

Participants who met the inclusion criteria and agreed to participate were given written and oral information about the studies and the activity monitoring. Participants in Paper II were informed that the aim was to assess the accuracy of the device when used on older persons after stroke, after hip fracture or inpatients in a geriatric unit during performance of daily life activities that also were captured with a video camera. Participants in Papers III and IV were informed that the sensor registered movements of their lower extremity, and that they should continue doing what they usually did.

3.5 ACTIVITY MONITORING

This thesis focuses on accelerometer-based activity monitoring for long-term recording of free living PA, with exception off the validation in Paper II where the activity monitor was used during performing an in-lab mobility task test protocol and not for longer periods. In the systematic review in Paper I, long-term monitoring was defined as recording periods of 24 hours or more. Paper III included data from one week registrations and Paper IV included data from one registration day (24 hours).

The systematic review (Paper I) included studies using different activity monitors based on accelerometers, that were not limited to upper-extremity or head activity/motions or wheelchair activity. The most frequently used instruments were actigraphy-based sensor systems (ActiGraph, MTI, ActiWatch, Mini-Motionlogger) that together were used in 34 studies, the Caltrac was used in 24 studies, and the RT3 Research Activity Monitor (also called Stayhealthy) in 17 studies. The *activ*PAL was used in 4 of the 134 articles included in this review.

Papers II, III and IV used the *activ*PAL as measuring device. This activity monitor is a small, light-weight, single-axis accelerometer that samples at 10 Hz (44), with a battery capacity for continuous recording for more than one week. The monitor is worn on the participants' thigh, and registers thigh inclination while wearing it. The manufacturers' software derives information on changes in postures from sitting and lying to standing or walking, step counts and cadence during walking, and also estimates energy expenditure. The algorithms embedded in the sensors are not known to the users. Outcomes have been validated in healthier groups in the past (65, 66). Paper II used three activity monitors, attached to the participants' upper body (sternum) and one on each thigh. Papers III and IV used only one activity monitor attached to the participants' non-affected lower thigh.

3.6 PA OUTCOMES

Activity monitors vary in their possibilities, strengths, and limitations, and choosing the optimal activity monitor and outcomes can be quite a challenge. Paper I presents different outcomes commonly used in the included papers, namely estimated energy expenditure (kcal per day), walking time (minutes per day) as well as upright time (minutes per day).

The activity monitor used for data collection in the studies reported in Papers II, III, and IV (*activ*PAL) was attached to the participant's thigh, and time spent in positions related to thigh inclination and changes in body position (transitions) as well as recognition of steps from the vertical accelerations during walking were derived as outcomes. Figure 2 gives an overview of the use of *activ*PALs and the process of activity recognition from this sensor system.

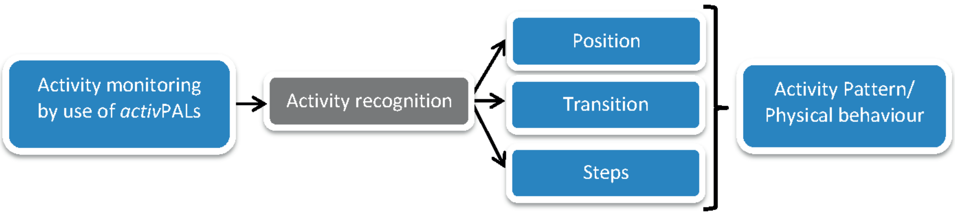

Figure 2. *Use of raw data from activity monitors from PAL Technologies.*

From the classification of position, different outcomes such as time in upright (standing and walking) or sedentary (sitting/lying) can be derived. Because of the thigh placement of the sensor, sitting is impossible to distinguish from lying. Furthermore information about transitions can be derived, and calculated as number of sit-to-stand and/or stand-to-sit transitions (called upright events in Paper IV). Finally, step count can also be derived by use of this activity monitor.

Paper II evaluated the validity of recognition of posture, transition and step count in different samples, and results from this validation were used when choosing outcomes in the subsequent studies. Figure 3 shows the raw acceleration signals an older person and a healthy adult during two periods of walking from this validation study. The peaks at the figures represent steps for the leg where the monitor is worn. Although the steps during walking are registered for both the younger and the older person with impaired mobility, the acceleration amplitudes are lower for the older person, which makes recognition of steps more difficult for the algorithms used to detect steps in the software. This was the reason for not using step counts as outcome in the subsequent studies. For a similar reason, we could not use time in walking because it could not be reliably differentiated form standing. Thus papers III and IV used time in upright as the main outcome. The rationale for this will be discussed in Part 5 (5.4.2, page 61).

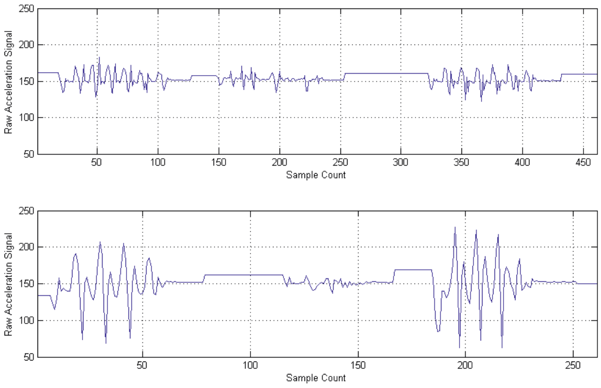

Figure 3. *Raw acceleration signals during walking back and forth 5 meters at normal gait speed, in an older person after hip-fracture walking with a roller (upper), and a healthy adult walking without walking aids (lower). Data from Paper II.*

Activity pattern as an outcome is a new way to look at data from activity monitors. If the model described in the introduction of this thesis is interpreted as a hierarchical model, similar to the model described by Granat (2012) (3), outcomes of activity pattern will be more detailed than primary outcomes derived from activity monitors. In Paper IV, outcomes of activity pattern were calculated based on transitions and upright time, and length of upright events and upright time during all hours during the day were presented. Further knowledge about activity pattern in older persons after a hip fracture should be more at focus in future research.

Table 3 provides reports on PA from hospital settings, derived from papers included in the systematic review (Paper I) (109). The table illustrate the different activity monitors that have been used in these studies, as well as the different outcomes that have been reported.

Table 3. *PA from activity monitoring studies in in-hospital settings*

Output Setting/characteristics (n)	**Results**	**Instrument** (Placement)	**Refs**
Upright time (minutes)			
City day hospital (n=20)	Mean 233.3 (±112.5)	*activ*PAL (thigh)	(39)
Steps per day (no.)			
Acute care for elders (n=239)	Mean 739.7 (IQR 89-1,014)	SAM (ankle)	(116)
Minutes walked			
Acute illness (n=126)	Mean 48 (±41)	RT3 (waist)	(117)
Acute illness (n=127)	Mean 52 (±51)	RT3 (waist)	(117)
Vector movement			
Acute illness (n=126)	Mean 46.049 (±26.662)	RT3 (waist)	(117)
Acute illness (n=127)	Mean 51.773 (±44.682)	RT3 (waist)	(117)
% of time spent in different positions			
Medical wards (n=45)	Mean lying 83.3 (±12.2)	Wireless accelerometers (thigh and ankle)	(89)
Medical wards (n=45)	Mean sitting 12.9 (±10.4)		(89)
Medical wards (n=45)	Mean stand/walk 3.8 (±3.5)		(89)
Counts (6 a.m. – 9p.m.)			
Geriatric psychiatry unit (n=10)	Mean 129.0 (±54.9)	Actiwatch (wrist)	(118)
Geriatric psychiatry unit (n=10)	Mean 187.6 (±114.0)	Actiwatch (wrist)	(118)
Counts (3 p.m. – 9p.m.)			
Geriatric psychiatry unit (n=10)	Mean 52.9 (±26.3)	Actiwatch (wrist)	(118)
Geriatric psychiatry unit (n=10)	Mean 80.3 (±49.1)	Actiwatch (wrist)	(118)
Counts (9 p.m. – 6a.m.)			
Geriatric psychiatry unit (n=10)	Mean 42.4 (±30.2)	Actiwatch (wrist)	(118)
Geriatric psychiatry unit (n=10)	Mean 54.0 (±55.9)	Actiwatch (wrist)	(118)
Counts per minute per day			
2th day after CABS (n=14)	Mean 78.31 (±29.25)	Actigraph (wrist)	(119)
3rd day after CABS (n=14)	Mean 102.41 (±29.61)	Actigraph (wrist)	(119)
4th day after CABS (n=14)	Mean 101.49 (±20.19)	Actigraph (wrist)	(119)
5th day after CABS (n=14)	Mean 108.82 (±25.43)	Actigraph (wrist)	(119)

CABS=coronary artery bypass surgery

3.7 OTHER VARIABLES PRESENTED IN THE THESIS

Variables in the studies including participants (Papers II, III and IV) are presented in Table 4. Background variables of age and gender are presented in all three papers, Papers II and III also include height/weight, and modified Rankin Scale (mRS) scores (120) are presented for participants in Paper II. Furthermore, gait speed (m/sec) is reported in all papers.

Activities of daily living at the three months examination (Papers II and III) and before the hip fracture (assessed retrospectively) (Paper IV) were assessed by use of Barthel Index (BI) (121) in all three papers, and in addition, by use of Nottingham Extended Activities of Daily Living Scale (NE-ADL) (122) in Paper III and IV. The validation study in Paper II used a 0-100 scale for the BI, while Papers II and III report BI by use of the 0-20 scale. Results presented in Table 2 on page 37 are therefore recalculated for the samples in Paper II, to be able to compare results across the studies.

Table 4. *Outcome measures Papers II, III and IV*

	Paper II	**Paper III**	**Paper IV**
Background variables			
Age	X	X	X
Height	X	X	
Weight	X	X	
Gender	X	X	X
mRS	X		
Activities of daily living			
BI	X	X	X
NE-ADL		X	X
Cognitive function			
MMSE		X	
Balance test			
BBS		X	
Mobility			
TUG		X	
SPPB			X
CAS			X
Use of criterion measure	X	X	
*Outcomes from activ*PAL			
Upright time	X	X	X
Step count	X		
Transitions	X		X
Activity Pattern			X
Gait speed	X	X	X

Paper III used the Mini Mental State Examination (MMSE) (0-30) to assess global cognitive function at the three months examination (123). In the same study, the Timed Up-and-Go

(TUG) was used to assess mobility (124) and the Berg Balance Scale (BBS) (0-56) (125) to assess functional balance at the three months examination.

The need for help with mobilisation the first three days post-surgery was collected for the participants in the RCT (Paper IV) by use of the Cumulated Ambulation Score (CAS) (106). This provided separate scores (0-6) for each day, and a summary score for the entire three-day period ranging from zero to 18, where 18 is the best score and indicates independence in mobilisation. Paper IV also used a performance based test, SPPB (126), on the 5th day post-surgery to assess lower extremity physical function. The SPPB consists of a balance task, including three different standing positions, a five repeated chair-rise task and a 4-meter gait task, each scored as time on a 0-4 Lickert scale, providing a total score ranging from 0 to 12 points, where 12 is the best score.

3.8 SAMPLE SIZE CALCULATION (Paper IV)

Sample size calculation for the Trondheim Hip Fracture Trail was performed for the primary endpoint in this study, the SPPB, four months after hip fracture. With a power of 0.8 and an alpha = 0.05, a sample size of 304 participants was needed. A drop-out rate of 0.1 due to death and 0.1 due to withdrawals was expected during the first four months. At inclusion, 380 participants were therefore needed for 304 participants to remain at the four months examination. The goal was therefore to include 400 participants. Further details are described in the protocol paper for the study (126). A total of 397 participants were included in this study, and 317 participants with complete 24-hours of activity registrations were included in the final analysis in Paper IV.

3.9 DATA ANALYSIS AND STATISTICAL METHODS

In Paper I, the systematical review, descriptive statistics were used to report on PA outcomes in older persons from the 134 papers included. Because of the variety of outcome measures used, only three outcomes were presented in figures, comparing results across studies. Papers reporting both mean and standard deviation/standard error values were included here, and standard deviation values were recalculated into standard error values. Outcomes of energy expenditure were derived from 13 papers and 18 samples in total; time in walking was derived from 11 papers and 16 samples; and total time in activity was derived from 8 papers and 17 samples.

Paper II is a method study with focus on agreement between the *activ*PAL and video observations for posture recognition, transitions and step counts. The Bland and Altman method (127) with use of Bland-Altman plots with limits of agreement was used to assess agreement between the activity monitor and video observations, where the individual differences between the two methods (*activ*PAL and video) were plotted against the mean of the two, and the limits of agreement defined as ±1.96 x the observed standard deviation of the differences between the two measurements per subject. Furthermore, the absolute percent error (APE) was calculated to provide an absolute value of measurement error, because we wanted to present the absolute percentage error between the two methods.

In Paper III we found large between participant variation in PA and a non-constant standard deviation between days for the participants in this study, making it inappropriate to use standard methods for similar research questions on normal distributed data (128). To be able to present the results on reliability of using different number of consecutive days as outcome as compared to one week of recordings, we used the Coefficient of Variation presented for both within and between participants. Furthermore, the 217 combinations of upright time for 1, 2, 3, 4, 5, and 6 consecutive days (that is 31 participants with seven combinations each for 1, 2, 3, 4, 5 and 6 different numbers of consecutive days) were compared to the criterion measure of one week of recordings, and differences were presented as the median and interquartile range (IQR). To be able to give recommendations of how many days should be used as reliable measure of PA, a cut-off value of half an hour was used. This is the range from 15 minutes more to 15 minutes less than for one week recordings, as shown in Figure 1B in Paper III, where 15 minutes represent 6% of total upright time three months after a hip fracture. Furthermore, a paired sample t-test was used to investigate whether the mean difference in upright time between the weekend (mean of Saturday and Sunday) and the week days (mean of Monday to Friday) differed, and the significance level was set to $p<.05$.

A new software version from PAL Technologies was available when we performed the final analyses of data for Paper IV, where number and duration of upright events could be derived by use of an Excel spreadsheet from the manufacturers' software version 6.0.8 (*activ*PAL, PAL Technologies Ltd., Glasgow, UK). Furthermore, a custom made MATLAB (MATLAB version 7.1. The MathWorks Inc., Natick, MA, 2005) program was used to generate an Excel (Office Excel version 11.0, Windows XP Professional, Microsoft; 2003) spreadsheet with outcome values for all participants.

We compared demographic details for completers (n=317) with non-completers (n=80) in the study by using Mann-Whitney U tests, t-tests and chi-square tests. Normality was checked by visual inspection of Q-Q plots, showing skewed distribution of the outcomes of upright time, upright events and lower limb function (SPPB). After transformation by use of the natural logarithm of upright time (after adding five to avoid taking the logarithm of zero) and SPPB (after adding one for the same reason), and the square root of events, differences between groups were assessed by use of linear regression. Final analyses included adjustments for gender and fracture type, because these are important prognostic factors for hip-fracture patients. The rationale for including gender is that men are shown to have poorer outcome, for example in mobility (129) and mortality (130, 131), and fracture type are shown to be important for functional outcomes (132, 133). This is in line with recommendations in Pocock et al. (2002 "Subgroup analysis, covariate adjustment and baseline comparisons in clinical trial reporting: current practice and problems", Stat.Med., vol.21, no. 19, pp2917-2930) and the protocol paper for this study where such adjustments are described (114, 134).

We did some ancillary analyses for Paper IV, investigating differences between the groups in upright time during night (00-06), day (06-12), afternoon (12-18) and evening (18-24) by use of the same transformation method as described above, by use of linear regression. We also presented median upright time in a figure showing upright time during all hours during the day for the two groups in this study.

4. SUMMARY OF RESULTS

A short description of results from Papers I, II, III and IV is presented in the following, as well as some unpublished illustrations. The interpretation of the results will be discussed in detail in the discussion chapter of this thesis. Table 5 (page 49) presents the results on upright time for the samples included in Papers I, II, III and IV.

4.1 PAPER I

Title: *Physical activity monitoring by use of accelerometer-based body-worn sensors in older adults: A systematic literature review of current knowledge and application*

This paper presents PA variables derived from body-worn accelerometers during long-term monitoring in healthy and in-care older persons. Abstracts from 1403 papers were evaluated and 134 included for the final full-text review. Results showed a rich variety of accelerometer-based sensors used to collect data on PA. Length of recordings varied from 2 to 450 days, although one week was the most common and used in 56 of the included studies.

Outcomes of PA were derived either from activity counts or from activity recognition, depending on device and the software used. Most studies presented two or more outcomes, although 67 out of the 134 papers reported one single outcome. Energy expenditure was most commonly reported. Reports on activity recognition were for example recognition of postures or transitions. Activity pattern is one outcome that is presented more recently.

Three variables could be compared across studies, level of energy expenditure in kcal per day and activity recognition in terms of total time in walking and total activity. These variables demonstrated large variation within both healthy and in-care samples between studies, and we could therefore not distinguish activity outcomes between healthy and in-care samples.

4.2 PAPER II

Title: *Evaluation of a body-worn sensor system to measure physical activity in older people with impaired function*

Paper II presents a cross-sectional validation study of the *activ*PAL in a convenience sample of 36 older persons with mobility limitations, as well as in a reference group of 10 healthy women. Participants performed a test protocol consisting of twenty-three tasks, including in-bed activities, transitions between positions, and upright activities (including walking), and data were collected from three *activ*PALs attached to the thighs and the sternum and from video recordings.

By use of the activity monitors on the thighs, results showed 100% accurate classification of sedentary (sitting/lying) and upright (standing/walking) position, as well as 100% accurate recognition of transitions from sitting to standing position. However, results showed that this activity monitor underestimated number of steps during walking. Placement on the non-affected thigh for stroke patients and hip fracture patients resulted in less underestimation of step counts than placement on the affected leg. Still, underestimation of step counts during walking was present especially at slow walking speeds and especially for the older persons. Step count in the reference group was also inaccurate, especially at slow walking speeds, but less so than for the older persons.

By use of an additioinal activity monitor placed on participants' sternum, results showed that it was possible to recognize lying from sitting position 100% accurate, as well as deriving 100% accurate measures of transitions from lying to sitting positions.

4.3 PAPER III

Title: *Multiple days of monitoring are needed to obtain a reliable estimate of physical activity in hip fracture patients*

Paper III evaluated how many recording days one should collect to get a reliable measure of PA when using activity monitors, and presents results from a cross-sectional study recruiting a convenience sample of 31 older persons three months after hip-fracture surgery. *Activ*PALs attached to the non-affected lower thigh were worn for one week and data on upright time used to evaluate the agreement in upright time between different numbers of consecutive days when using one week of recording as criterion measure.

Mean daily upright time for this sample was 4 hours and 21 minutes, but between-participant variation was large (standard deviation of 2 hours and 31 minutes). Because of both large variability between participants as well as non-constant within-participant variability between days, we found that at least 4 consecutive days of recordings are needed in order to obtain reliable estimates for individual persons' weekly PA. Nevertheless, at a group level one day of recordings is sufficient.

4.4 PAPER IV

Title: *Physical behaviour and function early after hip fracture surgery in patients receiving comprehensive geriatric care or orthopedic care. –A Randomized Controlled Trial*

The early effect of receiving comprehensive geriatric care (CGC) as compared to orthopedic care (OC) on upright time is presented in Paper IV, as well as the treatment effect on upright events and two measures of physical function.

