Physical activity behavior among people with disabilities

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PHYSICAL ACTIVITY BEHAVIOR AMONG PEOPLE WITH DISABILITIES

INSIGHT IN PHYSICAL ACTIVITY – THE MULTIDIMENSIONAL CONSTRUCT – BASED ON THE PROSPECTIVE COHORT STUDY 'ReSpAct'

PIM BRANDENBARG

This dissertation is a product of the Rehabilitation, Sports and Active Lifestyle (ReSpAct) study. The ReSpAct study is a collaboration between:
- Department of Human Movement Sciences,
  University Medical Center Groningen, University of Groningen.
- Department of Rehabilitation, University Medical Center Groningen,
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Table of contents

1

General introduction

Physical disability and/or chronic diseases

Worldwide an estimated 1.5 billion people are living with some form of disability; this is 15% of the global population [1]. In the Netherlands, around 12% of the population older than 12 years suffers from a moderate to severe physical disability, with a higher prevalence in the older population [2, 3]. Since the population is aging, with one in six people in the world being aged 60 or over in 2030, it is expected that the number of people with a physical disability and/or chronic disease[1] will continue to rise [4]. Consequently, health care in general, and rehabilitation specifically, will be under continued pressure with the subsequent growing demand in care and cure, while at the same time health care professionals are expected to decrease in number due to 'double aging effect' among health care personnel [5, 6]. Furthermore, it is expected that in 2060 one-third of the working people in the Netherlands are needed in health care to account for the demand [6]. Therefore, primary, secondary or tertiary healthcare prevention of disease or impairment is key to the future of sustainable rehabilitation medicine and health care practices in general [6].

The World Health Organization (WHO) developed the International Classification of Functioning, Disability and Health (ICF) model as a framework and common language to describe and discuss health and disability in a universal model for communication, health care strategies and policy making in health care around the world (figure 1). The framework proposes that health and disability are the result of an ongoing interaction among a person's health condition (e.g. a disorder or

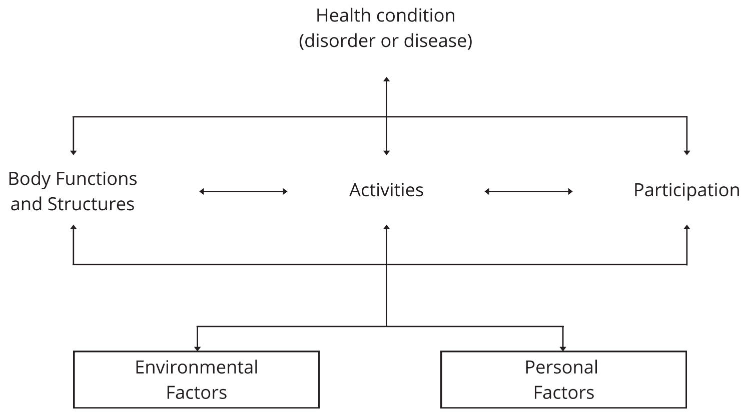

Figure 1. The International Classification of Functioning, Disability and Health (ICF) model [7]

1 Throughout this thesis the terminology 'people with physical disabilities and/or chronic diseases' refers to 'people living with one or more physical disabilities and/or chronic diseases which impact mobility'.

disease), body functions and structures, activities, participation and environmental and personal factors [7]. Physical activity (ICF domain: Activities) can play an important role in these interactions, and thereby amongst others in the healthcare related prevention of health symptoms in the field of rehabilitation and all other health care disciplines.

Physical activity behavior

Physical activity behavior is a complex multidimensional construct. Physical activity is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" [8], and can be characterized by the dimensions of frequency, intensity, duration, mode and setting [9]. Furthermore, the construct encompasses physiological and behavioral aspects. For instance, the intensity of physical activity can be measured physiologically through energy expenditure or metabolic equivalents, and behaviorally through the perceived intensity of the 'intrinsically observed' activity. To measure physical activity behavior, one can use self-report instruments (e.g. questionnaires, diaries) or device-based instruments (e.g. accelero-meter, pedometers). Self-report instruments use subjective information reported by de participant and combine that with standardized MET values based on activity compendia [10], to transform into an estimate of energy expenditure [11-13]. Device-based instruments on the other hand, record bodily movement directly, mostly counting accelerations above a certain threshold in one, two or three orthogonal directions. These raw data is then processed through algorithms (mostly developed and validated in a sample of the general population) into measures such as estimated energy expenditure and number of steps [14, 15]. Self-report and device-based instruments are assumed to capture different aspects of physical activity behavior, and both have their own advantages and disadvantages [15, 16].

The WHO recommends that adults should be physically active for at least 150-300 minutes of moderate intensity or 75-150 minutes of vigorous intensity per week (or an equivalent combination), with the addition of muscle-strengthening activities of at least moderate intensity twice per week and to limit the amount of time spent sedentary [17]. In 2020 the WHO published the first physical activity guidelines specifically for people living with disabilities. These guidelines recommended the same amount of physical activity for this population, but with the added note that even some physical activity is better than doing no physical activity at all [18]. For people with disabilities, being physically active has numerous health benefits on cognitive, mental and physical health, fitness and quality of life [19, 20]. Furthermore, being physically active also reduces or prevents long-term effects of an already established health problem/disease and reduces the impact of an established health problem/disease by restoring function and reducing disease-related complications (i.e. secondary and tertiary prevention) [1]. However, large-scale transdiagnostic longitudinal studies on physical activity behavior among people with physical disabilities and/or chronic diseases are needed to better understand the complex construct of physical activity behavior in this population, and inform the development of targeted interventions to better position physical activity stimulation as a secondary and tertiary health care prevention strategy. Currently these types of studies are lacking [17, 21-23].

Additionally, physical inactivity is considered a global pandemic. One in four adults worldwide is insufficiently active [24], with an even higher prevalence among people with physical disabilities and/or chronic diseases [21]. Without any changes to the prevalence of physical inactivity, it is estimated that between 2020 and 2030, worldwide, a total of 500 million new cases of preventable non-communicable diseases would occur, with an associated INT$ 523.9 billion on health care costs [25]. In the Netherlands alone, physical inactivity is estimated to account for approximately €2.7 billion in healthcare cost (2.3% of the total financial burden of disease) [26]. Furthermore, physical activity has a social return on investment of 2.76, meaning that every euro that is invested in physical activity leads to €2.76 societal benefit [27]. Since there is already considerable strain on the Dutch healthcare system, due to an increasing demand for healthcare (with a growing older population), a growing shortage of available healthcare personnel, and an aim to keep the healthcare cost unchanged [28], it is important to prevent non-communicable diseases. Therefore, stimulating and improving physical activity behavior among the general population as well as among people with physical disabilities and/or chronic diseases is of vital importance to societal wellbeing and health. What counts for the general healthcare system, is equally true for expected developments in the field of rehabilitation practice and medicine [29, 30].