The Trondheim Hip Fracture Trial was conducted with two parallel groups, where treatment was offered in two hospital wards, and 397 participants were included in the emergency room at the hospital prior to surgery and then randomized into one of the two wards. Patients received either of the two treatments pre- and post-operatively during the entire hospital stay. A total of 317 participants completed activity monitoring the fourth day post-surgery, and data on upright time and upright events were analysed for between-group effects. Need for help during mobilisation on the first three days post-surgery was evaluated by use of CAS, and mobility was evaluated by use of SPPB on day five post-surgery.

Results showed that hip-fracture patients treated with CGC spent significantly more minutes in upright time and had a significantly higher number of upright events on day four after surgery compared to hip-fracture patients treated with OC. On day five, participants in the intervention group had a significantly better score on SPPB as compared to controls. CAS did not differ between groups.

4.5 UNPUBLISHED RESULTS

Unpublished results are included here to provide illustrations of results further supporting what has been presented in published papers.

Figure 4 presents outputs from the activity monitors' software from PAL Technologies. Each block represents one hour, where 24 hours from 00 to 24 is shown. Sit/lie position is shown in yellow, standing and walking is shown in green.

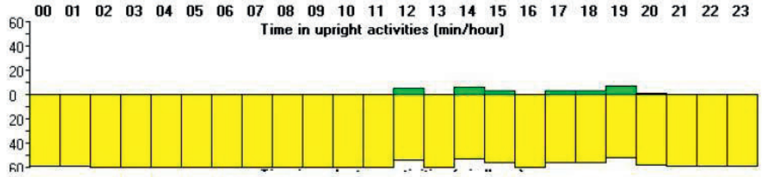

Figure 4. *Illustration of one participant's PA during activity monitoring the 4th day post-surgery (Paper IV).*

The output in Figure 4 illustrates one day of recordings from a typical hip-fracture patient on the 4th day post-surgery, where little time is spent in upright (standing and walking) positions. On average, participants in Paper IV spent 3.61% of the 24 hour recording in upright position. 74% of the participants spent less than 1 hour in upright. Eleven participants were not in an upright position at all during the entire day. Nineteen participants spent less than 5 minutes in upright, 29 spent less than 10 minutes, and 90 participants spent less than 30 minutes in upright. Finally, 168 participants spent more than 30 minutes in upright this day. The maximum registered length of an upright event was 1 hour and 36 minutes, but the median maximum length was a mere 6.7 minutes. For the total sample, most upright time was performed from 06 a.m. until 18 p.m., and only 16% of upright time was performed after 20 p.m.

Table 5 summarizes results for upright time from Papers I, III and IV, to compare results between studies. Note that data from different activity monitors are presented here. Upright time for the hip-fracture sample in Paper III can be compared with results from another study using the *activ*PAL on community-dwellers (34), with a mean upright time of 4 hours and 21 minutes and 4 hours and 11 minutes, respectively.

The sample presented in Paper IV spent only 52 minutes in mean upright time. A study from Grant et al. (2010) presented results from four samples of older persons (39), where little time was spent in upright time, although all spent more time in upright than our sample in Paper IV.

Table 5. *Results for daily upright time for Papers I, III and IV*

Paper	Study	Activity monitor	Population	Age		Complete recordings	Rec. days	Daily Upright time (minutes)	
				Mean	SD	n		Mean	SE
I	Lemaster et al. (2008) (135)	SAM	CD "inactive" with diabetic peripheral neuropathy	66.6	10.4	41	14	81	7
	Grant et al. (2010) (39)	*activ*PAL	Inpatients rehab (City ward)	81.8	6.7	20	7	70	11
			Ward-based patients undergoing rehab (Rural ward)	79.4	4.7	10	7	80	13
			CD attending a Day-hospital	74.7	7.9	20	7	233	25
			CD healthy older adults	73.7	5.5	20	7	360	25
	Cavanaugh et al. (2007) (38)	SAM	CD with functional limitations	79.3	4.5	12	6	298	28
			CD who were healthy	83.7	2.3	28	6	356	18
	Cavanaugh et al. (2010) (55)	SAM	CD "Inactive" (steps per day<5000)	80.2	6.4	25	14	189	3
			CD "Moderate active" (5000<steps per day<10000)	80.7	5.7	86	14	300	2
			CD "Highly active" (steps per day≥10000)	78.9	5.7	46	14	400	4
	Nicolai et al. (2010) (136)	Physilog	CD	80.8	3.9	44	7	301	12
	Buchheit et al. (2004) (137)	RT3	"Sport active" (routinely practice sport activities)	76.7	0.4	12	7	513	9
			"Sedentary" (not involved in any sport activity)	74.7	0.4	12	7	603	10
	McMurdo et al. (2010) (138)	RT3	CD "Inactive" (not meeting recommendations)	77.1	5.0	68	7	180	8
			CD "Inactive" (not meeting recommendations)	77.1	4.9	68	7	161	8
			CD "Inactive" (not meeting recommendations)	77.1	4.9	68	7	160	8
	Lord et al. (2011) (34)	*activ*PAL	CD	78.9	4.9	56	7	251	17
III	Taraldsen et al. (accepted) (111)	*activ*PAL	CD three months after hip fracture	81.8	5.3	31	7	261	27
IV	Taraldsen et al. (under review) (112)	*activ*PAL	Inpatients early after surgery for hip fracture	83.1	6.0	317	1	52	4

CD=Community-dwellers

StepWatch activity monitor (SAM) (OrthoCare Innovations, Mount Lake terrace, WA), attached on ankle using Velcro closures; *activ*PAL (PAL Technologies ltd., Glasgow, UK) attached on thigh; Physilog device (BioAGM, CH), attached to the chest by a harness; RT3 Accelerometer Research Tracker (Stay Healthy, Inc., Monrovia, CA), worn on the waistband

5. DISCUSSION

5.1 MAIN RESULTS

The overall aim for the work in this thesis was to assess methodological and clinical aspects of activity monitoring in older persons, with a special focus on older persons with mobility limitations and hip-fracture patients in particular. Results from the literature review showed large variation in methods used that makes comparison of results between studies difficult.

Results from the validation study showed that by use of an accelerometer-based activity monitor on the non-affected lower thigh, accurate measures of position (sitting/lying or standing/walking) and transitions (sit-to-stand and stand-to-sit) can be recorded for older persons with mobility limitations. Number of steps should not be used as outcome at the moment, because of inaccuracy and underestimation especially when walking at lower gait speeds. For the thigh-worn activity monitor used in this thesis, an additional device attached at the sternum can be used when distinguishing sitting from lying position is of interest. Four or more recording days are recommended to get reliable measures of one week of PA in terms of time in upright position, although one day might be acceptable for group comparisons.

Results from this thesis also showed that upright time and number of upright events during the day was higher in patients treated with CGC with a particular focus on mobilization as compared to participants receiving OC early after hip fracture.

5.2 METHODOLOGICAL CONSIDERATIONS

In terms of level of evidence provided in this thesis, several methodological strengths and limitations should be highlighted. The study designs and how the studies were carried out as well as validity aspects for the results from the papers included in the thesis will be discussed. Analyses of data from skewed distributions will also be discussed, along with some important ethical considerations.

5.2.1 Literature search as method

Literature studies aim to summarize and evaluate knowledge that exists on a certain aspect of a topic. Our study included current studies on outcomes from PA monitoring from all available activity monitors used to assess PA in older persons. A review of poor quality can be explained by a poor search strategy, lack of adequate reporting of methods used to perform the review, or lack of methodological quality assessment of the included studies (139).

The systematic literature review in Paper I (109) used data from published papers to derive information on which variables from activity monitoring have been used to describe PA in older persons, including both healthy and non-healthy older persons over the age of 65 years. The focus was activity monitoring for a minimum of 24 hours, and all available activity monitors based on accelerometers were included. The included studies had reported results from samples sizes consisting of ten or more participants. Smaller studies could have limited external validity, and this was the reason for the exclusion of seven studies with n<10 participants from this review. Nevertheless, 10 is a small sample size, but because this is a relatively new field with many small scale studies, we found this acceptable. The many small studies together with the use of many different outcomes make a meta-analysis not relevant to perform at this stage. This is in line with conclusions from other review papers on similar topics (49).

In total 134 full-text papers were included in the final review. The quality of the papers included was not evaluated in our review, and this lack of quality assessment of the included studies could be a limitation in terms of the validity of results seen. However, its strength is that a high number of studies are included, and results represent how activity monitoring is used today to present outcomes of PA in older persons.

5.2.2 Method studies on activity monitoring

To be able to use data derived from activity monitoring one should know whether the outcomes of PA are validated on the population of interest. Both the validation of outcomes reported in Paper II and the day-to-day variability reported in Paper III, are based on participants that were not randomly selected, but chosen to represent samples of the target populations.

In Paper II older persons with mobility limitations were included. Three different sub-samples of older persons participated, including stroke and geriatric inpatients as well as older persons three months after hip fracture. The total number of participants was 36. The major strength of the study was the selection of a combination of the three different sub-samples that together could represent the target population of older persons with mobility limitations.

In Paper III older persons with hip fracture were the target population. To be able to trust that the reliability of the outcome is good, an important step in the validation process is to assess how the outcome varies on repeated measurements of the same participant (140). A total of 31 older persons three months after hip-fracture surgery were included from a larger study. Although the inclusion criteria were wide, we had several considerations about selection bias that could affect the generalizability of results. Nevertheless, participants recruited showed similar scores on Nottingham Extended ADL Index score as the total sample from the larger study (113).

Together, the participants in Papers II and III represent samples of older persons with mobility limitations, exemplified by gait speeds of 0.46 and 0.59 m/s, respectively that rarely are included in method studies. This indicates that the results should be highly relevant.

5.2.3 Randomized controlled trial as method

The procedure for randomization in clinical trials and the success of the randomization should be discussed for Paper IV. Furthermore, some clinical studies have strict inclusion criteria, where samples are selected from a larger population. Thus, the representativeness of the included sample should also be evaluated (141).

To be able to evaluate the effect of two different hospital treatments, CGC as compared with OC, we conducted an RCT with random allocation of hip-fracture patients to either of two hospital wards. The randomization procedure should eliminate sources of systematic variation by ensuring an equal distribution of confounding factors (142). This is important so that variations seen should be due to the two different intervention treatments. Participants were randomized when arriving at the hospital in the emergency department. To ensure balance in the numbers of participants in the two groups we used computer-based block randomization. This also ensured that the randomization sequence was kept hidden from all persons involved in the trial.

Although 199 and 198 participants were randomized into each of the two groups, a larger number of participants from the OC group did not complete the activity registrations, and group size for those analyzed in Paper IV was therefore lower in the OC compared to the CGC group (n=175 for CGC versus n=142 for OC). However, the two groups of completers did not show any significant differences in their background variables (age, gender, pre-fracture BI and NE-ADL). Nevertheless, missing data were not completely at random. Those not completing (n=80) had lower scores in their background variables, so the frailest hip-fracture patients were not included in the final analyses of this study. There were no group differences in portion of women or intracapsular fractures of drop-outs. One can speculate whether reduction of missing data in the OC group only could have strengthened our results. Participants with missing data were among those with poorest function, and therefore possibly also at the lower end of PA level scale. Despite this, it is a weakness of the study that missing was larger in the OC than in the CGC, and that data were not missing at random, which weakens the internal validity of the study.

Statistical power was calculated for the primary endpoint in the main study, SPPB four months post-surgery, and not for upright time that was the main outcome in Paper IV. The risk of having an insufficient number of participants for our analysis was therefore present. Compared to other studies on post-hip fracture older persons, for example a RCT on nutritional supplement where activity monitoring was included with forty-six participants (143), our study included a solid number of participants.

The difference of 12.5 minutes in mean upright time between the two groups in our study should be interpreted with caution due to the fact that we do not know the clinical importance of this difference. Nevertheless, 12.5 minutes represents 24% of total time in upright for the sample, and could therefore probably represent an important difference in patients' upright time. The same positive effect as for upright time in favor of the CGC was shown for lower limb function (SPPB) on day five post-surgery that only strengthens our conclusion, treatment in a CGC has a positive effect on both PA and lower limb function in the early phase post-surgery.

The study included previous home-dwelling older persons above the age of 70 years with the ability to walk prior to the fracture. The inclusion criteria were wide and the exclusion criteria few, thus strengthening the external validity of the study when it comes to older home-dwelling persons suffering a hip fracture. Most patients are vulnerable and at high risk for functional declines following a hip fracture, especially if being immobilized. Participants receiving CGC spent more time in upright position as compared to participants receiving OC. For hip-fracture patients, the difference between CGC and OC could be important.

Assessors were not blinded in this study, as they had to assess the patients while being in the respective hospital wards. In order to get non biased results between groups, participants and staff at the two wards received the same information about the activity monitoring, and thus the bias should be similar in both wards. The assessors performing the SPPB were not part of the staff working at the wards. They were however part of the research group performing the RCT, which theoretically might have influenced the results. In order to minimize the effect of the lack of blinding of assessors, the first analyses of results between groups were analyzed with masked groups.

The study included 397 participants in total, of which 317 completed the activity registration. Of these 317 participants, 295 completed the SPPB, while the CAS was performed for 299 of them. The feasibility of the method was not at focus in this study, but results indicate that a solid sample of older persons early after hip fracture was able to complete the activity monitoring. The lower missing values for activity monitoring compared to the other outcomes, and the fact that those not completing the activity monitoring were among the frailest, suggest that missing of activity monitoring data is related to the population more than to the method. Activity monitoring can be performed in line with other measurement methods in samples with mobility limitations, although missing of data will probably happen among the frailest also when using activity monitoring as method.

Inclusion of older persons after their hip fracture made it impossible to obtain objective information about participants' pre-fracture PA, and thus we did not have a baseline value for activity monitoring. We therefore assessed differences between groups at one time point instead of assessing difference in change between groups. We adjusted results for gender and fracture type, because these are known clinically to be important factors affecting the regain of functions after a hip fracture. Results of difference between the hospital treatments are therefore strengthened.

5.2.4 Concurrent validity

In Papers II and III, the concurrent validity of activity monitoring outcomes against a criterion outcome or a gold standard was evaluated. The major strength is that the results are compared with a reference considered to provide accurate information, so that the level of accuracy for the new method at interest can be evaluated. Recordings from a video camera were used as criterion measure for the in-lab protocol study in Paper II. Using video camera recording as gold standard for similar purposes have also been performed by others (44, 65).

The pre-designed test protocol used in Paper II was performed in an in-hospital setting, and included basic tasks representing important physical functions and activities in older persons' daily life. However, results from a standardized in-lab setting could differ from daily life situations. Gait speed for example, could differ in different contexts, and additional evaluation in free-living settings are therefore important (67). Studies should include outdoor walking in their validation when this is considered relevant (65, 66).

Validation in free-living settings has typically focused on step count and gait speed (65-67). If the focus is on activity recognition, protocols for validation in free-living settings could be more difficult to design. Participants in our study performed a protocol consisting of tasks with clear instructions. For example a clear instruction about how to behave after finishing a gait task, where they had to stand still for some seconds before turning. Similar tasks in for example participants own home could be performed differently, because of several possible movement strategies not limited by a detailed instruction given prior to performing the pre-defined protocol in the lab. The results from a validation in a standardized in-lab setting could therefore possibly present more optimistic results as compared to real-life settings.

In Paper I we found one week of activity registrations to be the most used duration of accelerometer recordings (109). This was the reason for choosing one-week of registrations as the criterion measure in Paper III. Paper III evaluated the day-to-day variability, to find out the lowest number of recordings days that are needed to correctly represent one week of recordings.

When the focus is long-term PA, it is obvious that the more recording days, the better. The number of sufficient recording days could however be discussed. Some population-based studies, such as the Nakanojo study, include very long periods of data recordings, and there could be some arguments where for example one year recordings are relevant (50). If the focus is on knowing PA and activity pattern during the year, long periods of data should be used. Seasonal changes could be one important argument for this, such as in the population-based study in Norway where seasonal variations were suggested to affect a persons' PA (68). Nevertheless, the length of recording periods should be balanced with respect to the ethics of data collection and the compliance of wearing a sensor for longer periods (33). For most activity monitoring studies, the lowest acceptable number of recording days is therefore chosen, and factors affecting PA during this recording period should be taken into consideration when data is interpreted.

5.2.5 Approaches for statistics in skewed distributions

Participants in Papers III and IV provided data that could not be analyzed with standard statistical approaches because the data were not normally distributed. Alternative analyses were needed, and methods were carefully chosen for both studies.

The study presented in Paper III included a heterogeneous population of older persons after hip fracture, but with low average upright time. One week of recordings provided data that could not be analyzed with standard statistical approaches such as reliability analyses using intra-class correlation coefficients (ICC) as the main quantitative measure of accuracy. Our data showed heterogeneity both in terms of between-participant variability as well as within-participant variability for mean upright time between days. Furthermore, the within-participant standard deviation increased with the mean value of upright time, indicating that those spending more time in upright also had more variation in their upright time between days. In addition, some participants had extreme values because of low average upright time and large standard deviation between days. To be able to evaluate the sufficient number of recording days for this population where heterogeneity is included, we had to use a clinical approach for our main analyses.

To illustrate the variation of upright time between days, within- and between-subject coefficients of variation were used. We also presented the interquartile range for the outcome of upright time. A cut-off value of 30 minutes was established, to be able to make recommendations for the number of days one should choose for the registration period. The cut-off that was chosen was based on how physically active hip-fracture patients were, so that the cut-off is relevant for this study population. The cut-off of 30 minutes was the range from 15 minutes more to 15 minutes less than for recordings based on the entire week, which represented the best available estimate. For an average hip-fracture patient, 15 minutes represent 6% of total upright time. For less active persons, the percentage will be higher. For example, the early post-operative difference of 12.5 minutes in upright time shown in Paper IV represented 24% of their upright time.

Approaches for statistics in skewed distributions are different from more standard approaches used for analysis of data from more healthy samples of participants for similar research questions. Our study population in Paper III is a typical example where methods of analysis should be more carefully chosen, to be able to present results that are relevant for the population included in the study.

Participants in the study presented in Paper IV, also showed non-normality of data collected. The average low time spent in upright, low average number of upright events and low scores on SPPB were as expected, because the assessments were performed early after hip-fracture surgery. To be able to use parametric statistics in the analyses of these data for Paper IV, normality was obtained by use of transformation of upright time, upright event and SPPB.

5.2.6 Ethical issues when including vulnerable participants

Our studies followed the principles of the World Medical Association Declaration of Helsinki and the ethical principles for medical research involving human subjects. One overall aim for the Research Group on Geriatrics is to perform clinical research that aims to provide new knowledge and better treatment and rehabilitation pathways for older persons. It is of high interests to include older persons with mobility limitations in method studies and clinical trials evaluating treatment effects. Although, some participants in our studies might benefit from participation in the studies in terms of having extra attention and extra examinations, the results will mainly benefit future patients undergoing the same treatment. Furthermore, the results will provide new and important knowledge about these samples. This raises some ethical considerations that should be discussed, especially because we included vulnerable samples of older persons.

The samples included in Papers II, III and IV were frailer than older participants typically included in method studies and studies assessing PA with activity monitors (65, 66). Project workers in the studies were therefore clinicians, to ensure both participants' well-being as well as a safe context during testing. For participants in the RCT who were not able to give their informed consent, informed consent from the participants' next of kin was collected. We also got approval from the research ethics committee to collect data and consent from participants after the surgery, because performing the study and gaining knowledge from this study was considered important and the intervention was believed to be beneficial for this group. Mortality during the RCT was monitored, and analysis of the first 200 included participants confirmed that we safely could continue the last part of the study.

Activity monitoring is a non-invasive method. The activity monitor we used was small and fixed to the thigh with a tape and a water-proof plaster with the instruction that the "sensor" registered their movements in their leg, and that they should continue doing whatever they usually did when wearing the sensor. Almost all participants that were randomized agreed to wear an activity monitor, and only four participants did not want to wear an activity monitor that early after surgery. Nevertheless, 16 participants removed their sensor on the 4th day, and therefore did not complete the registrations. Although these participants did agree to wear the activity monitor, one can speculate to what extent they understood that they participated in a study.

5.3 WHY FOCUS ON ACTIVITY MONITORING?

Activity monitoring by use of small, wearable sensor systems is a relatively new method for collection of data on PA. Activity monitoring enables collection of PA from real-life settings, where the continuous recordings are superior to retrospective methods such as questionnaires, enabling objective, more reliable and detailed data on PA. One important reason for why activity monitoring is highly relevant in older persons is discussed in the following.

Activity monitoring will give information about what is actually performed during a day, and this knowledge will be important in addition to results from performance-based tests of a person's physical function. Treatment often focuses specifically on components of physical function that are impaired, such as trying to increase muscle strength or gait function after a hip-fracture surgery. Measures of for example need for assistance during ambulation measured by CAS (106), could be valuable to evaluate level of independence in ambulation. Performance-based tests such as the SPPB measures the lower limb function (126) and can say something about what a patient is able to perform. Activity monitoring on the other hand, will provide information about what a person actually does during a day that could be of great value in addition to, and not instead of, the measures of function.

Promotion of healthy ageing is of high priority and therefore also the maintenance of physical functions (144), but evaluation of different aspects of physical functions will not provide the same information and knowledge as outcomes derived from activity monitors. There is a close link between PA and function, and one should look for explanations also in results from activity monitoring when the focus is on physical function. Conclusions based on only one of the two would be of less value, and will not provide results that would give a more complete understanding. One example of this, is the comment from Kortebein (2012) where the results from research concerning hospitalization and factors affecting declines in physical functions are highlighted as important to interpret with caution, because the link to patients' PA are often lacking (100). Measures of what a person actually does during a day will be of great value, both in terms of explaining functional changes or lack of pre-operative regain of functions. Together, results can be used to achieve a wider understanding of PA as well as better understanding of rehabilitation progress or lack of progress.

It is for future studies to assess how daily life PA relates to function in different populations, and whether interventions aimed at improving physical function also improve PA in daily life.

5.4 INTERPRETATION OF RESULTS

The interpretations of the most important results from the thesis are highlighted in this section.

5.4.1 Reliable and valid outcomes of PA from activity monitoring

Results from Paper II were consistent with previous validation studies using the *activ*PAL (44, 66) in terms of 100% correct classification of positions and transitions. Compared to the step counts coded from the video, we found an under-reporting of step counts for the activity monitoring. A check of the raw data confirmed that steps had been registered (as shown in Figure 3, page 40), therefore the under-reporting of step counts was most likely due to the algorithms used to detect steps. Commercially available activity monitors are delivered with software systems and algorithms that most often are opaque to the users. The use of such “black boxes” with hidden algorithms could be problematic. For example, algorithms for step detection are typically developed for use in populations that walk at more normal gait speeds, and the use of the algorithms in older persons could be problematic because of slow walking.

One study investigated the step count accuracy at different gait speeds in healthy adults (65), but the accuracy was tested at gait speeds much higher than a typical older person with impaired mobility will use when walking. Another study investigated treadmill and outdoor walking and step count accuracy in older persons (66), and found that the mean difference between observed and monitored step count was less than 3 steps at all gait speeds. However, one study supports our results and makes a similar comment about problems with step count validity in frail older hospital patients. They detected acceleration signals for the steps but the software algorithms did not accurately classify these signals as steps (39). As a consequence, step count should not be used at the moment in reports on older persons because of underestimation especially at lower gait speeds. There is a need for more accurate algorithms for step counts, so that data on steps during walking can be classified correctly also in older persons in general, and older persons with mobility limitations in particular.

In populations spending very little time in upright position, the possibility of distinguishing sitting from lying positions could be relevant when it comes to activity level, for example in patients admitted to the hospital or other in-care settings where mobilization to a sitting position might be the first step in the early phase of mobilization. We attached a second activity monitor to the person’s sternum in order to distinguish sitting from lying, and results showed that this extra activity monitor placed on the sternum can accurately distinguish sitting from lying. To be able to use results from both the thigh-placed and the sternum-placed devices together, additional data processing was required because the manufacturers’ software system only derives results from one sensor system at the time. Hospital units treating for example stroke patients have typically used observational behaviour mapping to collect similar data (24, 145). Activity monitors may now be a good alternative for purposes such as monitoring of time spent in different positions, including the ability to distinguish between lying, sitting and upright position.

Activity monitoring is a new field, and software updates can include changes in algorithms that change the interpretation of results from earlier studies performed on previous versions of the software. This could then also affect the comparison of results across studies. In sum, basic properties of the algorithms and software are important to know in order to be able to consider data quality, and the accuracy and precision of the outcomes should be known (146).

5.4.2 Outcomes of PA considered relevant for the samples in Papers II-IV

Outcome measures derived from activity monitors can represent different aspects of PA, so the activity monitor and main outcome chosen should represent one or several aspects that are relevant for the target population. The activity monitor used in Papers II-IV enabled recognition of position, and time spent in upright was chosen as the main outcome because this was considered to be a relevant aspect of PA to evaluate in older persons with mobility limitations. There were several reasons for choosing time spent in upright.

Upright time includes time in standing and walking activities, and will include most upright activities the persons perform during a day. Most of their upright time will probably include activity in standing or walking, such as short distance walking while performing indoor activities like getting to the bathroom or kitchen. Choosing upright time as outcome measure of PA will probably be highly relevant for a typical older person with mobility limitations, although specific activities such as cycling that might be relevant for some, will not be included.

Upright time includes standing and walking activities regardless of energy cost. Results from the population-based study in Norway showed that few older persons met the PA guidelines of 30 minutes in MVPA per day (68). Therefore, the inclusion of light intensity activities is important when choosing an outcome for older persons in general, and for older persons with mobility limitations in particular. Participation in low intensity activity has been found to be important for physical functions such as stair climbing, walking and bathing (147), providing support to upright time as an important outcome in a population where most activities are performed at lower intensities and where maintaining daily life functions are of high priority.

Upright time will be especially important for hip fracture patients early after surgery, such as the participants in Paper IV. Figure 4 (page 48) can illustrate the limited time that was spent upright in this group the fourth day after hip fracture surgery. Interventions that result in increased upright time will probably be of great value for these persons. The overall aim for this study was to regain gait function, and upright time will therefore be of greater value than for example outcomes such as time spent in sitting. The research question will therefore point to the relevant outcome, such as in our study that evaluated differences in two approaches where one included a systematical approach for mobilization in terms of spending time in standing and walking.

In addition to upright time, other secondary outcomes of PA were considered relevant. To be able to say something about the frequency of upright time, the number of sit-to-stand transitions could be relevant to consider, as well as a more detailed analysis of activity patterns where for example the number of transitions and length of upright periods are evaluated together. In older persons with mobility limitations where limited time is spent in upright, the focus on reducing time in sedentary (sitting and lying) would also be highly relevant. Activity monitors that focus on position enables sedentary time to be defined by positions and will include activities performed in sitting or lying positions. The importance of reducing SB has also been suggested for the national recommendations for health in addition to recommendation for PA (96).

The status today is that a rich variety in methods, outcome measures and ways to present outcomes are used, such as illustrated in the content of Table 3 (page 41). This is in line with the conclusions in a recent review (148) as well as in the paper "Towards standardized evaluation tools" (57), suggesting that research groups should collaborate to come to consensus, so that relevant outcomes are used and can be compared across studies.

Activity monitors based on accelerometers cannot detect all types of activity the person is performing, such as for example vacuuming, raking leaves, swimming, indoor versus outdoor walking and so on. Participation in regular exercise groups will also not be registered. One should discuss whether these activities are important to capture, and whether one should collect separate information about certain activities in addition to the activity monitoring where details about exact types of activities that are being performed are not captured.

5.4.3 Relevant outcomes of PA for older persons with mobility limitations

The literature review of 134 papers and 213 samples of older persons showed that knowledge about PA from activity monitoring studies is based on many small studies and a few larger population-based studies. The variety in activity monitoring in older persons includes different activity monitors, differences in data collection procedures and analyse strategies, and how data on PA are presented.

PA has typically been presented in terms of estimates of energy expenditure or in terms of activity recognition (3, 109). Estimations of energy expenditure are suggested a more arbitrary threshold, for example when PA are distinguished from SB based on estimations. Activity recognition is suggested to be a more robust threshold because this is based on positions (3). Most studies present outcomes representing overall measures of PA such as estimated time spent in MVPA or upright time, although activity pattern as outcome is used in some studies as well.

Different outcomes can provide information about different aspects of PA, and the use of multiple outcomes could provide more complete information about a persons' PA. This is in line with what is presented in the paper from Lord and colleagues (2011), showing several possibilities of how data from accelerometers can be derived and presented (34). This paper explored both PA and SB, and showed that outcomes of walking, SB and transitions are distinct from each other. Furthermore, they argued that presenting several outcomes as well as the interplay between different outcomes could together explain more than a single outcome (34).

Activity monitors enable us to derive rich information about a person’s daily PA. As an example, the activity monitor used in this thesis provides many different possibilities for PA outcomes from the collected data. Because the raw data have a start and stop time, the profiles during the day can be derived in addition to the more overall measures for the entire day. Upright time can therefore be derived as total time spent during the entire day in upright position, or as how the upright time is for every hour during the day. Figure 2 in Paper IV illustrates the latter, showing examples of the mean time spent in upright for each hour during the day for the two groups included in this study (112). Furthermore, the same can also be presented as total time for each hour during the day for each individual. At the moment, consensus is lacking on how data on PA should be presented and which outcomes should be used for different purposes.

A recent paper highlights that the use of outcomes on PA from activity monitoring is at a relatively early stage (149), and that custom-designed computer programs typically are used to derive more outcomes than those available in outputs from the software systems. Although this enables more details from the collected data to be evaluated, one should also use a standard approach when analyzing data collected. This is important so that the most valuable information is presented, and will enable comparison and interpretation of data from different studies (3) as well as providing data for more general comparisons (49). However, data have been and are being presented in a various different ways, and descriptions of the methods used are therefore of high importance.

5.4.4 Number of recording days needed

The literature review documented that previous studies have used very different lengths of data collection periods, where the monitoring period varied from two to 450 days, with 56 studies showing one week as the most common recording period (109). Eight of the included studies collected data for one year. The length of recording days was discussed earlier in Chapter 5.2.4 on pages 54-55.

In older persons, upright time after hip fracture will vary between persons, as well as between days for some persons. Although one day can reliably represent one week of recordings on a group level, our recommendations (based on the cut-off described on page 38), is to use four or more days to provide representative measures of weekly upright time for individual persons. This was in line with another study on community-dwelling older persons (136).

This recommendation of number of recording days can be used in future studies including similar samples of older persons.

5.4.5 Effective treatment models to modify PA behaviour

The RCT described in Paper IV showed differences between two hospital wards when it comes to participants’ upright time and number of upright events. Results suggested that the lower activity demonstrated in the orthopedic ward is related to the routines and the treatment approach in the ward. Research has previously shown that prolonged periods of bed-rest can be dangerous for older persons (99), but the effect of spending time in upright position during hospital stays has not often been evaluated (100). Knowledge from a RCT study on a vulnerable population is rather unique, and provides important knowledge both on participants’ ability in terms of their lower limb function measured by a performance-based test, as well as how much time they actually spend being physically active measured by accelerometer-based activity monitors.

Data in our study were collected on the 4th post-operative day, and almost all participants (314 out of 317) were still receiving an active post-surgery hospital intervention at this time. The results can therefore be interpreted both as the effect of the intervention, but more importantly also as part of the intervention. We used the term “physical behaviour” instead of PA in this paper, because this illustrated what the participants actually did, their behaviour, during one day of treatment in the hospital setting in contrast to their capability of performing physical tasks, as assessed by the SPPB.

Hip-fracture patients mean scores on CAS, representing need for help during ambulation, were 9.9 for CGC and 9.4 for OC, out of 18, indicating that they needed the same amount of help during ambulation on the first three days. More importantly, 100% of the participants had a score <6 on each of the first three days post-surgery, indicating that none of the participants were independent in their basic mobility and were not able to ambulate on their own. The difference seen in upright time between the two hospital wards may therefore represent differences in the nursing staff’s success in ambulation of patients.

PA can be affected by the context where it is being performed, and one should have the context in mind when looking for explanations for patients’ PA as well as when looking for possibilities to increase certain behaviours. Systematic approaches such as the CGC executed in the geriatric ward intended to be more aggressive in their mobilization approach to try to affect patients' upright time. Figure 2 in Paper IV illustrates this, where the upright time during the day is shown to be limited to certain hours for patients in the control group, as compared to the intervention group where upright time happened in several periods during the day. Results are highly relevant to understanding how the "hospital culture" can affect patients' PA or physical behaviour during the day.

Older persons with mobility limitations are especially vulnerable when being immobilized because they can rapidly loose important physical functions. The link between PA and physical function should therefore be considered, and systematical approaches including early mobilisation could be crucial for patients after periods of bed-rest caused by surgery or short-term disease. The difference in treatment procedures at CGC and OC were highlighted as important for the results presented in Paper IV, not the hospital wards in and of themselves, although the intervention paper based on the study suggested that the location of the geriatric ward was designed to be "suitable for moving around" (108).

5.5 CLINICAL APPLICATIONS

This thesis is a small contribution to research focusing on activity monitoring in older persons. The samples included in the thesis have more severe mobility limitations than participants in most other papers on activity monitoring published so far, and results provide new knowledge that is valuable both for future research and for use in clinical settings.

We have highlighted the ethics in studies with more frail older persons than those normally included, and patient safety and research ethics should always have top priority in clinical studies. The results from this thesis indicate that older persons with mobility limitations in general and hip-fracture patients in particular, can easily wear activity monitors and the assessment of PA is probably very important for these groups. Activity monitoring data from 317 out of 397 included participants were collected in the study presented in Paper IV. In comparison, need for assistance during ambulation reported by nurses or physiotherapists in the wards by use of CAS, was collected for 299 out of the 317 with complete activity monitoring. In addition, 295 out of the 317 performed the SPPB on day five post-surgery. This illustrates good compliance for the activity monitoring compared to other assessments used in this study, possibly because most participants can easily wear an activity monitor regardless of their functional levels. Together with results from Paper II, the small, body-worn activity monitors are suggested to be suitable for collection of PA data in older persons including those with mobility limitations, although step counts should not be used as outcome at the moment for this group.

Activity monitoring can provide knowledge about patients’ PA during a hospital stay. Results from the RCT confirmed that upright time on average is low early after hip fracture surgery. This is important to know in settings treating older persons at risk of mobility disability. Results also showed that the two treatment groups, CGC and OC, differed in their upright time, suggesting that how the treatment is delivered could be important for how much time patients spends being physically active. A systematic approach where mobilization is at focus and also included in care plans, is suggested to be important in order to make the most out of every daily activities so that patients spends more time in upright during their hospital stay. Nevertheless, the total treatment effect of CGC will also be important for regaining function and being physically active after a hip fracture, the medical treatment should therefore be optimal so that the patients also are able to be mobilized.

Results from activity monitoring can sometimes be eye openers for persons working with older persons on a daily basis. Data can reveal information about how little time persons actually spends on being physically active during daily life activities, where these activities are important for their health as well as for the maintenance of independence in daily life functions. Furthermore, information from activity monitoring can also provide new knowledge that is not necessary similar to other measures of PA or physical function. Activity monitoring provides PA data on behaviour, where persons’ own choices are one of many factors that will influence the level and pattern of PA. Activity monitoring can for example reveal whether an increase in physical function is also reflected in increased PA.

Paper IV provides an important message to clinicians. Efforts should be made in making the most out of daily life situations. Relatives, nursing staff, care workers and others are important contributors to be able to do this, by encouraging and supporting the older persons to be more physically active. If activity monitoring can affect persons’ PA, one should use this in clinical settings to set focus on PA both towards the patient and for persons working with older persons with mobility limitations, because of the important link to physical function and independent living.

5.6 FUTURE RESEARCH

New technology and methods for analyzing data have rapidly changed the information we can derive from activity monitoring. The research field of activity monitoring as a way of assessing PA is only in its early beginning, so new knowledge and methods will continue to be developed in the future. In the near future, we should focus on one of the major concerns, namely achieving and standardization in methods for activity monitoring in older persons. In particular, some standards enabling results to be interpreted and compared across studies should be provided. The suggestion from Strath (2012) as well as de Bruin (2012), among others, is important – research groups should take the challenge and develop common guidelines for how we should collect and present data on PA in older persons (4, 57). What type of terms we should use and when should also be discussed in more detail in the future.

Older persons with mobility limitations spend little of their time being physically active, therefore the link between upright time and the regain of physical functions, for example, should be of interest for future research. Looking at associations between different outcomes of PA and physical function or gait function could also be relevant for future studies, as well as looking at effects of PA on both physical and cognitive function. Future research should also include activity monitoring when exercise interventions are evaluated, to be able to evaluate whether an increase in a person's physical function results in increases in PA as well.

For an older person, the consequence of a hip fracture could be decline in their ability to ambulate, especially the ability to walk outdoors on their own. The ability to walk outdoors is of major importance for independent living, so to be able to distinguish between indoor and outdoor walking should be of great interest. Activity monitors typically do not detect all types of activities that are being performed, but looking into possibilities of doing this is highly relevant for future research. By use of activity monitors based on accelerometers that classify postures, the possibilities of data analysis are enormous (3), and we are only at the early start of how we can use data collected with accelerometers.

Knowledge on the role of sedentary (sitting and lying) in relation to PA (standing and walking) should be taken into greater consideration in future research focusing on promotion of healthy living and healthy ageing in terms of preventing physical disability (34, 150). The ultimate aim is that research results are implemented in clinical practice, so that better treatment is delivered to these groups of older persons in the future.

6. GENERAL CONCLUSIONS

Activity monitoring is increasingly used in studies in older persons in general, and in older persons with mobility limitations. The field is at an early stage, and methods are continuously under development. This makes results difficult to compare across methods and studies, because of no standardization or consensus on how to collect data and report these data. So far, mainly outcomes of activity counts or activity recognitions have been reported, as well as more recent outcomes describing activity patterns. In order to compare results between studies, guidelines for activity monitoring protocols and how to report and present results across studies and instruments are necessary.

Results from this thesis provide knowledge about how accurate outcomes are when used in older persons with mobility limitations. Results showed valid results for positions and transitions recognitions, while step counts needs to be improved for the applied sensor system to be acceptable especially at lower gait speeds. Outcomes based on activity recognition, such as upright time and number of transitions, are suggested to be important outcomes of PA in older persons with mobility limitations, enabling us to look at overall activity outcomes as well as activity patterns during the day.

Older persons with mobility limitations are a heterogeneous group. To provide a reliable estimate on weekly PA for individual persons, at least four days with activity recordings should be collected. Collecting data over several days is especially important for those spending very little and those spending very much time in upright position on an average day, where one day measurements would not accurately represent their weekly activity. Wearing an activity monitor during four days is realistic to perform for the majority of older persons and also in most settings, indicating that data can be collected also in this population.

We found differences in upright time and upright events between patients receiving two different treatment approaches in two hospital wards. Results suggest that specific procedures for early mobilisation should be included in wards where older persons with mobility limitations are treated, because how treatments are delivered could possibly both affect and explain patients’ PA during the hospital stay.