Behavior change

Eliciting long-term behavior change is a very difficult, multifactorial and challenging process [31]. In the scientific literature, there are numerous theories, models and frameworks to understand this complex process of behavior change, such as the Health Action Process Approach [32], the Theory of Planned Behavior [33] and the Transtheoretical model [34]. A theoretical framework specifically designed to describe and understand the relationship between physical activity, its determinants and functioning of people with disabilities, is the Physical Activity for people with a Disability (PAD) model (figure 2). This PAD model integrates the Attitude, Social influence and self-Efficacy model [35] into the ICF-model [36]. Furthermore, the stages of change of the Transtheoretical model, which describe the phases that an individual experiences when changing his or her health behavior, are compatible with the PAD model, by combining intention and the actual physical activity status into the stage of change [36]. In the Transtheoretical model the stages of change are categorized into precontemplation, contemplation, preparation, action, and maintenance [34]. While the Transtheoretical model does not explicitly make this distinction, the five stages of change can be viewed as two broader categories, namely initiating and maintaining physical activity behavior. The first three stages (precontemplation, contemplation and preparation) focus on initiating behavior, while the last two (action and maintenance) focus on maintaining behavior. People who are already physically active may have other needs to maintain being physically active as opposed to people who initiate being physically active [32]. Informed by these behavior change theories and models, multiple studies provide insight in important determinants for physical activity behavior [37-40]. However, these existing studies are mostly cross-sectional [38], while determinants of physical activity (e.g. motivation, self-efficacy) are suggested to change over time. Therefore, to better understand the complex process of physical activity behavior change in people with physical disabilities and/or chronic diseases, it is important to also study changes in determinants over time, and their effect on changes in physical activity behavior. Moreover, existing literature is often diagnosis specific [38], while the process of behavior change may be suggested to be uniform over different physical disabilities and/or chronic diseases [32, 36], and for practical reasons, physical activity stimulating strategies are often offered as diagnosis-overarching interventions [41, 42]. Taking together, this advocates for transdiagnostic, longitudinal studies that are currently lacking.

The timing of eliciting behavior change is an important factor for sustained results. A new diagnosis of a health problem may be a teachable moment for a person for adopting a healthier behavior [44]. Within this context, for people with physical disabilities and/or chronic diseases, the period during and just after rehabilitation appears to be a critical and promising window to promote a physically active lifestyle [45, 46]. As such, the integration of personalized physical activity prescription and coaching into routine patient care, referred to as Exercise is Medicine (a worldwide movement originating in the USA [47]), has received increased emphasis the past decades [48, 49]. An effective strategy to elicit behavior change is personalized counseling supported by techniques such as motivational interviewing [50]. A combination of engagement in physical activity as part of the rehabilitation under the supervision of a rehabilitation professional, and individually tailored counseling during and after rehabilitation was proven effective for increasing physical activity behavior in people with a physical disability and/or chronic disease [51, 52]. However, health benefits of physical activity behavior diminish over time when an active lifestyle is not sustained [53], and gained increases in physical activity behavior are typically lost when the intervention is finished [54]. This shows a need for focus on long-term sustained physical activity behavior, using longitudinal research that spans a sufficiently long time-frame.

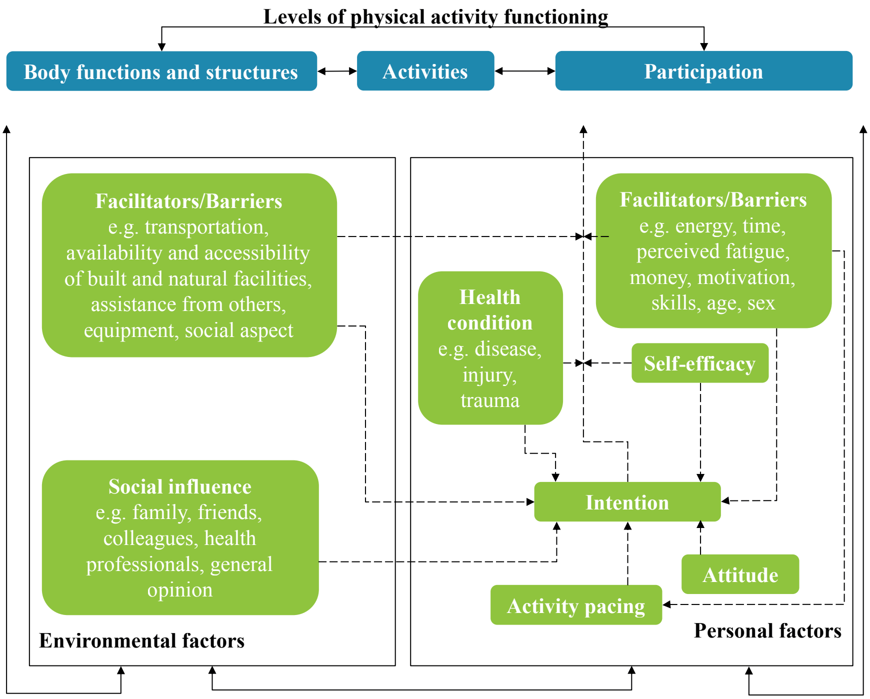

Figure 2. Updated Physical Activity for people with a Disability model (Hegeman-Seves [43]; adapted from Van der Ploeg et al. [36])

Dutch rehabilitation practice

In the Netherlands, rehabilitation practice is a form of secondary and tertiary multidisciplinary care. Rehabilitation medicine is recognized as a distinct medical discipline within the healthcare system and often the leading discipline in rehabilitation practice [55]. Rehabilitation practice adopts a holistic approach to patient care, emphasizing the enhancement of patients' quality of life and well-being, while facilitating optimal societal participation [56-58]. Rehabilitation practice in the Netherlands is highly institutionally organized and is characterized by its strong multidisciplinary approach, involving close collaboration with various other medical disciplines such as neurology, surgery, pulmonary medicine, internal medicine, cardiology, and paramedical disciplines such as physiotherapists, occupational therapists, technicians and psychologists [59]. Apart from specialized rehabilitation centers (n=34; [60]), the country is home to numerous rehabilitation departments within hospitals, together providing inpatient, outpatient, and consultative care [61]. Furthermore, the Dutch rehabilitation practice and medicine place significant emphasis on sports and exercise participation, as well as physical activity in general in daily practice [62].

Rehabilitation, Sports and Exercise (RSE)

Based on the research from Van der Ploeg et al. [63], the Rehabilitation, Sports and Exercise (RSE; in Dutch: "Revalidatie, Sport en Bewegen") program was developed and implemented nationwide in the Dutch routine rehabilitation care [64, 65]. The RSE program is a person-centered physical activity promotion program informed by the PAD model. RSE is provided during rehabilitation and in the immediate period after discharge from rehabilitation. Through counseling sessions, RSE aims to stimulate an active lifestyle during the rehabilitation period and guides participants in the transition from discharge from rehabilitation to their home setting in obtaining and/or maintaining physical activity. Just before discharge from rehabilitation, participants are referred to a sports counselor, for face-to-face counseling, followed by four telephone-based counseling sessions up to thirteen weeks after discharge from rehabilitation (figure 3). The counseling sessions are based on the motivational interviewing technique [50]. Due to the individual tailored nature of the program, it is deemed to be applicable to a heterogenous population of people with physical disabilities and/or chronic diseases.