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PAPERS I-IV

Paper I

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Review

Physical activity monitoring by use of accelerometer-based body-worn sensors in older adults: A systematic literature review of current knowledge and applications

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ABSTRACT

Objectives: To systematically review the literature on physical activity variables derived from body-worn sensors during long term monitoring in healthy and in-care older adults.
Methods: Using pre-designed inclusion and exclusion criteria, a PubMed search strategy was designed to trace relevant reports of studies. Last search date was March 8, 2011.
Study selection: Studies that included persons with mean or median age of >65 years, used accelerometer-based body-worn sensors with a monitoring length of >24 h, and reported values on physical activity in the samples assessed.
Results: 1403 abstracts were revealed and 134 full-text papers included in the final review. A variety of variables derived from activity counts or recognition of performed activities were reported in healthy older adults as well as in in-care older adults. Three variables were possible to compare across studies, level of Energy Expenditure in kcal per day and activity recognition in terms of total time in walking and total activity. However, physical activity measured by these variables demonstrated large variation between studies and did not distinguish activity between healthy and in-care samples.
Conclusion: There is a rich variety in methods used for data collection and analysis as well as in reported variables. Different aspects of physical activity can be described, but the variety makes it challenging to compare across studies. There is an urgent need for developing consensus on activity monitoring protocols and which variables to report.

Contents

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1. Introduction

Physical inactivity is detrimental to the health and functioning of older persons [1]. Physical activity is a key component in interventions aimed at promoting health and well being [2], preventing falls [3], and functional loss [4], as well as in most rehabilitation programs for older adults. In addition, physical activity is important for mental health [5]. However, little is known about types and patterns of physical activities and the particular dosage needed to prevent functional decline or to regain function following rehabilitation programs. One reason for this is lack of suitable and accurate assessment methods for physical activity in the past.

Physical activity has traditionally been assessed by questionnaires. Such assessment is easy to administer in large groups and can be performed at low cost. However, use of questionnaires has been associated with recall bias particularly in older adults. In addition, most generic instruments have assessed leisure time physical activity, meaning that activities performed as part of daily life activities have not been assessed [6,7]. This is a serious limitation when used in older persons where most physical activity is performed as part of daily life activities. Furthermore, activities assessed through questionnaires may be age as well as cultural specific, thus limiting the use of questionnaires across populations and countries. Finally, subjective measures of physical activity grossly overestimate activity levels. A report from a population-based study has demonstrated that the proportion of people fulfilling the recommended physical activity guidelines [2] drops from 40 to 60% typically found through questionnaires [8] to 20% when assessed by use of objective measures [7]. Thus, objective measures of physical activity are needed in order to increase knowledge about the role of physical activity for health and functioning.

Physical activity can be measured objectively with body-worn sensors. The simplest method is mechanical or alternatively electronic pedometers used to count steps taken during walking. Reliability and validity of such methods have been described elsewhere [9]. However, pedometers are limited to assessing ambulatory activity only. Another option is to assess physical activity by use of single or multi-sensor systems including inertial accelerometers or a combination of accelerometers, inclinometers, and gyroscopes. By use of such methods it is possible to collect and store information about physical activity performed by a person over longer periods. At present, it is not known which variables derived from accelerometer-based activity monitoring are best suited for assessing physical activity in older persons. Consequently, there is also a lack of reference data on physical activity in older adults as well as physical activity in patient groups derived from activity monitors. Therefore, the aim of this systematic review is to identify variables of physical activity derived from body-worn sensors used for long term monitoring in older adults and to describe amount and pattern of physical activity in different groups of older persons.

2. Methods

A systematic literature review was performed with a preplanned review protocol specifying inclusion and exclusion criteria for the revealed studies and data analysis. Only peer-reviewed, English-language papers were considered relevant, excluding reviews, case reports, and method studies. Median or mean age of the sample(s) being assessed had to be at or above 65 years of age. Only studies using accelerometer-based activity monitoring with a monitoring time >24 h were eligible for inclusion. The studies had to report on physical activity variables and not be limited to upper-extremity or head activity/motions or wheelchair activity. Studies performed as in-lab studies or focusing on sleep monitoring were not included. To be included in the review, sample size should be ≥10 participants in relevant samples.

We performed a search in PubMed for relevant studies up till March 8th 2011. Applying both free-text terms and MeSH terms, we combined groups of search terms that expressed the concepts ‘accelerometer’, ‘body worn’, ‘physical activity’ and ‘aged’. Additional search terms aimed to exclude case reports, reviews, animal studies, and paediatric studies. Detailed search criteria are presented in Appendix A.

To check agreement on whether the articles fulfilled the inclusion criteria or not, three of the authors assessed a random sample of 50 references from the list of revealed papers prior to the extraction of data. Two and two authors performed independent reviews of titles and abstracts, and in case of disagreement a third author did a review. In case of uncertainty, the paper was included for full text review. Four of the authors took part in the full text review, where each read ¼ of the total number to determine final relevance. In case of uncertainty, a second author read the same paper, and a decision was made based on consensus.

Information from each article was abstracted into a pre-established review table, containing information on the following items: study design, instrument name and specifications, placement on body, outcomes of physical activity, recording period, sample information, and overall results on physical activity (PA). Results were organized into the sections: study selection, study characteristics, participant characteristics, and variables and parameters reporting on PA.

2.1. Data analysis

A descriptive summary of the results was carried out to provide information about outcomes used to describe physical activity in older adults. Results reported for different samples of older adults were classified into two groups; in-care or healthy. In-care groups included samples with specific diagnoses (for example Parkinson disease) or conditions (for example post hip fracture), inpatients or long term residents in continuing care facilities. Healthy groups included community-dwelling or older adults described as sedative or more active without specific reported diseases. Note that ‘healthy’ can be a relative term for the samples included the latter group.

We wanted to present a few variables of PA that were possible to compare across studies. These were Level of estimated Energy Expenditure related to Physical Activity (PAEE, defined as Total Energy Expenditure – Resting Energy Expenditure), presented as kcal per day, from 13 studies and 18 samples of older adults, daily time in walking from 11 studies and 16 samples of older adults, and total activity from 8 studies and 17 samples of older adults. Only

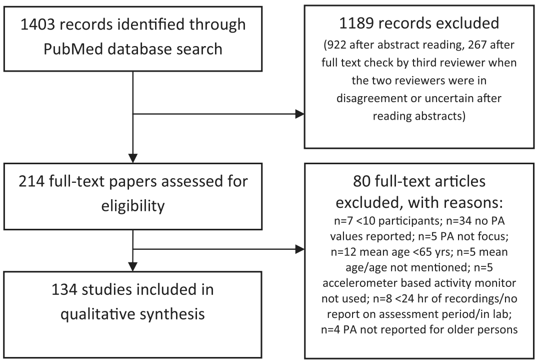

Fig. 1. Study selection through the different phases.

studies presenting mean and standard deviation/standard error values were considered, and only baseline values from intervention studies were included. In order to compare PA between studies, standard deviation values were recalculated into standard error values.

3. Results

3.1. Study selection

The database search identified 1403 records of possible interest. Fig. 1 illustrates the selection process of relevant papers. After reading titles and abstracts of all identified papers, full text check was performed and 267 additional papers were excluded. Finally, 214 full text articles underwent full text review and another 80 were excluded according to our inclusion and exclusion criteria, leaving 134 studies for final inclusion.

3.2. Study characteristics

The 134 included studies reported PA obtained from accelerometer-based body-worn sensor recordings for in-care older adults and/or healthy older adults. The oldest published study was from 1992, while 75 studies were published between 2008 and 2011. Most study designs were cross sectional (60%). Results were presented for a total of 213 samples, 129 of them including less than 50 participants. Only 29 samples included more than 100 participants.

A variety of different accelerometer-based instruments were used for PA registrations: ActiGraph/MTI/ActiWatch/Mini-Motionlogger (34 studies); Caltrac [24]; RT3/Stayhealthy [17]; StepWatch/Step Activity Monitor (SAM) [16]; Lifecorder [15]; Tritrac [5]; SenseWear [5]; ActivPAL [4]; Dynaport [3]; Activity Monitor (Gähwiler) [2]; Actical [1]; Activ Style Pro [1]; Bio-trainer Pro [1]; Dynalog [1]; ActiReg [1]; Physilog [1]; Dynastream [1]; Aipermon GmbH [1]; other accelerometer devices [2]; instrument not reported [1].

Monitoring period varied from two to 450 days [10], with 1 week as the most common recording period (56 studies). Eight of the included studies collected activity data for one year by use of the Lifecorder, reporting on number of steps and intensity of activity (metabolic equivalent, METs). Details of included studies (including complete reference list of all 134 included studies) are available to subscribers in *Maturitas* online.

3.3. Participant characteristics

Data of PA for samples of in-care older adults were presented in 61 studies, for healthy older adults in 62 studies, and for both in-care and healthy older adults in 11 studies. In total, results for 100 samples (7405 participants) from in-care and 113 samples (10,279 participants) of healthy older adults were included.

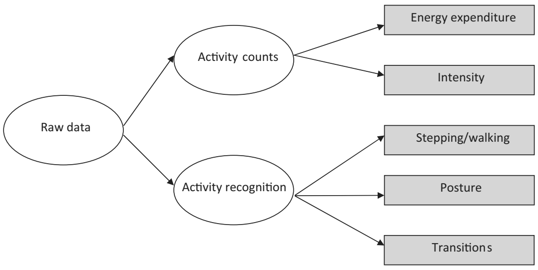

Fig. 2. Outcomes used to describe physical activity in older persons. Activity pattern is not included in this figure, but explained in text.

Samples of in-care older adults included coronary heart diseases (27 samples), peripheral arterial disease (PAD) or venous leg ulceration (16 samples), chronic obstructive pulmonary disease (COPD) (8 samples), Parkinson disease (4 samples), stroke (7 samples), diabetes (2 samples), obesity (2 sample), post hip fracture (3 samples) and total hip replacement (1 sample), osteoarthritis of the knee (1 sample), osteoporosis (1 sample), Alzheimer disease or dementia (4 samples), cancer (1 sample), hemodialysis (1 sample), in-hospital/ward patients (6 samples), sarcopenia (1 sample), continuing care facilities/nursing home residents (13 samples), as well as 2 samples where participants had chronic conditions from different diagnoses.

Samples of healthy older adults (113 samples) differed with respect to gender, age, activity levels, as well as functional limitations (also including 2 samples of cancer survivors). Some of the samples (12 out of 113) functioned as controls in studies assessing in-care older adults.

3.4. Physical activity outcomes

The review showed a rich variety of variables to present PA in older adults. Fig. 2 demonstrates how raw accelerometer signals were used to derive variables based on “activity counts”, for example the variable Energy Expenditure which is derived from the amplitude of the acceleration signals [11], or based on “activity recognition”, such as variables of recognized postures, transitions, and activities the persons perform during a day [12]. In addition to activity counts and activity recognition, other variables describing activity patterns have been proposed. Mean length of activity events is one example of an activity pattern variable [13].

Most studies present two or more variables derived from the same PA monitoring, but 67 out of 134 included studies reported only a single variable. Energy Expenditure was most commonly reported, where units such as kcal, kJ, accelerometer vector magnitude, or counts were used.

In some studies, different PA variables were compared. For example, Buchheit and colleagues (2004) compared two variables, derived from activity counts and from activity recognition, in two groups, and found that those spending more hours per week doing activities at higher intensity had lower total amount of PA [14].

3.4.1. Results reported on physical activity in older adults

In order to provide reference values for PA in older adults, we selected three commonly used variables of PA that were comparable across studies. Fig. 3 presents the level of estimated PAEE as kcal per day, while results on activity recognition of postures in terms of total time in walking and in activity are presented in Figs. 4 and 5, respectively.

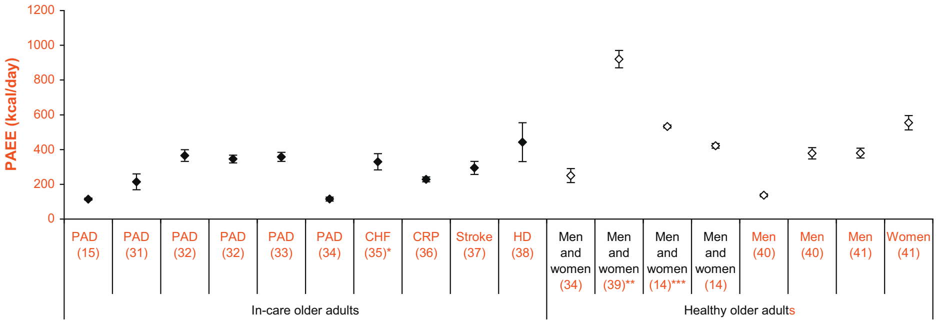

Fig. 3. Estimated PAEE, reported as kcal per day (mean ± SE) [14,15,31–41]. PAD, peripheral arterial disorder, CHF, chronic heart failure, CRP, cardiac rehabilitation patients, HD, hemodialysis patients. *Reported for the entire sample here, but separate reports for men and women are available [35]. **Reported for the entire sample here, but separate reports are available for a sarcopenic and a non-sarcopenic part of the total sample [39]. ***Corresponds to the sports active sample presented in Fig. 5 as well.

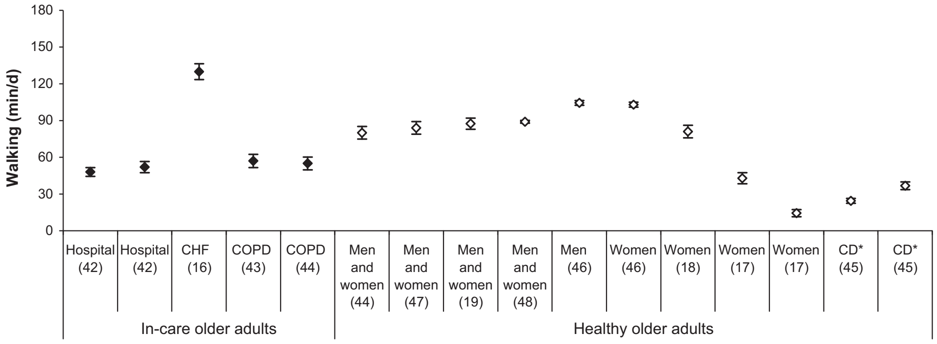

Fig. 4. Walking reported as minutes per day (mean ± SE) [16–19,42–48]. CHF, chronic heart failure, COPD, chronic obstructive lung disorder, CD*, community dwellers (gender not reported).

The lowest reported value of PAEE was 114.49 kcal/d for a sample with peripheral arterial disease ($n = 84$) [15], and highest reported value was for a healthy cohort ($n = 50$) reporting 920 kcal/d. The highest reported time in walking was 2 h and 9.9 min/d in a small pilot study ($n = 12$) for a sample of older adults with chronic heart failure. The authors concluded that walking time could be important as an indicator of clinical capabilities and disease progression [16].

In studies reporting walking time, half of the 16 samples walked less than 1 h per day, and the lowest value reported was 14.4 min/d for a small sample of healthy women ($n = 14$) [17]. Only two studies reported both walking time and total PA time, and in both studies walking was approximately one third of total PA time [18,19].

The lowest reported total PA time was 70.3 min per day for a sample of older adults from a city ward ($n = 20$) [12]. The study from Buchheit and colleagues (2004) reported the highest value of total PA for a sample of healthy older adults not involved in sports [14]. This group spent approximately 10 h per day in total PA, which was significantly different from the comparison sample of sports active older adults who spent 1.5 fewer hours in total activity. In contrast,

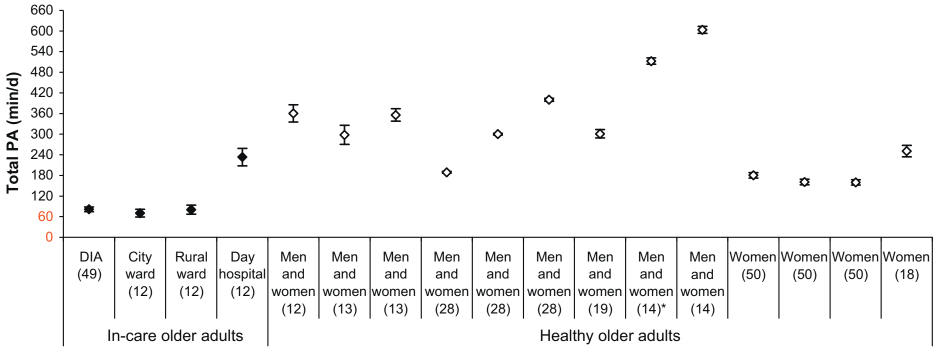

Fig. 5. Total time in physical activity reported as minutes per day (mean ± SE) [12–14,18,19,28,49,50]. DIA, diabetes. *Corresponds to the sports active sample also presented in Fig. 3.

the sports active sample showed significantly higher values of PAEE and significantly more time spent in PA of intensity higher than 3 METs compared to the sample of older adults not involved in sports.

3.4.2. Recent outcomes reported on activity patterns in older adults

Thirteen studies reported new variables beyond activity counts and activity recognition. Such "activity pattern" variables can be derived from activity counts or recognition, or from new analyses of raw acceleration signals. Variables of activity patterns were most often reported together with posture and stepping. Examples of activity patterns are reports on when during the day long events of moderate to vigorous intensity are performed [20] or reports on PA related to certain time periods of the day, for example mid-day level of PA [21–23]. Studies that monitor PA over long time periods, such as the Nakajano study, enable reports on PA related to seasonal variations [24] and meteorological factors [10]. PA can also be reported using outcomes describing how repeatable or variable the activity pattern was [13,18,25]. Number of steps per activity event is also an alternative for expressing activity pattern [26]. Others argue for using thresholds or cut-off points to define "meaningful" activity related to for example intensity [27], such as number of activity events ≥10 min above a certain intensity threshold.

4. Discussion

This systematic review included 134 papers that used accelerometer-based activity monitoring in older adults, mostly studies with a sample size of <50 persons and where the majority of papers were published in 2008 or later. The studies included healthy older adults and in-care older adults particularly within the fields of heart diseases, peripheral arterial disease, and pulmonary disease.

Full-text review revealed a wide variety of instruments being used. PA variables were derived from activity counts and/or activity recognitions and Energy Expenditure was the most commonly used variable. Comparison across studies of PAEE, walking time per day, and total activity time per day revealed variation in activity levels between samples but did not distinguish between healthy and in-care groups. For other variables, algorithms and parameters varied widely and monitoring time differed as well, making it challenging to compare results across different studies.

A variety of variables have so far been derived from activity monitoring, but up till now there has been little focus on which are the most valid variables for different purposes. Comparison of results on PA from different variables can provide new insights, especially for variables such as Energy Expenditure and postures [14] that represent clearly different aspects of PA, particularly with regards to intensity of activity. For example, the sample of healthy older adults involved in sports from the study from Buchheit and colleagues (2004) had lower levels of total PA compared to the healthy older adults not involved in sports. However, the same samples showed reverse results concerning PAEE, with the healthy older adults not involved in sports having lower levels of PAEE compared to the healthy older adults involved in sports [14]. Furthermore, a recent population-based study from Norway [7] that used accelerometers found that men spent less time being active but had higher intensity of activities than women, but that women showed more total activity than men. The authors discuss the importance of avoiding sedentary activity, and the advantageous role of activity independent of intensity. Because most older adults and particularly frail persons or persons with chronic diseases perform most of their total PA during everyday life situations where intensities are typically low, outcomes of PA that are able to capture these aspects can be expected to be of great importance.