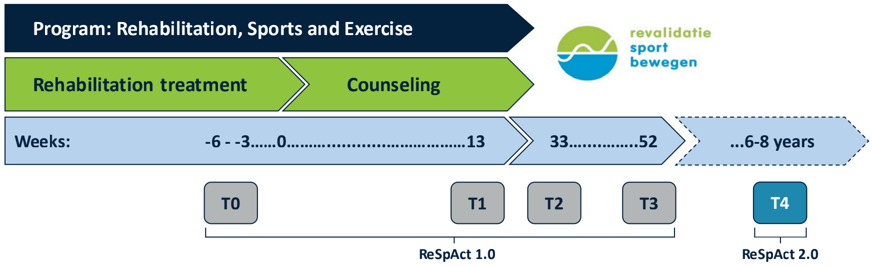

Figure 3. Schematic timeline of RSE and ReSpAct. RSE = Rehabilitation, Sports and Exercise, which includes the rehabilitation treatment and counseling sessions. ReSpAct = Rehabilitation, Sports and Active lifestyle, which is the prospective cohort study. At T0, the face-to-face counseling session is held. Between T0 and T1 the four telephone-based counseling sessions are held. T0 to T4 are the measurement moments of the ReSpAct 1.0 and 2.0 studies.

ReSpAct

Alongside the implementation of the RSE program in the Dutch rehabilitation care, the Rehabilitation, Sports and Active lifestyle (ReSpAct 1.0 and 2.0) study was set up. The ReSpAct 1.0 study was performed from 2013 to 2017, and evaluated the implementation and effects of the RSE program over time in 18 rehabilitation institutes (12 rehabilitation centers and 6 rehabilitation departments of hospitals) in the Netherlands. Results of the implementation evaluation show the successful adoption, implementation and continuation of the RSE program in the 18 rehabilitation institutes, by using a multifaceted implementation strategy [65]. The effects of RSE were evaluated using a prospective cohort study with physical activity behavior as main outcome measure [64] using the Adapted Squash questionnaire [66]. Participants were included from May 2013 until August 2015 on a voluntary basis, and monitored over time using a standardized set of questionnaires at four measurement moments: 3-6 weeks before discharge of rehabilitation (T0), and 14 (T1), 33 (T2) and 52 (T3) weeks after discharge from rehabilitation [64] (figure 3).

As a follow-up of ReSpAct 1.0, ReSpAct 2.0 was initiated in 2018. A part of ReSpAct 2.0 focused on the role of perceived fatigue and activity pacing behavior for sustained physical activity and health among people with physical disabilities and/or chronic diseases, with a specific focus on stroke survivors [43]. This research showed that high levels of experienced fatigue are associated with low levels of physical activity and health-related quality of life. Furthermore, this research indicated the potential of activity pacing in managing fatigue, and in increasing physical activity behavior and health-related quality of life [43]. The other part of ReSpAct 2.0 aimed to investigate long-term physical activity behavior. Participants of the ReSpAct 1.0 study were asked to complete an additional wave of the standardized questionnaires 6-8 years after discharge from rehabilitation (T4).

Construct of physical activity behavior

Collecting these additional data has led to a unique large cohort with a diagnosis-overarching study population with data on the short-term, mid-term and long-term after discharge from rehabilitation. This allows us to prospectively study the construct of physical activity behavior among a heterogeneous cohort of people with physical disabilities and/or chronic diseases who were observed from the end of their clinical or ambulant rehabilitation trajectory up to 8 years later. Using data from the ReSpAct study, collected using self-reported questionnaires, we describe and analyze physical activity behavior over time and its determinants, as subjective part of the construct 'physical activity behavior', and the literature of device-based measurement tools of often called 'objective physical activity behavior'.

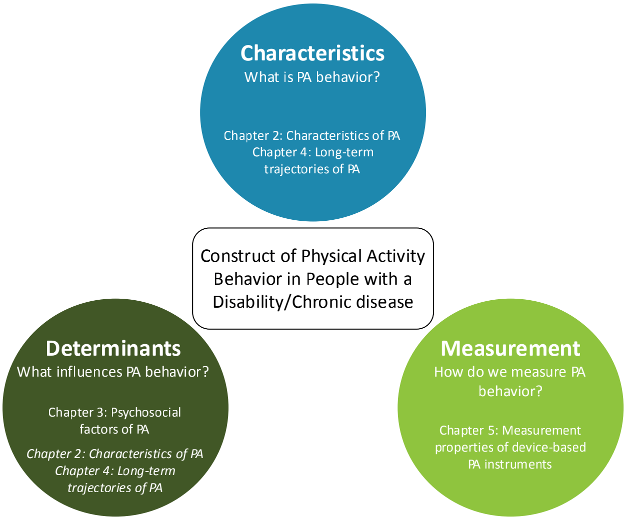

Figure 4. Overview of thesis. PA = physical activity

Aims and outline of this thesis

The current thesis aims to provide a comprehensive exploration of the construct physical activity behavior among people with physical disabilities and/or chronic diseases. The exploration focused on three distinct themes, all in relation to the described population, namely 1) characteristics of physical activity behavior; 2) determinants of physical activity behavior; and 3) measurement of physical activity behavior. Figure 4 shows an overview of this thesis, visualizing the three themes with the different chapters of this thesis.

Chapters 2 and **3** describe respectively the characteristics and determinants of physical activity from 3-6 weeks before discharge of rehabilitation up to one year post-rehabilitation by using data from the ReSpAct 1.0 study. **Chapter 2** explores the different dose characteristics of physical activity behavior, the development of physical activity behavior over time and the influence of personal and disease characteristics on physical activity behavior and its development over time. **Chapter 3** describes the associations between psychosocial factors and physical activity behavior over time. Furthermore, we explore if these possible associations differ between people who initiate a physically active lifestyle and people who are already engaging in physical activity and try to maintain this behavior.

Chapter 4 explores the heterogeneous development of physical activity behavior on the long term from 3-6 weeks before discharge up to 6-8 years post-rehabilitation. Using data from both ReSpAct 1.0 and the long-term follow-up collected in ReSpAct 2.0, we identify different trajectories of physical activity behavior. Additionally, we analyze the associations between modifiable determinants measured during rehabilitation and membership of physical activity trajectories.

Chapter 5 explores the theme of measurement of physical activity behavior. In particular, a critical mapping is provided of the existing literature on the measurement properties of device-based instruments that measure physical activity behavior among people with physical disabilities and/or chronic diseases.

Finally, **chapter 6** provides a summary of the main findings of this thesis, a critical discussion of these findings, and recommendations for clinical practice and future research, resulting in an overall conclusion.

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2

Physical activity behavior up to 1 year post-rehabilitation among adults with physical disabilities and/or chronic diseases: results of the prospective cohort study ReSpAct

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Abstract

Background: Little is known of physical activity behavior among adults with a disability and/or chronic disease during and up to one year post rehabilitation. We aimed to explore 1) dose characteristics of physical activity behavior among adults with physical disabilities and/or chronic diseases during that period, and 2) the effects of personal characteristics and diagnosis on the development of physical activity over time.

Methods: Adults with physical disabilities and/or chronic diseases (N=1256), enrolled in the Rehabilitation, Sports and Active lifestyle (ReSpAct) study, were followed with questionnaires: 3-6 weeks before (T0) and 14 (T1), 33 (T2) and 52 (T3) weeks after discharge from rehabilitation. Physical activity was assessed with the Adapted-SQUASH. Dose characteristics of physical activity were descriptively analyzed. Multilevel regression models were performed to assess physical activity over time and the effect of personal and diagnosis characteristics on PA over time.

Results: Median total physical activity ranged from 1545 (IQR: 853 – 2453) at T0 to 1710 (IQR: 960 – 2730) at T3 min/week. Household (495 to 600 min/week) and light-intensity (900 to 998 min/week) activities accrued the most minutes. Analyses showed a significant increase in total physical activity moderate- to vigorous-intensity physical activity and work/commuting physical activity for all time points (T1-T3) compared to baseline (T0). Diagnosis, age, sex and body mass index had a significant effect on baseline total physical activity.

Conclusion: Physical activity is highly diverse among adults with physical disabilities and/or chronic diseases. Understanding this diversity in physical activity can help improving physical activity promotion activities.

Keywords: Epidemiology, Rehabilitation medicine, Sports medicine, Public health

Strengths and limitations of this study

- This is a largescale prospective cohort study that gives a detailed overview of the different dose characteristics of physical activity behavior in adults with physical disabilities and/or chronic diseases.
- We measured physical activity with a self-reported questionnaire specifically designed for adults with disabilities giving detailed information on the different dose characteristics.
- We included a large heterogeneous group of adults with physical disabilities and/or chronic diseases, which makes it more applicable to the general rehabilitation setting and population.
- Potential sample selection bias may be present, since participants could only participate in the ReSpAct cohort study if they received physical activity counselling support during their rehabilitation treatment

Introduction

Regular physical activity (PA) has many benefits on cognitive, mental and physical health, fitness, and quality of life, both for the general population as well as for adults with physical disabilities and/or chronic diseases [1-4]. Besides the direct health benefits for adults with physical disabilities/chronic diseases, being more physically active is also considered a secondary (reducing or preventing long term effects of an established health problem/disease) and tertiary (reduce impact of an established health problem/disease by restoring function and reduce disease related complications) prevention mechanism.[5, 6] Despite these benefits, PA behavior is suggested to be low among adults with physical disabilities/chronic diseases [7-9].

The recently updated World Health Organization (WHO) guidelines for PA recommend that all adults, including those with physical disabilities and/or chronic diseases, should be physically active for at least 150-300 minutes of moderate-intensity or 75-150 minutes of vigorous-intensity per week or an equivalent combination, with the addition of muscle-strengthening activities of at least moderate-intensity twice per week [10, 11]. While these recommendations are formulated for adults with physical disabilities/chronic diseases, the development of the guidelines is mainly informed by evidence from studies in the general population [11]. As highlighted by the WHO PA Guidelines Development Group and the accompanying research agenda there is a clear need for more research on PA among adults with physical disabilities/chronic diseases [12, 13].

Despite various calls for more research on PA in people with disabilities [14-16], measuring and understanding dose-response relationships of the construct of PA in the context of a heterogeneous population with disabilities is not straightforward.

PA is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" [17]. It is by definition a multidimensional construct, with setting (e.g. PA during leisure time, work), mode (e.g. walking, bicycling), frequency (e.g. times per week), duration (e.g. in hours) and intensity (e.g. low, moderate or vigorous) as its crucial constituents [18, 19]. These dimensions could also be called the dose characteristics of PA, and are important to understand PA among different subgroups, as well as to study the dose-response relations of PA and health during and after rehabilitation. Furthermore, it could be an important aspect in tailored PA counseling, as more information on dose characteristics can lead to more focused PA recommendations. Only a few studies described details on multiple dose characteristics of PA in adults with physical disabilities/chronic diseases [20-22]. These studies either mainly concern validation of instruments that measure multiple dose characteristics, and not focused on describing the dose characteristics itself [20, 22] or are of a cross sectional nature in small diagnosis specific populations [21]. Consequently, there is a need for largescale prospective studies that take this multidimensionality of PA within and among adults with a diversity of disabilities/chronic diseases into account.

An important step to enhance our understanding of PA is to explore the effect of personal characteristics on the multidimensional construct PA behavior. Adults with physical disabilities/chronic diseases are a heterogeneous group, both in PA behavior [9] and personal and disease characteristics [23]. Personal characteristics, such as age and sex, are determinants for PA in the general population and specific diagnosis groups [24-27], yet it is largely unknown how these characteristics influence the development of PA over time during and after a PA promoting rehabilitation program. As such, it is important to understand which dimensions of PA behavior contribute to the dose of PA and how this is perceived in the context of personal characteristics or diagnoses. Such insights will help to understand PA behavior over time, and will enable to individualize PA stimulation programs.

The multicenter prospective cohort study "Rehabilitation, Sports and Active Lifestyle" (ReSpAct) offers a great opportunity to start addressing these knowledge gaps [28, 29]. This study was built around the implementation of a PA behavioral intervention in Dutch rehabilitation care [28, 29]. Uniquely, the ReSpAct study includes data on self-reported PA behavior and potential determinants in a large, diverse population of adults with physical disabilities/chronic diseases at four occasions: 3-6 weeks before discharge up to 1 year after discharge of rehabilitation [28, 29].

Using data from the ReSpAct study, the primary aim of this study was to explore the different dose characteristics of PA behavior (duration, setting, intensity, mode and frequency) among a diverse group of adults with a physical disability and/or chronic disease at discharge from rehabilitation up to one year post rehabilitation.

The secondary aims were to explore the development of PA behavior over time, and to analyze the effects of personal characteristics and diagnosis on PA behavior and its development over time.

Methods

Study overview

This study is part of prospective cohort study ReSpAct to evaluate the nationwide implemented Dutch rehabilitation program Rehabilitation, Sport and Exercise (RSE, Dutch: "Revalidatie, Sport en Bewegen") [28, 29]. RSE is an evidence-based PA counseling program involving multiple counseling sessions based on motivational interviewing during and after rehabilitation to stimulate a physically active lifestyle in adults with physical disabilities/chronic diseases [28-31]. Participants, recruited between May 2013 and August 2015, were followed over time with a set of questionnaires: at baseline (T0: 3-6 weeks before discharge), and at 14 (T1), 33 (T2) and 52 (T3) weeks after discharge from rehabilitation.[28] The study was approved by the Ethical Committee of the Center for Human Movement Sciences of the University Medical Center Groningen (reference: ECB/2013.02.28_1). All participants voluntarily participated after signing an informed consent.