Recently, activity pattern has been suggested as a new group of PA outcome that may provide additional information beyond reports of activity counts and activity recognition [28]. For example, Bankoski and co-workers (2011) suggest that PA breaks are important in order to avoid prolonged periods of sedentary behaviour [29]. However, it is important that studies measuring activity patterns use adequate equipment and robust analysis methods to obtain valid results [30].

It has been suggested that sedentary behaviour is an important aspect to investigate when collecting accelerometer-based data. Older adults spend much time being inactive and particularly patterns of sedentary behaviour can be an important supplement, providing both complimentary and distinctive information [18] to PA outcomes. Combined results on both PA and sedentary behaviour may therefore provide better insights into the role of different aspects of PA and should be investigated in more detail.

Results from the review showed differences in PA depending on factors beyond simple classification in in-care versus healthy older adult groups. For example, Jehn et al. (2009) argue for using total walking time or other PA variables derived from activity monitoring as an indicator of disease progression [16], suggesting that samples with mild disease burden should be more active than samples where disease burden is severe. However, data presented in this review did not find clear differences in PA between samples of healthy and in-care groups or between comparable in-care groups with different degree of problems. Most study sizes were small and it can be questioned how representative such small samples can be. In order to use PA to describe functional level or as a predictor of change in function, studies are needed with larger sample sizes and more representative samples.

This review has a few limitations. Because accelerometer-based activity monitoring is a relatively new field, we wanted to include a variety of studies and did not exclude studies with small sample sizes. Furthermore, we did not perform validity checks of the different instruments used on older adults. We classified included study samples into in-care or healthy groups, for want of a better term, and we recommend readers interested in specific results reported here to examine the inclusion and exclusion criteria of the specific study. As we excluded studies that used mechanical pedometers only, we have not presented results on number of steps. It remains to be seen what comparison of results on this particular variable might reveal about PA in older adults. Finally, even results on the same PA parameter may differ because of differences in algorithms. Algorithms embedded in many standard software packages that come with the sensor systems are typically unavailable to the user. In addition to sample differences, algorithm differences may have caused differences in the results presented here as well.

5. Conclusion

Activity monitoring is increasingly used in studies both on in-care and healthy older adults. It is a relatively new field of research, where monitoring methods are still under development and new possibilities for data extraction and data analysis continue to develop. Outcomes have typically been derived from activity counts and activity recognition, but lately have been described in terms of activity pattern as well. Different groups of outcomes may give different information about PA, and their particular role for health and functioning in older adults needs to be further explored. In order to compare results between studies and develop normative data on PA, it is necessary to standardize activity monitoring protocols and report on common variables across studies and instruments.

Contributors

Dr Helbostad provided concept/idea/research design. Mrs Taraldsen, Mrs Riphagen, Dr Vereijken, and Dr Helbostad

contributed to search design. Mrs Taraldsen, Dr Chastin, Mrs Riphagen, Dr Vereijken, and Dr Helbostad contributed to abstract reading. Mrs Taraldsen, Dr Chastin, Dr Vereijken, and Dr Helbostad contributed to full-text review. All authors contributed to writing and review of the manuscript before submission.

Competing interests

There are no conflicts of interests.

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Provenance and peer review

Commissioned and externally peer reviewed.

Appendix A. Table 1

Table 1
Details from the PubMed search strategy, March 8th 2011.

#1	Acceleromet*[tiab] OR Actical[tiab] OR ActivPAL[tiab] OR ActiGraph[tiab] OR ActiReg[tiab] OR ActivTracer[tiab] OR Actiwatch[tiab] OR Aw16[tiab] OR BioTrainer[tiab] OR Caltrac[tiab] OR (CSA[tiab] monitor[tiab]) OR Cyma Step Watch*[tiab] OR Dynaport[tiab] OR Dynastream[tiab] OR IDEEA[tiab] OR Large-Scale Integrated Activity Monitor[tiab] OR Lifecorder[tiab] OR Mini-Motionlogger[tiab] OR piezoresistive[tiab] OR Prosthetic Activity Monitor[tiab] OR RT3[tiab] OR SenseWear*[tiab] OR StepWatch*[tiab] OR Step Activity Monitor[tiab] OR Tracmor*[tiab] OR tri-axial research tracker[tiab] OR Tritrac R3D[tiab] OR pedometer*[tiab]
#2	Monitoring, ambulatory[mesh] OR Monitoring, physiologic[mesh:noexp] OR Anthropometry[mesh:noexp] OR Kinesiology, applied[mesh] OR recorder*[tiab] OR sensor[tiab] OR sensors[tiab] OR monitor[tiab] OR monitors[tiab] OR logger*[tiab] OR instrument[tiab] OR instruments[tiab] OR multisensor[tiab] OR device*[tiab] OR sensing[tiab] OR recording[tiab] OR monitoring[tiab]
#3	mounted[tiab] OR wearable[tiab] OR worn[tiab] OR portable[tiab] OR body fixed[tiab] OR body worn[tiab] OR trunk[tiab] OR armband*[tiab]
#4	#1 OR (#2 AND #3)
#5	Acceleration[mesh] OR Activities of daily living[mesh] OR Gait[mesh] OR Motor activity[mesh] OR Movement[mesh:noexp] OR Locomotion[mesh] OR Posture[mesh] OR Walking[mesh] OR acceleration[tiab] OR physical activity[tiab] OR sedentary activity[tiab] OR sedentary behaviour[tiab] OR energy expenditure[tiab] OR motion[tiab] OR gait[tiab] OR cadence[tiab] OR position[tiab] OR stand-to-sit[tiab] OR sit-to-stand[tiab] OR kinematic*[tiab] OR postural transition[tiab] OR postural transitions[tiab] OR ambulatory activity[tiab] OR step activity[tiab]
#6	Aged[mesh] OR geriatr*[tiab] OR gerontol*[tiab] OR senior*[tiab] OR elderly[tiab] OR ((aged[tiab] OR old[tiab] OR older[tiab]) NOT medline[sb])
#7	Review[pt] OR Case reports[pt]
#8	Animals[mesh] NOT Humans[mesh]
#9	Children[ti]
#10	#4 AND #5 AND #6 NOT (#7 OR #8 OR #9) AND hasabstract (1403 hits)

Key to search commands: * truncation; [mesh] Medical Subject Heading including narrower terms to MeSH field, [mesh:noexp] Medical Subject Heading not including its narrower terms; [sb] PubMed subfile; [pt] publication type; [ti] title word; 'hasabstract' restricts results to references having an abstract; OR-AND-NOT are Boolean operators; # set number.

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Paper II

Evaluation of a Body-Worn Sensor System to Measure Physical Activity in Older People With Impaired Function

Kristin Taraldsen, Torunn Askim, Olav Sletvold, Elin Kristin Einarsen,
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Background. There is limited information on reliable and valid measures of physical activity in older people with impaired function.

Objective. This study was conducted to compare the accuracy of single-axis accelerometers in recognizing postures and transitions and step counting with the accuracy of video recordings in people with stroke (n=14), older inpatients (n=14), people with hip fracture (n=8), and a reference group of 10 adults who were healthy.

Design. This was a cross-sectional study, evaluating the concurrent validity of small body-worn accelerometers against video observations as the criterion measure.

Methods. Activity data were collected from 3 sensors (activPAL) attached to the thighs and the sternum and from registration of the same activities from video recordings. Participants performed a test protocol of in-bed, transfer, and walking activities.

Results. The sensor system was highly accurate in classifying lying, sitting, and standing positions (100%) and in recognizing transitions from lying to sitting positions and from sitting to standing positions (100%). Placement of a sensor on the nonaffected leg resulted in less underestimation of step counts than placement on the affected leg. Still, the sensor system underestimated step counts during walking, especially at slow walking speeds ($\leq$0.47 m/s) (limits of agreement=-2.01 to 16.54, absolute percent error=40.31).

Limitations. The study was performed in a controlled setting and not during the natural performance of activities.

Conclusions. The activPAL sensor system provides valid measures of postures and transitions in older people with impaired walking ability. Step counting needs to be improved for the sensor system to be acceptable for this population, especially at slow walking speeds.

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[Taraldsen K, Askim T, Sletvold O, et al. Evaluation of a body-worn sensor system to measure physical activity in older people with impaired function. *Phys Ther.* 2011;91:277–285.]

Physical activity seems to be one of the most important factors in effective treatment in stroke units[1] and in the rehabilitation or prevention of functional decline in older people.[2] Physical activity in older people with impaired function is mostly performed as part of daily activities, such as getting out of bed or up from a chair, standing, and walking. Thus, the measurement of physical activity in this population should include such activities.

Small, lightweight, body-worn accelerometers that are able to record activity over longer periods of time now are available commercially.[3] Outcomes are energy expenditure,[4] time or frequency of activities recognized by the sensors, and movement kinematics.[5,6] Detection of body positions and transitions and step counting are based on algorithms embedded in the sensor system's software. Algorithms used to predict such variables should be able to extract data from different movement patterns,[7] including data derived from older people with impaired function.

An activPAL Professional single-axis accelerometer* attached to the thigh can collect activity data at a frequency of 10 Hz for up to 7 days without recharging.[8] The activPAL was shown to have good accuracy for detecting positions and step counting during walking in people who were healthy[5,9,10] and community-dwelling older people without impaired function.[11] However, it is not known whether the software algorithms are accurate when used in older people with impaired function, who may have different movement patterns and who move slowly and shuffle while walking. In particular, the recognition of steps during walking may be challenging because slow gait has a small acceleration amplitude, which may hamper the recognition of steps.[12] Before the activPAL can be recommended for long-term monitoring in older people with wide variations in levels of functioning, it should be validated in people with impaired function.

The main purpose of this cross-sectional study was to evaluate the concurrent validity of the activPAL Professional single-axis accelerometer in recognizing postures (sitting or lying, standing, and walking) and transitions (from sitting to standing positions) and step counting in people with acute stroke, older inpatients, and people 3 months after surgery for hip fracture; video observations of the same activities were used as the criterion measure. A second aim was to assess whether step counts were affected by placement of a sensor on the affected limb versus the nonaffected limb in people with hip fracture and acute stroke. Finally, we also wanted to determine whether 2 sensors could be used to distinguish between sitting and lying positions.

Method

Participants

Study participants included patients who had a diagnosis of acute stroke[13] and were admitted to the stroke unit at a university hospital (n=14), older inpatients at the department of geriatrics at a university hospital (n=14), and patients with hip fracture that had occurred 3 months earlier (n=8). Participants with hip fracture were home dwelling and were recruited at the end of participation in an observational study. These 3 groups of participants were convenience samples representing different groups of older people with impaired function; they served as the test group. All participants signed an informed consent statement. Participants were included if they were able to walk with or without a walking aid or with support from 1 or 2 people, if they were able to follow verbal instructions about movements, and if their medical conditions were stable.

For evaluating whether step counts were dependent upon gait speed, 10 adults who were healthy were recruited from employees at the Norwegian University of Science and Technology and the hospital staff at St. Olav's Hospital, Trondheim University Hospital. These participants served as a reference group.

Of the 36 older people in the test group, 14 were men and 22 were women; their mean age was 79.7 years (SD=7.3, range=62.0–92.8). The 10 adults in the reference group were women. Seven of the 14 people with stroke, 10 of the 14 older inpatients, and 5 of the 8 people with hip fracture were women. The characteristics of the participants are shown in Table 1.

Instruments

For this study, activPAL Professional single-axis accelerometers (inclinometers) were used. The sensor (including the battery) weighs 20 g, and the outline dimensions are 7 mm (depth) × 53 mm (length) × 35 mm (width). The sensor collects data at 10 Hz, and the battery capacity allows continuous recording for up to 7 days. Data are transferred from

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* PAL Technologies Ltd, 50 Richmond St, Glasgow G1 1XP, Scotland.

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Table 1.
Characteristics of Participants[a]

Characteristic	Test Group								Reference Group (n=10)	
	Total (n=36)		People With Stroke (n=14)		Older Inpatients (n=14)		People With Hip Fracture (n=8)			
	X̄	SD	X̄	SD	X̄	SD	X̄	SD	X̄	SD
Age (y)	79.7	7.3	75.2	6.2	84.0	5.8	80.1	7.6	46.3	9.0
Height (cm)	164.8	11.3	169.3	13.2	161.4	11.0	163.0	4.8	170.0	5.3
Weight (kg)	67.0	13.4	75.3	13.0	60.3	11.5	63.8	8.5	65.9	4.3
mRS score (0–6)	2.9	1.2	3.3	0.8	3.5	0.7	1.1	0.4	0	0.0
BI score (0–100)	79.2	18.7	77.5	16.6	70.0	18.2	98.1	5.3	100	0.0
Speed (m/s)	0.46	0.2	0.41	0.1	0.43	0.1	0.58	0.2	0.84	0.1

[a] mRS=modified Rankin Scale, BI=Barthel Index, speed=preferred gait speed (mean from tasks 11 and 12).

the sensor to a Windows[†]-compatible PC by use of a USB docking station. The software package (activPAL Professional Research Edition) processes the raw acceleration data signals by using proprietary algorithms not controlled by the user (Intelligent Activity Classification), summarizes activity as time in sedentary (sitting or lying) and upright (standing and walking) positions, registers the number of transitions from sitting to standing positions, and registers step counts during walking. Data in 1-second bytes can be converted into an Excel[†] spreadsheet issued by the activPAL manufacturer, allowing a more detailed analysis. The activPAL registers the number of steps taken by the lower extremity with the attached sensor only, and an algorithm doubles the total number of steps taken.

A 2D Sony mini digital video camera[‡,14] was used to capture the same activities as the sensors. The video camera has a 1.0-second timing system. Video camera time was manually synchronized with sensor time by using the PC time. In addition to steps being counted from the video, steps were counted and recorded in writing during the performance of each task.

Test Procedure

Before testing, all sensors were connected to the same PC for the synchronization of time. Three sensors were used in this study; all were attached with PALstickies* (dual-layer hydrogel adhesive pads): 1 sensor each on the right midthigh and the left midthigh[5] and 1 sensor on the chest at midsternum. Participants performed a test protocol of 23 tasks, including in-bed activities, transfers between positions, and upright activities selected from tests of mobility in older people[15–17] (Tab. 2). Instructions and the starting cue "Are you ready? 3, 2, 1, . . . start" were given before every task. Before starting and after finishing each task, the participants were asked to stand or lie still for 5 seconds. Standing and walking tasks were performed with shoes on. The six 5-m walking tasks were performed at slow, preferred, and fast instructed speeds. The protocol was performed in an open room measuring 15 m × 8 m. A stationary video camera operated by a person captured performance during the entire test sequence, which lasted from 20 to 60 minutes. The video camera was placed at the same 2 positions for all participants: in front of the bed for the in-bed tasks and in front of the participant for the walking tasks (capturing the whole body or at least the lower extremities from behind or in front when participants walked back and forth). The person operating the video camera ensured that the participants and activities being performed were captured on the video. The reference group performed the six 5-m walking tasks only (tasks 9–14) (Tab. 2).

Outcome Measures

The participants' age, height, weight, modified Rankin Scale[18] scores, and Barthel Index[19] scores were used to describe the sample. Outcomes from video observations and activPAL sensors included the type of activities performed (sedentary or upright and sitting or lying), the duration of activities (seconds), the number of transitions (from sitting to standing or standing to sitting positions and from sitting to lying or lying to sitting positions), and the number of steps during walking. Gait speed (m/s) was calculated from the time taken to perform the 5-m walking tasks. For the reference group, the number of steps and gait speed during walking were used as outcome variables.

[†] Microsoft Corp, One Microsoft Way, Redmond, WA 98052-6399.

[‡] Sony Corporation, 1-7-1 Konan, Minato-ku, Tokyo 108-0075, Japan.

Table 2.
Test Protocol[a]

Order	Task	Classification (Body Position)
1	Transition from sitting position to lying position	Sedentary (sitting and lying)
2	Turning right in bed	Sedentary (lying)
3	Turning left in bed	Sedentary (lying)
4	Transition from lying position to sitting position	Sedentary (sitting and lying)
5	Sitting on the edge of the bed for 20 s	Sedentary (sitting)
6	Moving from sitting on the edge of the bed to a chair	Sedentary (sitting) and upright (standing and walking)
7	Transition from sitting position to standing position	Sedentary (sitting) and upright (standing)
8	Transition from standing position to sitting position	Upright (standing) and sedentary (sitting)
9 and 10	Back-and-forth 5-m walking at slow speed	Upright (walking)
11 and 12	Back-and-forth 5-m walking at preferred speed	Upright (walking)
13 and 14	Back-and-forth 5-m walking at fast speed	Upright (walking)
15	Turning 180°	Upright
16	Turning 360°	Upright
17	Timed "Up & Go" Test	Sedentary (sitting) and upright (standing and walking)
18, 19, and 20	Three 4-step walking sequences	Upright (walking)
21, 22, and 23	Three 8-step walking sequences	Upright (walking)

[a] Tasks were performed in a fixed order and are classified according to categories derived from activity monitoring. Participants were asked to stand or lie still for 5 seconds before starting and after finishing each task so that the beginning and the end of each task could be identified during data analysis.

Data Analysis

An activity was defined as the lying position when both the thigh sensor and the chest sensor for the same sequence registered the activity as sedentary. When the chest sensor registered the activity as upright and the thigh sensor registered the activity as sedentary, the activity was defined as the sitting position. When both sensors registered the activity as upright, the activity was defined as the upright position.

Video data were analyzed before activPAL data were analyzed. Observations from the video recordings were replayed on the camera, and 1 researcher classified start and stop times (time intervals) and counted steps for each of the tasks in the test protocol. The number of steps counted from the video observations were compared with the number of steps counted and recorded in writing during the performance. If the numbers of steps counted by these 2 methods differed, the video recordings were reanalyzed. If disagreement persisted, the results from the video observations were used. Time intervals were plotted and stored as Excel files.

An Excel spreadsheet provided by PAL Technologies was used to read processed activPAL data and display collected data as second-by-second cumulative output. For synchronizing start and stop times from activPAL data with those from video data, a custom-made MATLAB[§] program was used.

Twenty of the 23 tasks from the test protocol were used in the data analysis. Task 6, moving from sitting on the edge of a bed to a chair, was not included because participants used different movement strategies (moving while keeping a seated position or moving by rising to an upright position). The 2 standing and turning tasks (tasks 15 and 16) were excluded because the steps during turning were difficult to count from the video recordings.[20]

Time in sedentary (sitting or lying) and upright (standing and walking) positions was calculated from tasks 1 to 5, 9 to 14, and 18 to 23. Transitions from sitting to standing positions and from standing to sitting positions were counted from tasks 7, 8, and 17. Analyses of time in sitting and lying positions were based on tasks 2, 3 and 5. When evaluating whether transitions from sitting to lying positions and from lying to sitting positions could be classified by the thigh and chest sensors, a transition was counted when the position changed in tasks 1, 4, 7, 8, and 17. Tasks 9 to 14 and 18 to 23 were used for evaluating asymmetric gait, and the most accurate lower sensor was then used for the step count accuracy analysis for a single monitor. Tasks 9 to 14 also were used in the

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[§] The MathWorks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.

step count accuracy analyses for the test group and the reference group.

To ensure that the entire movement and position sequence was included in the analysis, we included 2 seconds before and after every transition and step count time interval in the analysis.

Step count accuracy was assessed from all walking tasks performed at slow, preferred, and fast speeds. For the test group, we divided gait speed into slow and fast speeds. *Slow speed* was defined as a gait speed equal to or lower than the mean gait speed for the sample, whereas *fast speed* was defined as a gait speed higher than the mean gait speed.