Patient and public involvement

Representatives of the Dutch community organizations Knowledge Centre for Sport Netherlands and Stichting Special Heroes (former: Stichting Onbeperkt Sportief) were involved as collaborators and consultants in the design and conduct of the ReSpAct study [28, 29]. Rehabilitation professionals (counsellors, project leaders, physicians, managers) from the participating rehabilitation centres and hospitals were involved as consultants in the design and conduct of the ReSpAct study. We did not involve people with disabilities/chronic diseases as consultants/ advisors/collaborators in the study. The current paper reports results from the primary outcome measure of the ReSpAct study (physical activity).

Study population

Inclusion criteria for this study were: 1) aged 18 years or older; 2) having a physical disability and/or chronic disease; 3) receiving inpatient, outpatient or consultancy rehabilitation treatment at one of the participating rehabilitation departments or institutes; 4) participating in the RSE program; 5) data available on diagnosis; and 6) valid data available of the adapted version of the Short Questionnaire to ASsess Health enhancing physical activity (Adapted-SQUASH) at baseline and at least one follow-up measurement.

Participants were excluded if they 1) were unable to complete questionnaires, even with help; 2) participated in a PA program other than RSE.

PA behavior

Self-reported PA behavior was measured using the Adapted-SQUASH, a 19-item recall questionnaire to assess PA among adults with disabilities based on an average week of the past month [32]. Participants had to fill out the number of days (frequency), average hours and minutes per day (duration) and the perceived intensity (intensity: light, moderate, vigorous) of different types of activities (mode: e.g. walking, cycling, wheeling, gardening) that were pre-structured in different settings: activities during commuting, activities at work and school, household activities and leisure time activities. The Adapted-SQUASH has a good reliability (ICC = .67 and .76, for total activity score and total minutes of activity per week respectively), and a validity comparable to other PA questionnaires when using accelerometer derived PA (ρ = .40 for total activity score and ICC = .22 for total minutes of activity per week) [32].

Raw Adapted-SQUASH data were processed with a custom created syntax (SPSS statistics 26, IBM). Minutes of activity per week were calculated by multiplying frequency by duration. Intensity of activity was calculated by combining the perceived intensity of each activity with a corresponding metabolic equivalent of task (MET) value based on the Ainsworth compendium of physical activities [33] and a compendium of energy costs of the physical activities for wheelchair dependent individuals [34] into light (<4 MET for people 18-65 years old, <3 MET for people older than 65), moderate (4-6.5 for people 18-65 years old, MET 3-6 MET for people older than 65) or vigorous intensity (>6.5 for people 18-65 years old, >6 MET for people older than 65) [32, 35]. Primary outcomes were total minutes PA per week, minutes PA per setting, minutes PA per intensity, and the frequency of PA modes.

Adapted-SQUASH data of a measurement occasion was deemed valid when no more than one of the pre-structured settings was missing and the total minutes PA per week was not higher than 6720 minutes (on average 16 hours/day).

Personal characteristics

Personal characteristics included age, sex, body mass index (BMI), marital status, current smoking habit, current alcohol usage, education level and work status. Current smoking habit was dichotomized into smoker and non-smoker. Current alcohol usage was categorized in no, light (1-3 or 1-2 drinks per week for males and females respectively), moderate (4-20 or 3-13 drinks per week for males and females respectively) and excessive ($\geq$ 21 or $\geq$ 14 drinks per week for males and females respectively) [8]. Education level was dichotomized into high (applied university and higher) and low, to make it internationally comparable. Work status was categorized into school, employed, unemployed, retired, unable to work and other (e.g. voluntary work). Personal characteristics were self-reported by participants, with the exception of age and sex, which were reported by the RSE counselor.

Rehabilitation characteristics

Rehabilitation characteristics included diagnosis, rehabilitation context (hospital or rehabilitation center), rehabilitation form (inpatient-, outpatient, or consultancy rehabilitation) and number of received counseling sessions from the RSE program (0 sessions, 1-3 sessions, 4 or more sessions).

Different diagnoses were grouped according to diagnosis groups of the Dutch Diagnose-Treatment Combinations, a structure for the financial aspects of a hospital visit, which has roots in the ICD-10 structure: amputation (both upper and lower extremities), brain disease (e.g. stroke, congenital brain diseases), chronic pain, musculo-skeletal disease (e.g. rheumatic conditions, conditions of upper-, lower extremities and spine), neurologic disease (e.g. Parkinson's disease, multiple sclerosis), organ disease (e.g. heart disease, chronic obstructive pulmonary disease), spinal cord injury (SCI) and other (e.g. chronic fatigue syndrome, medically unexplained symptoms). [36] Rehabilitation characteristics were reported by the RSE counselor.

Statistical analysis

Descriptive information of the population and the dose characteristics of PA behavior are shown in mean ± SD or median (IQR) for continuous variables, and percentages for categorical variables. Differences of baseline characteristics between included and excluded participants were tested with independent t-test for continuous variables and Pearson chi^2-test for categorical variables.

To evaluate the development of PA behavior over time, we created six separate multilevel regression models with total minutes of PA per week (model 1), minutes of PA per week per setting (models 2-5) and minutes of moderate to vigorous PA (MVPA) per week (model 6) as dependent variables, and measurement occasions (categorical) as independent variable. Each model consisted of measurement occasion at level 1, participants at level 2 (random intercepts) and rehabilitation institutes as level 3 (random intercepts). Since we expected variation among participants in their PA behavior over time, we added random slopes for measurement occasion on the level of participants. However, this resulted in non-converging (i.e. unreliable) models, and subsequently removed from the models.

To explore the effects of personal characteristics and diagnosis on the development of PA behavior over time, multilevel regressions models were created with measurement occasion, characteristic and an interaction term between measurement occasion and characteristic for each of the six dependent variables and for each characteristic separately. Evaluated characteristics were diagnosis (largest diagnosis in our data, i.e. brain disease, as reference), age (continuous, in years), sex (male as reference), BMI (continuous, in kg/m^2), smoking (non-smoker as reference), alcohol use (no alcohol use as reference) and education level (low as reference) [24-27]. Type III ANOVA tests were used to assess significance of the overall interaction between measurement occasion and the characteristics. Since multilevel regression analyses are robust against missing data, this was not addressed [37]. All analyses were done with R and RStudio [38]. The lmerTest package was used for multilevel regressions analysis [39]. Significance level was set at 0.05.

Results

Study population

Table 1 shows descriptors of included and excluded participants per measurement occasion. Of the 1719 participants in the ReSpAct cohort, 1256 participants were included in this study. The largest diagnosis groups were: brain disease (27.1%, n=341), musculoskeletal disorders (18.6%, n=234), chronic pain (15.8%, n=198) and neurologic disease (15.0%, n=188). Excluded participants were younger ($p<.001$), more often a smoker ($p=.04$), and received less counseling sessions ($p<.001$).

PA dose characteristics

Table 2 shows the PA dose characteristics (duration, setting, intensity, mode and frequency) at the four different measurement occasions.

Duration

Total duration of PA (min/week) varied over time and among participants, showing its lowest median value at discharge from rehabilitation (T0: 1545); followed by increased levels of 1770, 1830 and 1710 min/week at respectively T1, T2 and T3 (table 2).

Setting

Participants spent most PA time in household tasks (median range T0-T3: 495 to 600 min/week), followed by leisure time (median range T0-T3: 450 to 510 min/week). A large proportion of participants reported 0 min/week PA in work (range T0-T3: 52.6%-59.9%; largest IQR 0 – 1080 min/week) and commuting (range T0-T3: 70.4%-72.5%; largest IQR commuting 0 – 40 min/week) settings.

Table 1. Descriptive statistics of included participants at each measurement occasion (T0-T3) and excluded participants at T0.

	Included				Excluded
	T0	T1	T2	T3	
N	1256	1114	966	860	463
Age (years)	50.7 ± 13.4	51.1 ± 13.4	51.5 ± 13.0	51.6 ± 13.2	47.5 ± 14.3**
Sex (% male)	47.3	47.9	47.6	49.2	42.1
BMI (kg/m^2)	27.5 ± 8.6	27.5 ± 8.8	27.4 ± 9.1	27.4 ± 9.3	27.0 ± 5.9
Diagnosis					
% Brain disease	27.1	26.8	26.5	27.4	24.4
% Musculoskeletal disease	18.6	18.0	17.6	17.3	18.1
% Chronic pain	15.8	15.8	14.9	14.9	18.1
% Neurologic disease	15.0	15.5	16.1	16.9	12.5
% Organ disease	12.1	12.7	12.7	12.4	9.9
% Amputation	4.5	4.7	4.9	4.7	4.3
% Spinal cord injury	3.0	2.7	2.8	2.8	4.3
% Other diseases	3.8	3.8	4.5	3.6	3.2
Smoking					*
% Yes	16.3	16.6	15.4	15.3	13.0
% No	71.3	73.5	74.9	75.2	39.7
Alcohol use					
% No	58.0	57.9	59.0	58.7	34.6
% Light	10.4	10.5	11.0	10.9	5.4
% Moderate	24.0	25.0	24.0	24.1	11.2
% Excessive	2.2	2.4	2.3	2.0	0.6
Marital status					
% Single	26.8	27.7	27.7	27.7	21.4
% Married/living with partner	62.9	63.9	63.9	63.9	39.3
Education level					
% Low	67.0	67.8	68.2	69.5	47.5
% High	22.5	23.7	23.5	22.7	12.7
Work status					
% School	1.8	1.8	1.1	1.7	1.9
% Employed	31.2	32.3	31.9	32.1	20.1
% Unemployed	11.6	11.9	11.4	11.7	9.3
% Retired	15.4	16.4	16.0	16.9	7.6
% unable to work	21.7	21.8	22.3	21.5	14.9
% Other	7.7	7.5	9.0	8.1	6.3
Rehabilitation context					
% Rehabilitation center	71.6	71.6	72.3	72.8	75.4
% Hospital	28.4	28.4	27.7	27.2	24.6

Table 1. Continued.

	Included				Excluded
	T0	T1	T2	T3	
Rehabilitation form					
% Inpatient	2.8	2.6	2.3	2.3	3.7
% Outpatient	89.8	90.3	89.8	90.5	90.1
% Consultancy	7.4	7.1	8.0	7.2	6.3
Number of counseling moments					**
% 0	11.4	11.0	10.8	10.0	21.0
% 1-3	56.4	55.8	56.3	57.0	55.3
% 4 or more	32.2	33.1	32.9	33.0	23.8

Data presented as mean ± SD or %
Note: For some participants information was missing, leading to not all percentages adding up to a 100%. There was more missing data in the excluded group of participants compared to the included group of participants.
* and ** Significant difference between the included and excluded participants based on independent sample t-tests for continuous variables and based on Chi-square tests for categorical variables without unknown category between baseline participants and those excluded. (*p<0.05; **p<0.001).

Intensity

Participants spent between T0 and T4 a median of 900 – 997.5 min/week in light-intensity PA, 120 – 150 min/week in moderate-intensity and 100 – 120 min/week in vigorous-intensity. In household tasks, most minutes were spent in light intensity (median range T0-T4: 480-540 min/week) and little to none in moderate and vigorous-intensity (range T0-T4: 82.0%-87.6% 0 min/week and 100%-100% 0 min/week, respectively). Leisure time activities were predominantly in MVPA (median range T0-T4: 40-60 min/week light; 60-90 min/week moderate; and 90-120 min/week vigorous). Intensity of work activities were of light (range T0-T4: median 0-0, IQR 0-165 to 0-420) or moderate-intensity (range T0-T4: median 0-0, IQR 0-0 to 0-60) and not of vigorous-intensity (100% 0 min/week at all measurement occasions). Commuting activities were mostly spent in vigorous (range T0-T4: 16.1%-17.0% >0 min/week), followed by light (range T0-T4: 11.2%-12.3% >0 min/week) and moderate-intensity (range T0-T4: 4.5%-6.6% >0 min/week).

Mode and frequency

Walking is the most frequent mode of leisure time activities at all measurement occasions, with an average frequency ranging from 3.3 ± 2.7 to 3.6 ± 2.7 times/week. Bicycling is the second most frequent mode, with an average frequency ranging from 1.6 ± 2.1 to 1.8 ± 2.2 times/week. Gardening, odd jobs and fitness are frequented around 0.6 times/week (Table 2).

Table 2. Physical activity behavior of adults with physical disabilities/chronic diseases per measurement occasion as measured with the Adapted-SQUASH[32].

	T0	T1	T2	T3
Total PA				
N	1256	1114	966	860
Total (min/week)	1545 (852.5 - 2453)	1770 (990 - 2780)	1830 (981 - 2730)	1710 (960 - 2730)
Light (min/week)	900 (360 - 1680)	997.5 (420 - 1920)	960 (409 - 1980)	900 (360 - 1800)
Moderate (min/week)	120 (0 - 480)	180 (15 - 596)	180 (0 - 690)	150 (0 - 630)
Vigorous (min/week)	100 (0 - 246.25)	120 (0 - 300)	120 (0 - 300)	120 (0 - 289)
Adherence to the aerobic WHO PA guidelines (%)	68.3	74.9	71.3	71.2
Leisure time				
N	1252	1098	955	843
Total (min/week)	450 (230 - 795)	510 (270 - 853)	480 (240 - 840)	465 (240 - 840)
% 0 min/week	3.6	2.4	4.1	4.4
Light (min/week)	60 (0 - 323)	60 (0 - 330)	60 (0 - 300)	40 (0 - 270)
% 0 min/week	43.6	44.4	44.6	46.9
Moderate (min/week)	75 (0 - 255)	90 (0 - 300)	60 (0 - 300)	70 (0 - 273)
% 0 min/week	37.6	32.1	36.8	38.0
Vigorous (min/week)	90 (0 - 213)	120 (0 - 268)	100 (0 - 240)	100 (0 - 240)
% 0 min/week	30.8	27.2	31.0	30.8
*Frequency of leisure time activities per week**				
Walking	3.6 ± 2.7	3.5 ± 2.6	3.3 ± 2.6	3.3 ± 2.7
Bicycling	1.8 ± 2.2	1.7 ± 2.1	1.6 ± 2.1	1.7 ± 2.1
Wheelchair riding	0.4 ± 1.5	0.4 ± 1.5	0.4 ± 1.5	0.4 ± 1.5
Handcycling	0.0 ± 0.4	0.1 ± 0.5	0.1 ± 0.5	0.1 ± 0.4
Gardening	0.7 ± 1.2	0.6 ± 1.1	0.5 ± 1	0.5 ± 1.1
Odd jobs	0.7 ± 1.4	0.5 ± 1.2	0.5 ± 1.1	0.5 ± 1.1
Fitness	0.6 ± 1.1	0.7 ± 1.1	0.5 ± 1	0.4 ± 0.9
Swimming	0.3 ± 0.7	0.3 ± 0.6	0.2 ± 0.5	0.2 ± 0.5