Statistical Analysis

Statistical analysis was performed with SPSS version 17.0 software.[‖] The significance level was set to $P<.05$. Agreement between activPAL sensor registrations and video observations was assessed by the method of Bland and Altman,[21] as follows: The differences between sensor registrations and video observations were plotted against the average measures obtained by the 2 methods. Horizontal lines were drawn at the mean difference, and the limits of agreement (LOA) were defined as the mean difference plus or minus 1.96 times the standard deviation of the difference. The absolute percent error (APE) was calculated with the following formula: (sensor data − video data)/video data × 100.

Role of the Funding Source

The health authorities of Mid Norway funded this study. No financial support was received from any commercial agency.

Results

There were significant differences in age between people with stroke and older inpatients ($P=.001$), in weight between people with stroke and older inpatients ($P=.002$) and between people with stroke and people with hip fracture ($P=.035$), and in modified Rankin Scale and Barthel Index scores between people with stroke and people with hip fracture ($P<.001$) and between older inpatients and people with hip fracture ($P<.001$).

If needed, participants in the test group used their own walking aids during the walking tests; 12 walked without a walking aid or support from another person, 5 used a cane or a crutch, 17 used a roller, and 2 used their walking aids only during fast walking. Twelve participants in the test group were not able to perform the entire test protocol.

Classification of Posture

Classification of sedentary and upright positions was based on a total of 555 tasks performed by 34 participants in the test group. The sensors showed no misclassifications of time in a sedentary position versus time in an upright position, and the maximum time difference between video observations and the single-sensor registrations was 1 second. When 1 thigh sensor was used, tasks 2, 3, and 5 were classified as sedentary positions; when 2 sensors (thigh and chest) (2-sensor unit) were used, tasks 2 and 3 were classified as lying positions and task 5 was classified as a sitting position.

Recognition of Transitions

Analyses of recognition of transitions from sitting to standing positions and from standing to sitting positions were based on 101 tasks involving 132 transitions performed by 35 participants in the test group. Analyses of recognition by the 2-sensor unit of transitions from sitting to lying positions and from lying to sitting positions were based on 70 tasks. The numbers of transitions from lying to sitting positions and from sitting to standing positions were identical for activPAL registrations and video observations.

Placement of a Sensor on the Affected Lower Limb Versus the Nonaffected Lower Limb

Data were obtained from both right and left thigh sensors for 11 of the 14 participants with stroke and all 8 participants with hip fracture; in 9 of these participants, the right lower limb was affected, and in 10 participants, the left lower limb was affected. Three participants with stroke were excluded from these analyses because of technical problems with 1 of the sensors. Four participants were not able to complete all 12 walking tasks, leaving a total of 211 tasks for the analysis.

Figure 1 shows the level of agreement between video observations and activPAL registrations for total step counts. The mean step counts during all 211 tasks were 10.66 (SD=4.70) for the video camera, 6.30 (SD=3.94) for the sensor on the nonaffected limb, and 4.97 (SD=3.85) for the sensor on the affected limb. The 95% LOA, derived from Bland-Altman analyses, were ±4.36 steps for the sensor on the nonaffected limb and ±5.69 steps for the sensor on the affected limb. The APEs for the sensor on the nonaffected limb and the sensor on the affected limb were 26.91 and 53.40, respectively.

Step Counts

A total of 188 tasks were performed by participants in the test group during the back-and-forth 5-m walking tasks at slow, preferred, and fast speeds. The overall mean gait speed during these tasks was 0.47 m/s (SD=0.21 m/s). The mean gait speed for slow walking was 0.32 m/s (SD=

[‖] SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.

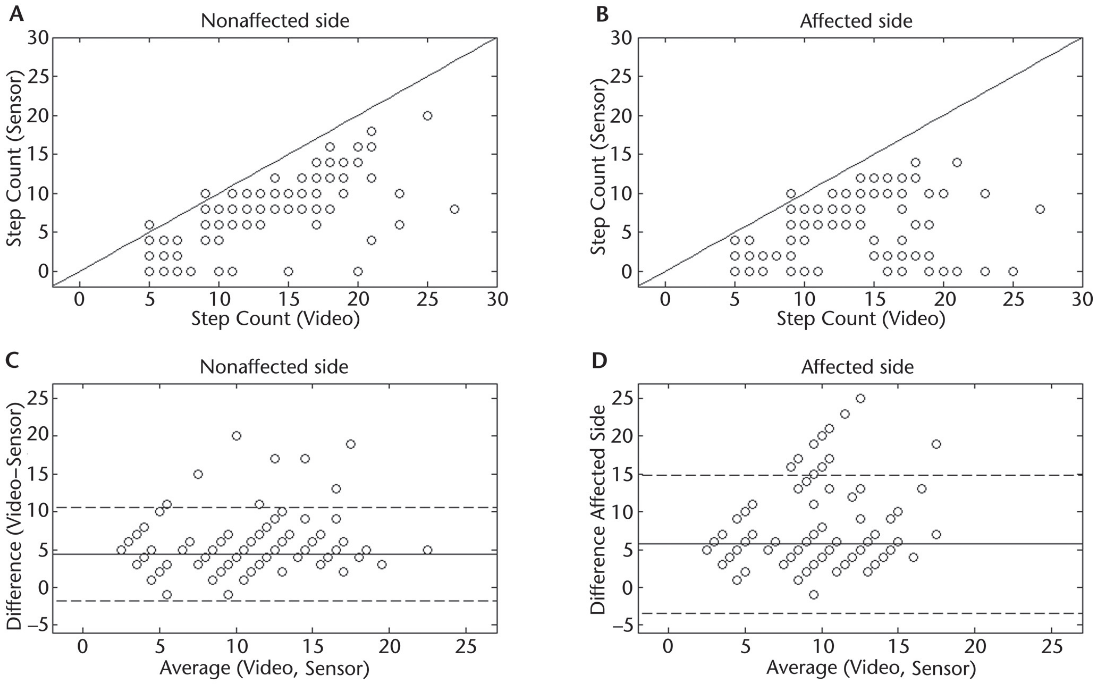

Figure 1.
Scatterplots of total step counts obtained from activPAL sensor registrations and video observations for the nonaffected limb (A) and the affected limb (B) and Bland-Altman plots of agreement between activPAL sensor registrations and video observations for the nonaffected side (C) and the affected side (D) in 19 participants with 1 affected lower limb (participants with stroke or hip fracture).

0.11 m/s), that for walking at the preferred speed was 0.45 m/s (SD=0.16 m/s), and that for fast walking was 0.62 m/s (SD=0.22 m/s).

A total of 60 walking tasks were performed by participants in the reference group. The overall mean gait speed was 0.86 m/s (SD=0.36 m/s). The mean gait speeds for slow walking, walking at the preferred speed, and fast walking were 0.47 m/s (SD=0.08 m/s), 0.84 m/s (SD=0.09 m/s), and 1.26 m/s (SD=0.20 m/s), respectively.

For 3 walking tasks in the reference group and 1 walking task in the test group, the step counts obtained from activPAL registrations were higher than those obtained from video observations. Inspection of the raw activPAL data revealed double registrations of steps for these data sequences.

Figures 2 and 3 show the level of agreement between video observations and sensor registrations for step counts for the reference group and the test group, respectively. The 95% LOAs for participants in the test group were ±7.27 steps (lower limit of agreement [LLOA]=−2.01; upper limit of agreement [ULOA]=16.54) for slow speed and ±3.34 steps (LLOA=0.31; ULOA=6.39) for fast speed. For participants in the reference group, the 95% LOAs were ±3.88 steps (LLOA=−0.22; ULOA=7.91) for slow speed and ±1.62 steps (LLOA=−1.82; ULOA=5.05) for fast speed. The accuracy was poorest and the APE was highest for step counts at or slower than 0.47 m/s for walking tasks performed by participants in the test group. Walking at slow speed by participants in the test group was performed with more steps than walking at other speeds. The APEs for slow speed and fast speed by participants in the test group were 40.31 and 29.13, respectively; the APEs for slow speed and fast speed by participants in the reference group were 33.06 and 19.32, respectively.

Discussion

The aim of the present study was to assess the accuracy of activPAL sensor registrations of positions during physical activity or inactivity, numbers of transitions, and numbers of steps during walking in older people

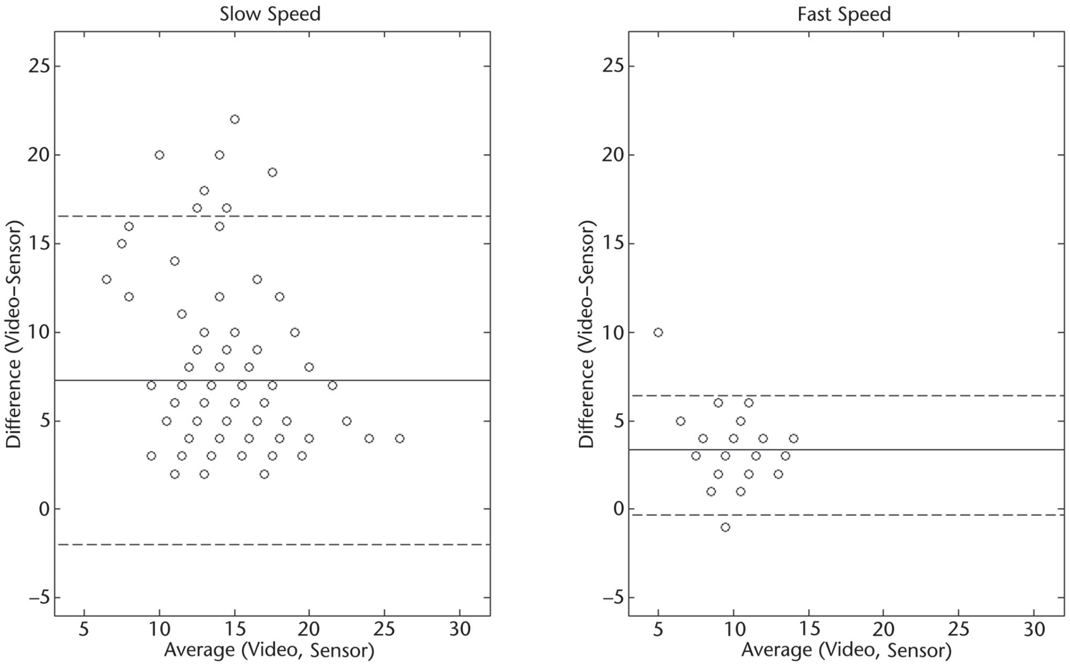

Figure 2.
Bland-Altman plots demonstrating step count agreement between activPAL sensor registrations and video observations for participants who had impaired function and walked at slow speeds (≤0.47 m/s) (n=105) (left) and fast speeds (>0.47 m/s) (n=83) (right).

with impaired function. The results demonstrated high accuracy of the activPAL sensor in classifying activities as sedentary or upright and in recognizing transitions from sitting to standing positions and from lying to sitting positions in older people who were frail, people with hip fracture, and people with acute stroke. Placement of a sensor on the affected limb resulted in a greater underestimation of step counts than placement on the nonaffected limb. Still, the sensor underestimated step counts during walking, especially at slow gait speeds, in these groups of people.

Step Detection in Older Adults Who Were Frail

Gait speed obviously affected step count accuracy. Participants in our study walked at slower gait speeds than participants in earlier validation studies with activPAL sensors,[9,11] a fact that may explain the poorer results in our study.

Our study revealed that activPAL underestimated step counts; the greatest underestimation was noted for people walking at gait speeds slower than 0.47 m/s. Inspection of the raw data demonstrated that all steps had been registered by the accelerometers. However, the activPAL step count is calculated from raw acceleration data signals by an automatic software procedure. The findings, therefore, indicate that the algorithms are not effective at detecting slow stepping. Older adults who are frail may walk slowly, and development of a more appropriate algorithm for recognizing gait acceleration patterns is needed to provide acceptable step count accuracy for use in people who walk slowly. Because the activPAL underestimated step counts, the calculation of energy expenditure (in metabolic equivalents) also was inaccurate. The findings from our study support earlier results[22] and suggest that the sensor should be attached to the nonaffected lower limb to enhance accuracy.

Classification of Sedentary Versus Upright Positions

The sensors showed no misclassifications of activities in sedentary versus upright positions. These activities, therefore, are accurately registered in older people who are frail. Older people with impaired function spend most active periods performing indoor activities of daily living. Time in an upright position during the day may be a relevant measure of activity

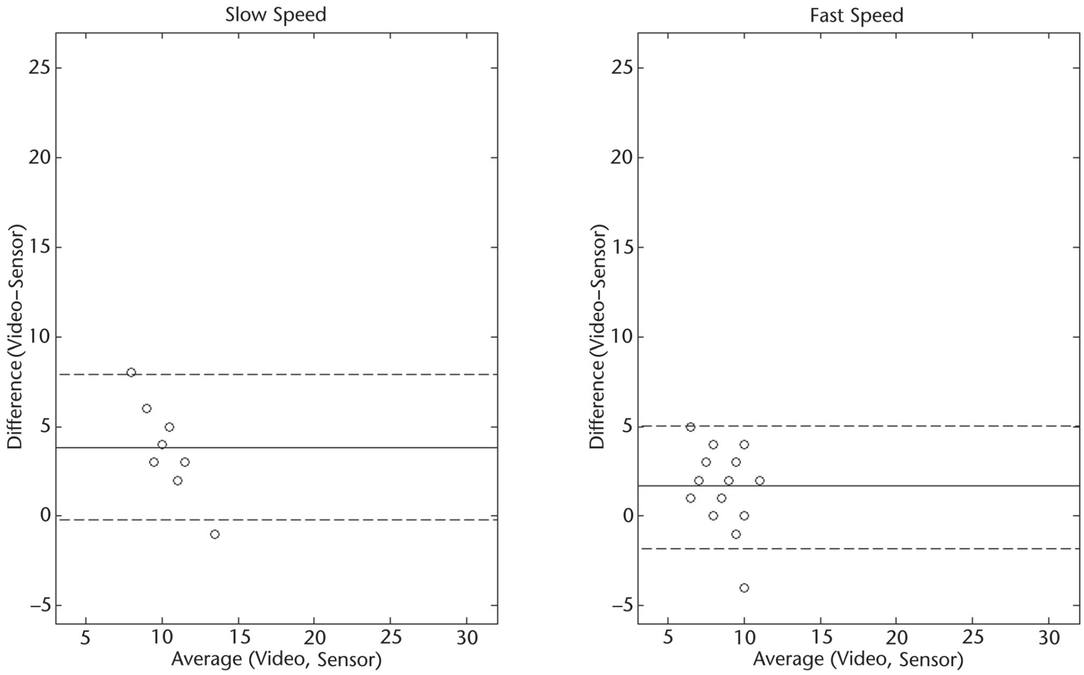

Figure 3.
Bland-Altman plots demonstrating step count agreement between activPAL sensor registrations and video observations for adults who were healthy and walked at slow speeds ($\leq$0.47 m/s) (n=13) (left) and fast speeds (>0.47 m/s) (n=47) (right).

and a focus of interventions to increase or maintain activity levels.

The accurate results for transitions and time in sedentary and upright positions in our study are comparable to the results of previous studies of participants who were healthy and used activPAL sensors,[5] confirming that use of the activPAL is an accurate method for activity monitoring in older adults who are frail. Transition counts could provide valuable information about changes in activity and could serve as supplementary measures of activity during the day. Other outcomes, such as number and duration of periods in an upright (standing or walking) position during the day, also might serve as interesting measures of changes in activity and length of active periods and should be explored in future studies.

Expanding the Range of Use With an Additional Chest Sensor

The strengths of a single-axis acceleration sensor system are simplicity and ease of use. The limitation is the number of activities that the system can distinguish. By using a second sensor, we were able to distinguish between lying and sitting positions by synchronizing the outputs from the 2 sensors through a MATLAB-based procedure. This finding confirms that 2 sensors can be used as a 2-sensor unit when necessary and is comparable to findings from other studies with similar methods.[23] This important finding expands the applicability of activPAL to monitoring, recording, and registering early mobilization out of bed, which has been documented to be the most significant factor for a good functional outcome for people after stroke[1] and probably also for other groups of people who are frail and bedridden.

Limitations

The present study raises several methodological considerations. We used only a short walking distance (5 m), and it is likely that this short distance partly explains the extent of measurement error. The activPAL sensor was attached to 1 thigh, and every second step was doubled to capture both right and left steps during the walking sequences. This process resulted in a 25% chance of calculating 1 step fewer than was actually performed, depending upon which leg took the first step and which leg took the last step. Longer walking distances could have decreased the measurement error by reducing the percentage of steps used during gait initiation and stopping compared with the percentage of steps used during steady-state walking. However, longer walking distances were neither an option nor a relevant approach for our study population. Walking shorter distances at slow speeds is the main daily activity of our study population, and this activity needs to be calculated with high accuracy if it is to be used as an outcome for people with decreased levels of functioning. We did not consider information about the medical conditions of the participants in our study; such information could be useful for comparing our study population with other groups of older people.

We evaluated accuracy during a controlled test protocol and not during the natural performance of activities. This protocol may have yielded lower measurement errors than natural conditions. On the other hand, the testing period in our study was short compared with typical activity monitoring periods of up to 1 week for describing activity patterns and levels. Thus, it is likely that relative errors decrease with increasing monitoring time.

Conclusion

The activPAL system can be used as a single sensor or as a 2-sensor unit to provide a valid measure of activity or inactivity for the long-term monitoring of older people with impaired function. The step count algorithm is not acceptable for slow walking speeds and needs to be improved before the activPAL system can be recommended for use in people who are frail. Future studies should investigate the validity of outcomes from activity monitoring for changes over time and for the detection of people at risk of functional decline.

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Paper III

Multiple days of monitoring are needed to obtain a reliable estimate of physical activity in hip fracture patients

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Abstract

The aim of the study was to investigate the precision of estimated upright time during one week in community-dwelling older persons after hip fracture when monitoring activity for different numbers of consecutive days. Information about upright time was collected by thigh-worn accelerometers during seven consecutive days in 31 older persons (mean age 81.8 years ±5.3) three months after hip fracture surgery. Mean time in upright position, including both standing and walking, was 260.9 (±151.2) minutes per day. A cut-off value of half an hour was used to provide recommendations about number of recording days. Large variability between participants between days, as well as a non-constant within-participant variability between days indicate that at least four consecutive days of recording should be used to obtain a reliable estimate of upright time for individual persons. However, at a group level one day of recording is sufficient.

Keywords: Activity monitoring, accelerometers, coefficient of variation, aged

Introduction

Regular physical activity (PA) is shown to be important for the preservation of physical function at advanced age (DiPietro, 1996; Landi et al., 2007). Most interventions include PA in terms of exercise as a constitutive part of rehabilitation after hip fracture (Binder et al., 2004; Sylliaas, Brovold, Wyller, & Bergland, 2012). However, the specific role of daily PA in the regaining of physical function in older persons following a hip fracture is unclear. PA has mainly been assessed using questionnaires, but these are encumbered with recall bias (Melanson & Freedson, 1996) and can be severely limited when used in older persons. The largest challenge of using questionnaires is that low intensity PA, which may constitute a significant portion of daily PA in older persons, is not assessed (Harada, Chiu, King, & Stewart, 2001; Jorstad-Stein et al., 2005; Stewart et al., 2001). Objective measures of PA are therefore preferable and can now be obtained from body-worn activity monitors. These monitors enable recording of daily PA such as total time in upright, including all standing and walking activities and thus also low intensity PA. Previously, upright time has been found to be 100 % accurate in older persons with impaired mobility in general and in hip fracture patients in particular (Taraldsen et al., 2011). The focus on time spent in upright activities will be relevant for older persons after hip fracture, where the ultimate goal is to regain pre-fracture gait function.