2

Table 2. Continued.

	T0	T1	T2	T3
Household				
N	1234	1096	953	853
Total (min/week)	540 (180 - 960)	540 (210 - 1020)	600 (240 - 1020)	495 (210 - 930)
% 0 min/week	13.5	10.4	10.3	11.8
Light (min/week)	510 (180 - 960)	540 (210 - 960)	540 (210 - 960)	480 (185 - 900)
% 0 min/week	13.9	11.0	11.1	12.3
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	87.6	83.4	82.0	82.8
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100.0	100.0	100.0	100.0
Work				
N	1186	1093	943	844
Total (min/week)	0 (0 - 600)	0 (0 - 960)	0 (0 - 1080)	0 (0 - 1080)
% 0 min/week	59.9	52.6	52.9	54.5
Light	0 (0 - 165)	0 (0 - 420)	0 (0 - 300)	0 (0 - 240)
% 0 min/week	72.9	67.9	70.2	71.1
Moderate (min/week)	0 (0 - 0)	0 (0 - 60)	0 (0 - 60)	0 (0 - 60)
% 0 min/week	80.8	72.9	71.8	73.5
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100.0	100.0	100.0	100.0
Commuting				
N	1246	1108	959	847
Total (min/week)	0 (0 - 25)	0 (0 - 30)	0 (0 - 30)	0 (0 - 40)
% 0 min/week	72.5	71.3	71.3	70.4
Light (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	88.8	87.7	88.2	88.5
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	95.5	93.4	93.8	94.5
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	83.3	83.9	83.6	83.0

*Frequencies of leisure time activities per week are presented in mean ± SD. Other data is presented in median (interquartile range) or percentage.

PA behavior over time

Figure 1 and appendix 1 show the results of the multilevel regression models for PA behavior over time. Compared to baseline (T0), there is a significant increase (p<.001) in total minutes of PA per week over time for each of the three follow-up measurement occasions (increase: 218.6 [95% CI 142.9 – 294.3], 242.2 [95% CI 162.6 – 321.7] and 153.8 [95% CI 70.9 – 236.6] min/week at respectively T1, T2 and T3). Time spent in the settings work and commuting significantly increased at follow-up occasions (all p<.05). With the exception of one occasion, leisure time (T1, p<.01) and household tasks (T2, p<.05) remained stable compared to baseline values (T0). Time spent in MVPA significantly increased at each measurement occasion compared to T0 (increase: 105.0 [95% CI 57.6 – 152.2], 138.4 [95% CI 88.7 – 188.1] and 112.9 [95% CI 61.1 – 164.6] min/week at respectively T1, T2 and T3, all p<.001).

Effects of personal characteristics and diagnosis

Figure 2 shows total PA per measurement occasion and distribution of PA in the 4 settings separated for the different diagnoses. Appendix 2 provides a detailed description of PA behavior per diagnosis.

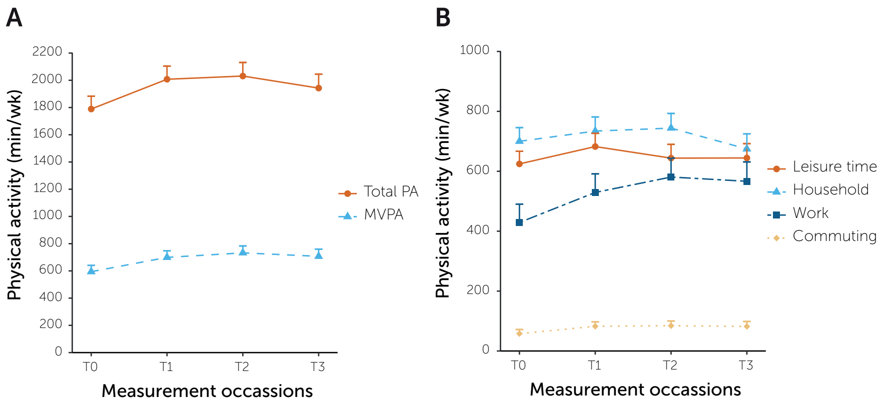

Figure 1. Regression lines of the multilevel regressions models for A) minutes of total physical activity (PA) per week and minutes of moderate to vigorous physical activity (MVPA) and B) for minutes of physical activity per week per setting.

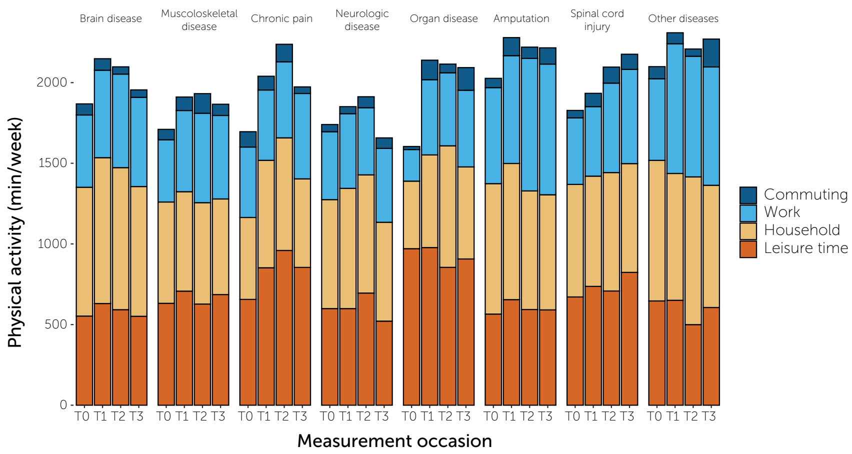

Figure 2. Descriptive data of total physical activity behavior and the distribution in the four settings per measurement occasion of each diagnosis.