A pertinent question for activity monitoring is the number of recording days needed to obtain a good estimate of activity over a certain period. High intra- and inter-participant variability in PA influences the accuracy of outcomes derived from activity monitoring (Baranowski & Moor, 2000; Nicolai et al., 2010). The longer the period of monitoring, the more stable estimate of a person's PA is obtained (Hart, Swartz, Cashin, & Strath, 2011). However, long-term monitoring has to be balanced against the practicality of wearing a sensor over longer periods and the acceptability in the study population (Maddocks et al., 2009). In order to obtain reliable estimates of PA, it is therefore important to know the lowest acceptable number of recording days. Studies on activity monitoring in older persons typically use recording periods between three to seven days (Trost, McIver, & Pate, 2005). To our knowledge, recommendations for hip fracture patients do not exist.

The aim of this study was to investigate the precision of objectively estimated PA using different numbers and combinations of consecutive recording days in hip fracture patients, when time in upright position is used as the outcome measure.

Method

A convenience sample (N=47) of older adults was recruited from a larger longitudinal hip fracture observation study (Sylliaas, Thingstad, et al., 2012) including community dwellers >65 years of age who were ambulant with or without assistance. The study was approved by the Regional Committee of Ethics in Medical Research (Mid-Norway) and written informed consent was obtained from the participants prior to inclusion. Participants were assessed three months post-surgery by using single-axis accelerometers (activPAL, PAL Technologies Ltd., Glasgow, UK) worn on the non-affected thigh for seven consecutive days, with varying first recording day. The sensors produce a signal related to the inclination of the thigh, and the concomitant software classifies upright (standing or walking) and sitting/lying positions (Grant, Ryan, Tigbe, & Granat, 2006). As step recognition has been shown to have low accuracy in older persons with impaired mobility (Taraldsen et al., 2011), we used time in upright position (called upright time), including standing and walking, as the outcome measure in the current study. Participants were told that the monitors recorded movements of their leg, and that they should continue doing what they normally did during the week.

Participants' height and weight were assessed three months after the fracture, and the mean of preferred gait speed of two consecutive trials was derived from an electronic gait mat (GAITRite$^{®}$) (Menz, Latt, Tiedemann, Mun San Kwan, & Lord, 2004). Barthel Index (0-20) (Mahoney & Barthel, 1965) and the Nottingham Extended Activities of Daily Living Scale (NE-ADL) (0-66) (Gladman, Lincoln, & Adams, 1993) were used to assess personal and instrumental activities of daily living. Global cognitive function was assessed by use of the Mini Mental State Examination (MMSE) (0-30) (Folstein, Folstein, & McHugh, 1975). Timed Up-and-Go (TUG) was used to assess mobility (Podsiadlo & Richardson, 1991) and the Berg Balance Scale (BBS) (0-56) (Berg, Wood-Dauphinee, Williams, & Maki, 1992) to assess functional balance. The in-hospital assessment was performed by a single physiotherapist.

Statistical analyses were performed using SPSS software, version 16.0. Upright time for each of the days from Monday through Sunday was calculated, and the mean upright time of all 7 days was used as criterion measure. The standard deviations (SD) of upright time for the sample demonstrated large variations in upright time between participants. Furthermore, a plot of individuals' mean upright time against their SD of upright time for one week, showed a non-constant SD between days for the participants. Therefore, the Coefficient of Variation was calculated using the formula CoV = (SD upright time / Mean upright time) *100. Variations in upright time across days were expressed as Coefficient of Variation within participants (CoV_w) and between participants (CoV_b).

The 217 combinations of upright time for 1, 2, 3, 4, 5, and 6 consecutive days were compared to the criterion measure of all seven days and the differences presented as median and interquartile range (IQR) values. To be able to give recommendations concerning how many recording days are needed for a reliable estimate of weekly activity, we used a cut-off value for the differences in upright time of half an hour, that is, the range from 15 minutes more to 15 minutes less than for recordings based on one week (see Figure 1B). For an average older person in our sample, 15 minutes represent 6% of upright time three months after hip fracture. According to Altman (1991), statistics based on hypothesis testing and testing of average differences should not be considered relevant for assessment of agreement between two methods (Altman, 1991), such as for our study of repeated measures using 1, 2, 3, 4, 5, or 6 recording days as compared to one week recordings.

Parametric paired-samples t-test was used to investigate the mean difference in upright time between weekend days (mean of Saturday and Sunday) versus week days (mean of Monday through Friday).

Results

Of the 47 included participants, 31 (77.4 % females) had complete data of one week PA recordings three months after hip fracture surgery. Seven participants removed the sensor before one week of recording, data from five persons were lost because of battery failure, and four sensors did not have any registrations due to technical reasons. Characteristics of participants three months after the hip fracture are presented in Table 1. Of the included participants, 18 had a fractured femoral neck while 10 had per-trochanteric and 3 sub-trochanteric fractures. Ten participants used walking aids, and two persons needed personal assistance during walking. During the previous 14 days, eight participants had been walking outdoor on their own, eight with some difficulties, and eight with assistance, while seven had not been walking outdoor.

Table 1. *Characteristics 3 months after hip fracture*

	N	Mean	SD	Min	Max
Age (years)	31	81.8	5.3	70	93
Gait speed (m/s)	29	0.59	0.25	0.13	1.06
BMI (kg/m^2)	28	23.2	3.9	15.7	32.4
Barthel Index (score)	31	18.1	2.6	10	20
NE-ADL (score)	31	37.8	18.1	6	66
MMSE (score)	30	26.2	3.2	12	30
BBS (score)	31	39.6	14.3	7	56
TUG (sec)	29	20.5	8.7	7.8	45.2

Mean upright time during one week of recording was 260.9 ±151.2 minutes, ranging from 29 to 596 minutes for individual persons, see Table 2 for details. Participants spent significantly less upright time during weekend days (mean 242.4 minutes) compared to week days (mean 268.3 minutes), p=0.018. Mean variability in upright time across days was 30.7 % (median 16.7%, range 8.8-164.0%) for CoV_w and 58 % for CoV_b.

Table 2. *Upright time for each day and for criterion measure of all 7 days*

	Upright time (hours and minutes)			
	Mean	**SD**	**Min**	**Max**
Monday	4h 28m	2h 38m	7m	9h 36m
Tuesday	4h 18m	2h 41m	4m	10h 1m
Wednesday	4h 39m	2h 38m	2m	10h 16m
Thursday	4h 48m	2h 43m	15m	9h 29m
Friday	4h 9m	2h 43m	4m	11h 51m
Saturday	4h 8m	3h 45m	1m	9h 43m
Sunday	3h 57m	2h 49m	1m	10h 13m
7 days	4h 21m	2h31m	29m	9h 56m

Figure 1A shows all participants' CoV_w (%) for the seven recording days, showing low values of CoV_w for most participants, except for three of the participants with relatively low PA levels whose CoV_w were above 100 % (116, 146, and 164 %, respectively). Figure 1B shows the difference expressed as IQR (in minutes) between all combinations of 1, 2, 3, 4, 5, and 6 consecutive recording days and the criterion measure of seven consecutive days. Results show that the median value of the difference in upright time between the combinations of number of consecutive days and the criterion measure was consistently low, showing the largest difference when using a single day (3 minutes). However, IQR values were large (59 minutes) when using one day as compared to seven days. The cut-off value of < 30 minutes for differences in upright time compared to seven days was met only for recordings of 4, 5, or 6 days (IQR of 24, 20, and 10 minutes, respectively).

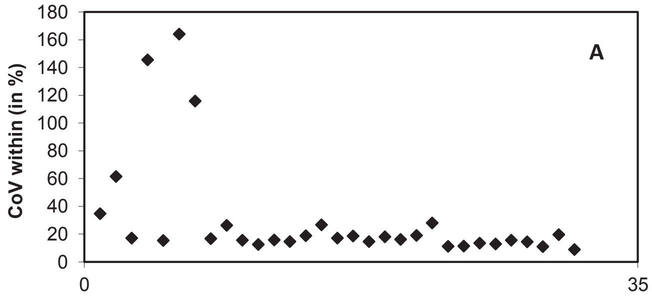

Figure 1A. *Individual subjects' CoV_w (in %) between 7 days of recordings for all 31 subjects, organized along the x-axis in ascending order of physical activity.*

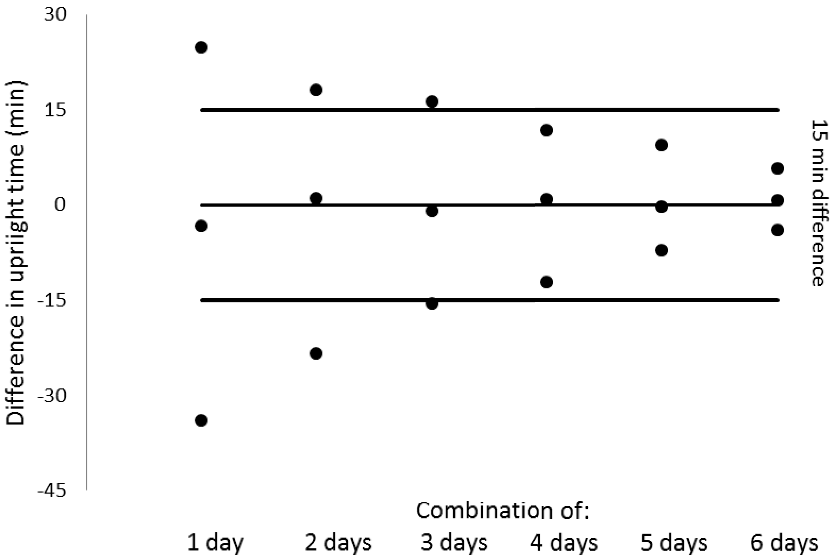

Figure 1B. *Differences (Median and IQR) between the different combinations of 1, 2, 3, 4, 5, and 6 consecutive days compared to the criterion measure of all 7 days.*

Discussion

Compared to previous studies, participants in our study were relatively old (mean age >80yrs), had slow gait speeds, and impaired mobility. Mean upright time was 260.9 ±151.2 minutes, which is substantially lower and more variable than found by Grant and colleagues (360.4 ±112.1 minutes) (Grant, Granat, Thow, & Maclaren, 2010) and Nicolai and colleagues (300.9 ±80.8 minutes) (Nicolai et al., 2010) in community-dwelling elderly.

At the group level, the absolute difference in mean upright time between combinations of 1, 2, 3, 4, 5, or 6 consecutive days and the criterion of seven recording days was low (maximum 3 minutes when using single day recordings), indicating that even a single day of recording provides a reliable estimate of a group mean upright time. However, at the level of an individual, the CoV_w between days could be very high, pointing to large variations in upright time between days, especially for participants with low levels of activity during the week. Furthermore, the IQR values indicated that multiple recording days are needed to provide reliable estimates both for more active persons where one day recording may underestimate weekly PA, and for less active persons where one day may overestimate their weekly PA. Our results show that one can expect IQR values of almost 1 hour when using a single day as compared to seven days. Therefore, single day recordings are not resulting in reliable estimates of a person's weekly PA following hip fracture. The findings are in line with previous studies on other community-dwelling elderly (Nicolai et al., 2010), and in geriatric patients (de Bruin, Najafi, Murer, Uebelhart, & Aminian, 2007). Our results demonstrate how increasing number of recording days leads to a more precise estimate of PA, and that one should aim at collecting data for at least four days to ensure an estimate of weekly upright time that is within a 15-minute error margin of actual weekly activity.

This study has some limitations. We recorded activity over a single week and can therefore not account for possible differences in activity between weeks or seasonal variations in PA. Only half of the participants were independent in outdoor walking, and PA consisted therefore mainly of indoor activities which are less likely to be affected by seasonal variations. Furthermore, 7 of the 47 participants removed the sensor earlier than the seven days of planned recordings. This questions the feasibility of longer periods of recording and should be taken into consideration when planning activity monitoring protocols for older persons. Nevertheless, we did only include participants with seven complete recording days, and evaluation of compliance was not the aim of the study. This study provides important knowledge about how many days of recordings one should choose, as well as knowledge about the precision of different estimates.

In conclusion, PA in older persons three months after hip fracture is low on average, but with large between-participant variability. On average, within-participant variability was relatively low, but with large variability between days for some participants. On a group level even a single recording day provides a reliable estimate of daily PA in terms of upright time. However, to obtain estimates that are reliable (IQR of < 30 minutes) for individual persons, a combination of any four or more consecutive days of recordings should be used.

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Paper IV

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Physical Behavior and Function Early After Hip Fracture Surgery in Patients Receiving Comprehensive Geriatric Care or Orthopedic Care—A Randomized Controlled Trial

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Background. This study is a part of the randomized controlled trial, the Trondheim Hip Fracture Trial, and it compared physical behavior and function during the first postoperative days for hip fracture patients managed with comprehensive geriatric care (CGC) with those managed with orthopedic care (OC).

Methods. Treatment comprised CGC with particular focus on mobilization, or OC. A total of 397 hip fracture patients, age 70 years or older, home dwelling, and able to walk 10 m before the fracture, were included. Primary outcome was measurement of upright time (standing and walking) recorded for 24 hours the fourth day postsurgery by a body-worn accelerometer-based activity monitor. Secondary outcomes were number of upright events on Day 4, need for assistance in ambulation measured by the Cumulated Ambulation score on Days 1–3, and lower limb function measured by the Short Physical Performance Battery on Day 5 postsurgery.

Results. A total of 317 (CGC $n = 175$, OC $n = 142$) participants wore the activity monitor for a 24-hour period. CGC participants had significantly more upright time (mean 57.6 vs 45.1 min, $p = .016$), higher number of upright events ($p = .005$) and better Short Physical Performance Battery scores ($p = .002$), than the OC participants. Cumulated Ambulation score did not differ between groups ($p = .234$).

Conclusions. When treated with CGC, compared with OC, older persons suffering a hip fracture spent more time in upright, had more upright events, and had better lower limb function early after surgery despite no difference in their need for assistance during ambulation.

Key Words: Geriatric assessment—Hip fracture—Physical activity.

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IMMOBILIZATION and bed rest in older persons admitted to hospital is known to lead to decreased activity and functional level (1). In patients immobilized longer than 2 days after hip fracture surgery, functional recovery and discharge from hospital is delayed (2). In contrast, early ambulation after hip fracture surgery has been found to improve short-term postoperative outcomes (3–5). Early mobilization regimes are therefore highly recommended after hip fracture surgery (6–8). However, few studies have objectively assessed how active patients are early after hip fracture surgery.

After hip fracture surgery, most patients need assistance in getting out of a bed and a chair, and for standing and walking. The level of assistance required appears to be important for short-term outcomes such as length of hospitalization, time to discharge, mortality, and medical complications (5). The reason for this may be that patients who require more assistance ambulate less. A recent study showed that older patients spent more time being upright if they were independent in mobility (9). The largest portion of time in upright for in-hospital patients seems to be in the morning hours (0800–1200 h) (10). This is likely because most ambulation occurs in situations where the nursing staff is assisting patients in carrying out self-care activities such as walking to the shower or walking to the dining room (10). The amount of available assistance, staff initiatives, and interdisciplinary efforts on assessment and treatment throughout the day may therefore have an important impact on the amount of daily ambulation a patient is able to achieve and may thus also affect rate of recovery.

Interdisciplinary treatment such as comprehensive geriatric assessment has been shown to be beneficial for acutely sick frail older persons (11,12). Hip fracture patients are often characterized by old age and frailty and are therefore likely to benefit from similar approaches during their hospital management (13,14). Treatment models for older hip fracture patients often include some kind of geriatric intervention (15–17) although these models differ in how, where, and when they are delivered.

Physical behavior, defined as patterns of daily physical activity, includes early mobilization and weight-bearing activities and is proposed as an important element of interdisciplinary treatment approaches (18). Currently, it is unknown whether interdisciplinary assessment and treatment approaches for hip fracture patients early after a fracture can improve physical behavior and thereby affect functional outcomes for a time after the hip fracture.

This study is a part of the Trondheim Hip Fracture Trial (REK 4.2008.335 and ClinicalTrials.gov, NCT00667914) (13,18). In this study, hip fracture patients were randomized in the emergency room to receive presurgery and early postsurgery treatment in either a geriatric or an orthopedic ward at St. Olavs Hospital, Trondheim University Hospital, Norway. In order to understand the role of early mobilization for functional outcomes 4 and 12 months after the fracture, the effect of treatment on mobilization was assessed during the hospital stay. The aim of this study was to assess if daily physical behavior as indicated by time spent in upright positions (standing and walking) the fourth day after surgery differed between hip fracture patients treated in a geriatric ward receiving comprehensive geriatric assessment compared with hip fracture patients receiving conventional treatment in an orthopedic ward. Because previous studies have shown significant benefits of comprehensive geriatric assessment, and hip fracture often occur in otherwise typical geriatric patients, we hypothesized that comprehensive geriatric care (CGC) also would result in increased time spent in upright position compared with orthopedic care (OC). We also aimed to assess differences in number of upright events during the day and physical function in terms of need for help during ambulation and lower limb functions.

METHODS

Study Design

The study is a randomized controlled trial, assessing intermediate outcomes of being treated with CGC or OC.

Participants

Participants included in the Trondheim Hip Fracture Trial were admitted to hospital because of a hip fracture, and they had to be at least 70 years of age, previously living in their own homes, able to walk 10 m, and able to give informed consent. Patient with pathological fractures, multitrauma injuries, or short life expectancy were excluded. Further details about eligibility criteria for participants are described elsewhere (13). Participants were included from April 2008 to December 2010.

Interventions

CGC was performed by an interdisciplinary team of specialized health professionals developing and executing an integrated treatment plan for hip fracture patients. The treatment included interdisciplinary assessment of health, function, disease, and social situation and regular interdisciplinary meetings. The assessment and treatment had a particular focus on comorbidity, pain relief, hydration, oxygenation, nutrition, elimination, delirium, and early mobilization. A systematic approach including use of checklists and predescribed treatment protocols, mobilization regimes, and early discharge planning was used (18). The mobilization plan was carried out in collaboration between the physiotherapist and nursing staff at the department and was based on the following principles: (a) If there were no contraindications, patients were assisted during mobilization as early as the first postoperative day. (b) Progression according to the individual's ability and progress was seen as an essential element. (c) Weight bearing was emphasized. (d) Short-term goals in individual rehabilitation plans were based on participants' prefracture function.

The day after surgery, the physiotherapist and the nurse mobilized the patient together. Based upon observation during this mobilization, prefracture functional status, and type of surgery, a procedure was made for the mobilization and expected progress for each individual patient. This procedure was integrated with care plans (18). The physiotherapists had particular emphasis patients who did not manage to progress as expected. Both physiotherapists and nurses assessed pain by using a Verbal Ration scale (19) at rest and during mobilization to optimize pain treatment. OC participants received conventional care including traditional in-hospital physiotherapy (13).

The comprehensive geriatric assessment was delivered in a geriatric ward somewhat better staffed per patient bed, in terms of nurses/assistance nurses (1.67 vs 1.48), doctors (0.13 vs 0.11/0.08), physiotherapists (0.13 vs 0.09/0.07), and occupational therapists (0.13 vs 0), compared with the OC delivered in the orthopedic ward. Further details of the assessment and treatment of participants and staffing in the two treatment arms are described in two separate articles (13,18).

Demographic Data

Prefracture function was assessed retrospectively using the Nottingham Extended Activities of Daily Living scale (0–66) (20) and the Barthel Index (0–20) (21). Other demographic variables included age, gender, and fracture type (intracapsular or extracapsular). Intracapsular fractures were further classified into groups based on surgery method (arthroplasty or osteosynthesis).

Outcomes

Physical behavior was assessed by commercially available, small, body-worn, single-axis accelerometer-based activity monitors (activPAL, PAL Technologies Ltd., Glasgow, United Kingdom). The activity monitors were attached to the front of the participants' nonaffected lower thigh with a waterproof tape on the third day postsurgery and removed on Day 5, and 24 hours of data, the fourth day postsurgery, were used for deriving activity outcomes.

The outcomes derived from this activity monitor have been validated on a population of older persons with impaired mobility (22), showing perfect accuracy in upright time and upright events. The ActivPAL software gives the number and duration of upright (standing and walking) events. In this study, we used upright time defined as the total time spent in upright (primary outcome) and the number of upright events (secondary outcome) during 24 hours as outcomes for physical behavior.

Other secondary outcomes the Cumulated Ambulation score (CAS) (5) assessed over the first 3 days postsurgery, and the Short Physical Performance Battery (SPPB) (23,24) on Day 5 postsurgery. CAS evaluates the need for assistance during three mobilization tasks (transfer from lay-to-sit-to-lay, transfer from sit-to-stand-to-sit, walking with appropriate walking aid) and was scored by the ward physiotherapists or nurses in the geriatric ward and ward nurses in the orthopedic ward, providing scores (0 = unable to perform despite assistance, 1 = only able with assistance, 2 = able to perform independently) for each of the three tasks and a summary score for each of the first 3 postsurgery days. The total score ranges from 0 to 18, where 18 indicates independence in ambulation during all 3 days. The SPPB assesses lower limb function and consists of a balance task, a chair-stand task repeated five times, and a 4-m gait task. Each task is scored on a scale ranging from 0 to 4, with a summary score ranging from 0 to 12, where 12 is the best score. The SPPB was performed by the same study assessors for the two treatment groups and was assessed immediately after removing the activity monitor in order not to include activity while performing the SPPB in the activity monitoring results.

Sample Size

Sample size calculation was performed for the primary outcome in the Trondheim Hip Fracture Trial, which was lower limb function as measured by SPPB 4 months after hip fracture (13). All available participants were asked to wear activity monitors, and participants with complete 24 hours of activity monitoring at Day 4 after the hip fracture were included in the analyses.

Randomization

Randomization to either CGC or OC was performed with a web-based computer program developed by the Unit of Applied Clinical Research, Norwegian University of Science and Technology. Randomization was performed in the Emergency Department by block randomization with equal block sizes.

Blinding

Blinding was not possible for staff that provided the intervention, study participants, or assessors during the hospital stay. However, the data analysis was performed blinded to group allocation.

Data Analysis and Statistical Methods

Number and duration of upright events were derived from the ActivPAL data using the manufacturer's Excel spreadsheets from software version 6.0.8 (activPAL, PAL Technologies Ltd.) and a custom made MATLAB (MATLAB version 7.1. The MathWorks Inc., Natick, MA, 2005) program to write an Excel spreadsheet (Office Excel version 11.0, Windows XP Professinal, Microsoft, 2003) with outcome values for all participants.

Statistical analyses were performed using SPSS Inc. (SPSS Statistics for Windows, Version 19.0. Chicago: SPSS Inc.). The demographic details for participants who did not complete the activity monitoring (n = 80) were compared with those who did complete the activity monitoring (n = 317), using bivariate statistics (Mann–Whitney U tests, t tests and chi-square). Normality distribution was checked by visual inspection of Q–Q plots. Upright time, upright events, and SPPB were skewly distributed. To obtain normality, transformation by use of the natural logarithm of upright time (after adding five to avoid taking the logarithm of zero) and SPPB (after adding one for the same reason), and the square root of events, as suggested by Tabachnick and Fidell (25), were used. Differences between the two groups were assessed by use of linear regression, and adjustments for gender and fracture type were included in the final analyses.

Ancillary analyses of the differences between the two treatment arms in mean upright time during night (00:00–06:00), day (06:00–12:00), afternoon (12:00–18:00), and evening (18:00–24:00) were analyzed by use of the same transformation methods. Differences in upright time over the day are presented in a figure showing median upright time for each hour over the day (00:00–01:00, 01:00–02:00, etc).

Results

Participant Flow

A total of 397 participants were randomized, of whom 361 wore activity monitors over 24 hours. Data were lost for 44 of the participants wearing an activity monitor. The flow diagram (Figure 1) presents the reasons for missing data. A total of 317 participants had 24 hours of monitoring data the fourth day after the hip fracture surgery and were included in the final analyses. Of these, three participants were discharged from the hospital during the monitoring hours.

The 317 participants completing the 24 hours activity monitoring had significantly higher prefracture scores on the Nottingham Extended Activities of Daily Living scale (median 47 vs 40, $p = .020$) and Barthel Index (median 20 vs 19, $p = .037$) compared with the 80 participants with no or noncomplete activity-monitoring data. A higher number of OC participants ($n = 58$) compared with CGC participants ($n = 22$) did not complete the monitoring. The portion of women and intracapsular fractures in the two groups of dropouts were not statistically different, even if there was a tendency toward more women in the CGC group of dropouts (90.9% vs 72.4%, $p = .077$).

Baseline Data

Participants mean age was 83.1 (range 70–97) years, and their characteristics are presented in Table 1. Although the number of included participants in the two groups was different, there were no significant differences in age (mean 83.1 vs 83.0 y, $p = .933$), gender (71.4 vs 78.2% women, $p = .171$), Nottingham Extended Activities of Daily Living scale (median score 46.0 vs 47.5, $p = .827$), or Barthel Index (median score 20 vs 20, $p = .442$) between groups.

Outcomes and Estimation

After adjustments for gender and fracture type, CGC participants had significantly more time in upright position (mean 57.6 vs 45.1 min, $p = .016$) and higher number of

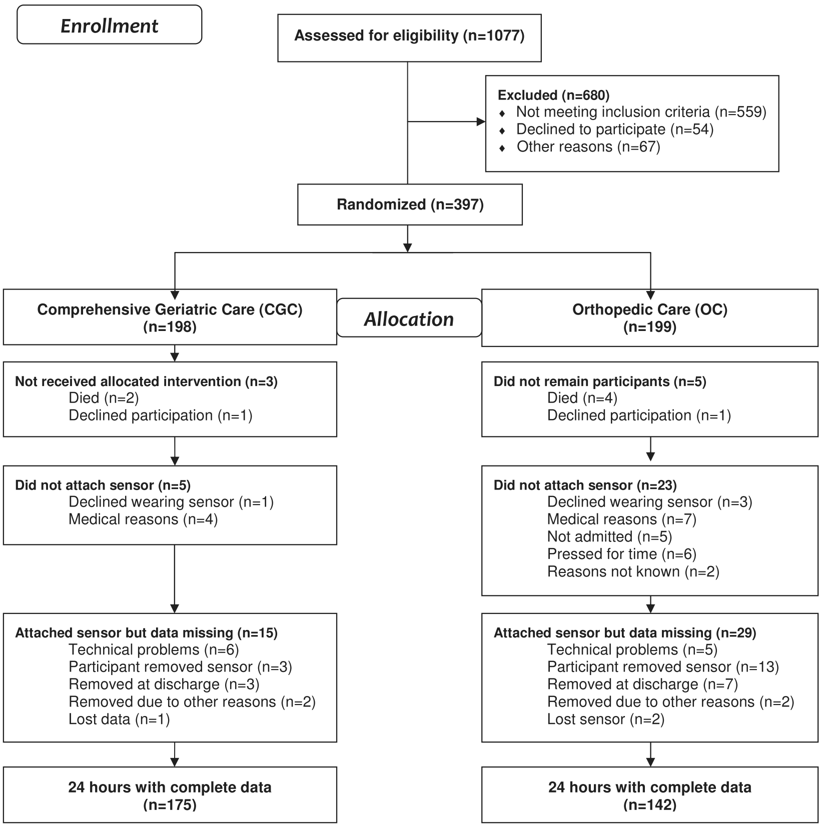

Figure 1. Flow diagram Trondheim Hip Fracture Trial.

Table 1. Participant Characteristics

	Total sample, *n* = 317	Intervention, *n* = 175	Controls, *n* = 142
Mean age, y, (*SD*)	83.1 (6.0)	83.1 (5.8)	83.0 (6.3)
Female gender (%)	74.4	71.4	78.2
Intracapsular fracture (%)	60	58	63
Intracapsular with arthroplasty (%)	65	64	65
Median Barthel Index (IQR)	20 (17–20)	20 (17–20)	20 (18–20)
Median NEADL (IQR)	47 (30.0–58.0)	46 (28.8–58.0)	47.5 (33.3–57.8)

Notes: NEADL = Nottingham Extended Activities of Daily Living scale, IQR = the interquartile range.
Barthel Index was performed for 299 of the 317 participants and NEADL for 314 out of 317.

Table 2. Measures of Physical Behavior and Physical Function Early After Hip Fracture

	Total sample	CGC	OC	Difference
	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	CGC–OC (adjusted *p*-value)
Upright	52.0 (63.7)	57.6 (67.9)	45.1 (57.7)	12.5 (.016)
Events	21.8 (19.9)	24.1 (22.1)	19.0 (16.5)	5.1 (.005)
CAS	9.7 (3.8)	9.9 (3.9)	9.4 (3.8)	0.5 (.234)
SPPB	1.4 (1.8)	1.6 (2.0)	1.0 (1.6)	0.6 (.002)
Upright time during the 24-h period				
Night	3.3 (7.2)	3.1 (6.4)	3.6 (8.1)	0.5 (.704)
Day	18.0 (23.9)	20.0 (24.5)	15.4 (22.9)	4.6 (.007)
Afternoon	17.1 (23.6)	19.3 (25.8)	14.4 (20.4)	4.9 (.007)
Evening	13.6 (17.6)	15.0 (19.6)	11.8 (14.8)	3.2 (.053)

Notes: Upright = time in upright position (min); events = number of upright events; CAS = Cumulated Ambulation score; SPPB = Short Physical Performance Battery score; CGC = comprehensive geriatric care; OC = orthopedic care.
CAS was performed by 299 of the 317 participants and SPPB for 295 out of 317.

upright events (p = .005) than OC participants. Need for help during ambulation measured by CAS during the 3 first postoperative days did not differ significantly between groups (p = .234). All participants performing SPPB on the fifth postoperative day used walking aids. CGC participants has better SPPB scores than OC participants (p = . 002). Details on results are shown in Table 2.

Ancillary Analyses

CGC participants spent significantly more time than OC participants in upright position during the daytime (20.0 vs 15.4 min, p = .007) and in the afternoon (19.3 vs 14.4 min, p = .007). Median upright time for each hour during all 24 hours during the day for both groups are shown in Figure 2. Ninety-nine participants in the CGC and 69 in the OC spent more than 30 minutes in upright on this specific day. The maximum registered length of an upright event was 1 hour and 36 minutes, whereas the median maximum length was 6.7 minutes. Eleven participants (four CGC, seven OC) were not in upright position at all during the day of the activity monitoring, whereas 19 (9 CGC, 10 OC) spent less than 5 minutes, 29 (14 CGC, 15 OC) spent less than 10 minutes, and 90 (49 CGC, 41 OC) participants spent less than 30 minutes in upright.

Adverse Event Management

CGC and OC treatment were offered in parallel, where surgery and follow-up of new incidences including adverse events after discharge were offered for both groups by the orthopedics and the primary health care system as standard routine. Mortality rate in the CGC and OC was, however, monitored specifically by group, without any significant differences between the two wards, and the trial was carried out as planned according to the protocol (13).

Discussion

This study assessed objectively measured physical behavior of hip fracture patients during 24 hours in a trial comparing the potential benefits of CGC performed in a geriatric ward with OC in an orthopedic ward. We found that participants treated with CGC spent more time in upright position and had a higher number of upright events the fourth postoperative day. No differences were found between the two groups when measuring the first 3 days in participants' need for assistance during ambulation by the use of CAS. For lower limb function as measured by the SPPB, the CGC participants had better lower limb function on the fifth day after surgery.

In this article we have highlighted ambulation and weight-bearing activities as important for the early treatment after surgery. It is important to underline that the positive results shown for the CGC group also reflect the total effect of the intervention program (18). Together, this could have ensured a more optimal approach than provided with standard treatment and may have made the patients able to spend more time in upright position. The difference of 12.5

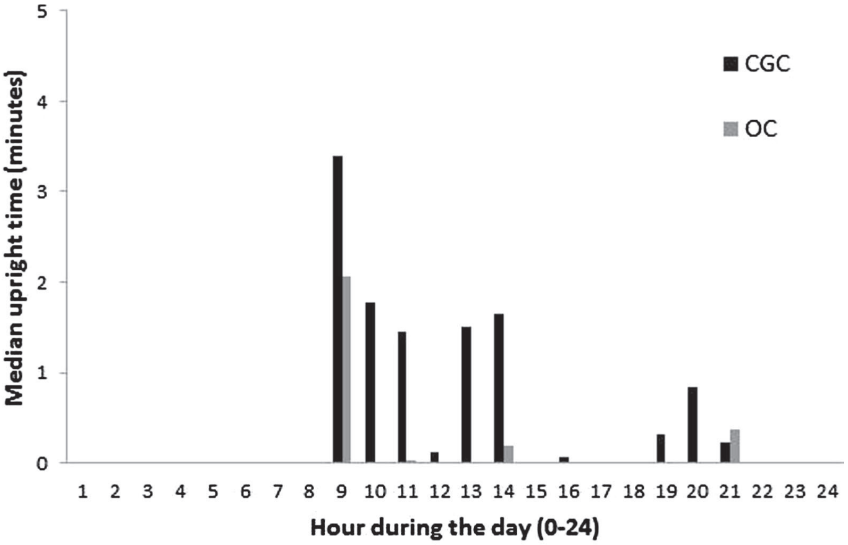

Figure 2. Upright time over 24 h the fourth day postsurgery, showing the median time in upright for each hour of the day for comprehensive geriatric care (CGC) and orthopedic care (OC).

minutes in upright time between groups constitutes 24% of total time in upright for the sample in this study, which might represent an important clinical difference in this very inactive sample. If so, it is suggested that the approach developed and executed for hip fracture patients in a geriatric ward with focus on mobilization can provide results that are beneficial for patients' physical behavior later in the trajectory after hip fracture. However, further studies are needed to conclude on thresholds for clinically meaningful differences of upright time in inactive samples.

CGC participants spent significantly more time in an upright position during daytime and afternoon. The patterns shown in Figure 2 suggest that for OC participants, most of the upright time happened between 8 and 9 AM, when patients performed important morning activities, compared with the CGC participants who also spent time in an upright position during other hours of the day. The difference in physical behavior between groups was likely not because the OC participants needed more help during ambulation as we found no difference in CAS scores between the two groups. It is likely that the interdisciplinary approach and the mobilization included in the care plans increased the number of times and the total time the CGC patients were mobilized. The spread in upright time throughout the day in the CGC participants suggests that the staff at the geriatric ward integrated mobilization with other activities like dining and visits to the toilet.

The participants in this study were old, most of them were women, they spent very little time in an upright position, they had a low number of upright events, and their most upright time occurred during day and afternoon. However, there was a great variation in upright time and upright events between participants, indicating a heterogeneous sample of older hip fracture patients in terms of physical behavior. Our findings were similar to other studies measuring physical behavior in hospital settings, such as a study on 50 upper abdominal surgery patients with mean age of 61 years reporting 34.4 minutes as median time in upright the fourth postoperative day (10). Another study showed that older inpatients with a mean age of 81 years, with different medical diagnoses, had less than 1.5 hours per day in upright time, ranging from 2 minutes to almost 4 hours (26). Physical activity during a typical inpatient stay seems to be low on average and with large between-patients variations. Any hospital treatment especially in older patients should therefore be tailored and delivered focusing on individual needs, such as a CGC program with particular focus on mobilization.

For our older hip fracture patients with impaired function already before the fracture, immobilization, or very low levels of physical behavior after the surgery would represent an extra risk of further functional loss, thereby additionally reducing the chance of independent walking and independency in daily life activities. Although the treatment groups did not differ in their prefracture functional levels, physical behavior after the surgery did differ, indicating that upright time and upright events can be affected and should therefore be more at focus early after hip fracture surgery. Our findings indicate that hospital staff, working with older hip fracture patients in wards can affect the amount of time patients spend in an upright position by focusing more systematically on routines for early mobilization. This is also supported in a previous study evaluating reasons for how nurses decide to ambulate older patients (27), where the authors highlight the complex nature of mobilization as a decisive factor. The patient focus in treatment models for older persons should probably be planned and carried out as a "care with" focus compared with a more passive "care for" focus, as described by Resnick and coworkers (28).

Our results demonstrate how little time the participants spend in an upright position and how few upright events are performed early after hip fracture. Activity monitoring data collected later in the rehabilitation phase can provide information about physical behavior when the medical status is more stable. In the study from Resnick and colleagues (29) participants spent only 70.4 minutes per day in all types of physical activities 2 months after hip fracture. The difference between CGC and OC in our study needs to be evaluated in later phases of the rehabilitation in future studies.

Upright time is a potentially important outcome of physical behavior in this population although it cannot distinguish between intensity of performed activities. Both low- and high-functional capacity groups of older persons spend most time in ambulatory activities at lower intensities (30), and little or no time is spent in high-intensity activities (29,30). The overall activity level is low in hip fracture patients, and total time in an upright position will capture most activities. The activity monitor used in this study did not distinguish between sitting and lying although time in sitting could be an important mobilization goal for some patients, especially because the total time in upright position was very low. Nevertheless, ambulation and time in upright position should be the main focus when aiming at regaining gait function.

A shortcoming with this study was higher number of dropouts in the OC, compared with the CGC group. The different reasons for this are reported in the flowchart (Figure 1). The dropouts had lower scores on prefracture function, indicating that data were not missing at random. The fact that the dropouts had lower scores than the included further strengthens the findings of better results in the CGC compared with the OC group.

The study used wide inclusion criteria, thus strengthening the external validity of the study. Several factors strengthen the findings of differences in upright time between groups: There were no group differences in prefracture function. Furthermore, group differences did not change after controlling for gender and fracture type. Finally, the group differences in favor of the CGC were also confirmed for the other outcomes except for the CAS.

The staffs at both wards were aware of the activity monitoring, and it is thus possible that this might have given an extra motivation to mobilize the patients. However, the staff at both wards received the same information about the activity monitoring, and it is thus likely that the bias is the same in both groups. Assessors performing the SPPB were not part of the staffs at the two wards but were, however, a part of the research group performing the study. To our best knowledge, we do not believe this has affected the test results for the two groups.

The study is part of the Trondheim Hip Fracture Trial that primarily aims to assess the effects of CGC on mobility 4 months after a hip fracture. A limitation for this study is that the aims were not specified in the protocol paper or in the ClinicalTrials.gov document. The results from this study may, however, be important for understanding possible differences in mobility between groups 4 and 12 months after the fracture.

CONCLUSION

Although older persons show great variation in physical behavior after hip fracture, a typical older person spends little time being upright the fourth postoperative day. This study showed that upright time and upright events, as well as lower limb function, can be modified if it is part of a planned and individually delivered comprehensive geriatric care in a geriatric hospital ward with particular focus on mobilization. The implications for regaining of function and physical behavior later in the rehabilitation should be further evaluated.

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CONFLICT OF INTEREST

One of the authors is a co-inventor of the activPAL physical activity monitor and a director of PAL Technologies Ltd.

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