Figure 3 shows the effect of each personal characteristic on total PA and MVPA. The multilevel regression model analyses showed that at baseline, a significant effect on total PA was found for diagnosis (musculoskeletal disease, β = 307.5 [95% CI 92.7 – 522.2], and other diseases, β = 392.7 [95% CI 5.0 – 780.3] more active than brain disease), age (higher age less active, β = -12.7 [95% CI -18.0 – -7.4]), sex (females more active than males, β = 273.9 [95% CI 130.9 – 417.0]) and BMI (higher BMI less active, β = -8.8 [95% CI -17.6 – -0.03]) (see also appendix 3). No interaction effects between these characteristics and measurement occasion were found, i.e. the effect of these characteristics on PA remained constant over time. There was one significant interaction effect for education on PA over time, with people with high education increasing their levels of PA more over time than people with low education ($p<.05$).

Appendix 3 provides a detailed description of the effects of the diagnosis and personal characteristics on baseline levels and the development over time of PA in each setting and MVPA. In short, diagnosis had a significant baseline effect for MVPA and all settings of PA, except for commuting, where we found an interaction effect of diagnosis. People with a higher age were less active in work, household and commuting, but more active in leisure time and MVPA. In the work setting, an older age led to increase in PA over time. Females were more active in household tasks, but less active in MVPA and in both household and MVPA females had less increase in PA over time. Smokers had less increase in MVPA over time than non-smokers. Alcohol use had baseline effects on leisure time (moderate alcohol

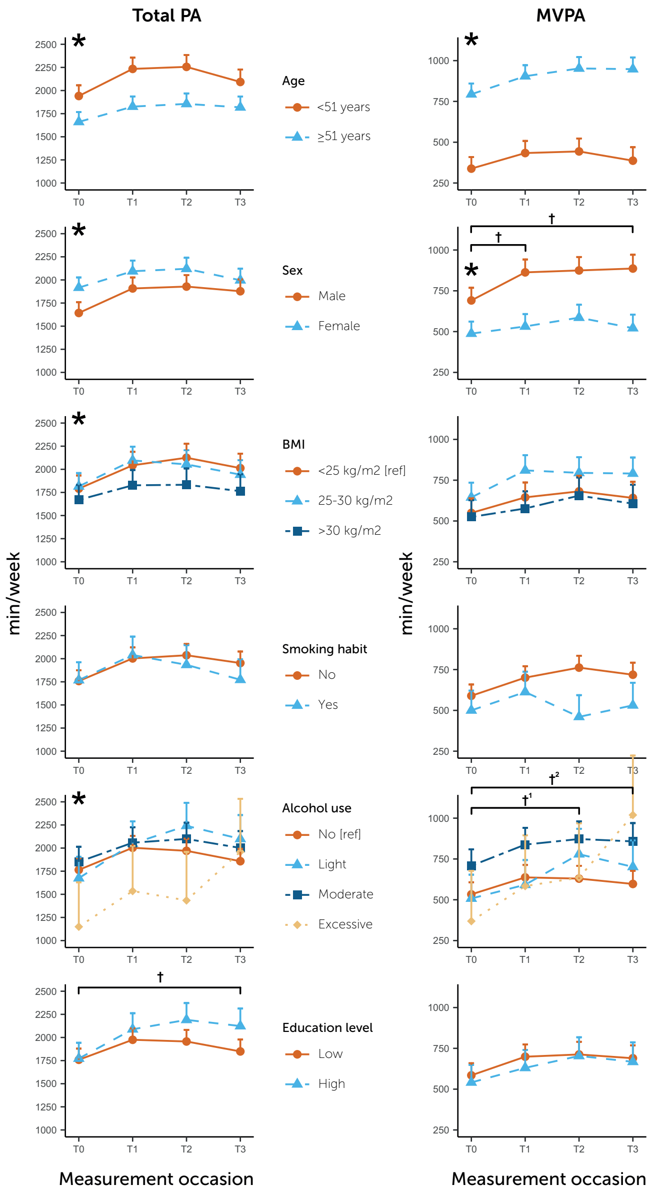

Figure 3. Effects of personal characteristics on baseline levels and development over time of total PA and MVPA, based on the individual multilevel regression models with 95% confidence interval. *significant difference between groups at baseline (p<.05). †significant difference in development over time between groups (1 between light alcohol usages and no alcohol usage, 2 between excessive alcohol usage and no alcohol usage) (p<.05).

usage more active, excessive alcohol usage less active) and on MVPA (moderate alcohol usage more active) and interaction effect on MVPA (light and excessive alcohol usage had more improvement of MVPA over time).

Discussion

We explored the PA dose characteristics in a broad population of adults with disabilities/chronic diseases from discharge up to one year after rehabilitation. We found a significant increase in total minutes per week of PA between baseline and all follow-ups. The largest increase in PA was found between baseline and 14 weeks after rehabilitation, and then more or less stabilized. Almost two thirds of the total minutes was light intensity PA. Most minutes of PA were in household setting. Leisure time contributed to the most minutes of MVPA. We found on average an active population, showing a considerable degree of variation in PA among this population and over time, in all dose characteristics and among personal and disease characteristics.

PA dose characteristics

To the best of our knowledge, this is the first prospective cohort study that considers all dose characteristics (duration, setting, intensity, mode and frequency) of PA in a large heterogeneous population of adults with physical disabilities/chronic diseases. Compared to previous studies (self-reported PA in specific disability groups and in a heterogeneous disability groups), our participants were more active in total PA, MVPA and leisure time PA [8, 20, 22, 40-45]. Furthermore, the proportion of participants adhering to the aerobic component of the WHO PA guideline (>150 min of moderate PA, >75 min of vigorous PA or combination of both) is higher in our population compared to previous research (68-74% versus 35-60%) [8, 46-48]. This suggests that the ReSpAct cohort is a potential positive selection regarding PA behavior. A possible explanation of our active population may relate to the fact that all participants voluntary engaged in the RSE program, and thus received PA counselling during and after rehabilitation.

Participants completed a large amount of light intensity PA. There are indications that the curvilinear relationship between PA and health found in able-bodied individuals [3], also apply to adults with physical disabilities/chronic diseases [49]. This means that for inactive people, even a small increase in PA (in any duration, intensity, mode and frequency), can lead to health benefits. Indeed, breaking up sedentary time into light intensity PA does have positive effects on PA in able-bodied individuals [50]. Also, a study in people with mobility limitations suggested a decrease in all-cause mortality by engaging in light intensity PA [51]. All this suggests the potential importance of light-intensity PA. However, as light-intensity activities might be harder to recall than MVPA, it is debatable how valid self-reported instruments can measure light-intensity. Future research should focus on reliably measuring light-intensity and the dose-response relationship between light-intensity PA and health outcomes.

PA behavior over time

In contrast to the common decline in PA after rehabilitation [52], we found a significant increase in total minutes of PA and in MVPA after rehabilitation. The largest improvement was found between just before discharge (T0) and 14 weeks after (T1) and remained more or less stable till one year after rehabilitation. We found a decrease in PA from 33 weeks (T2) to one year after rehabilitation (T3), but PA at T3 was still significantly higher compared to PA at T0. The improvement in PA aligns with the period that participants received personalized PA counseling (RSE program) [28, 29, 31]. As a previous RCT already showed the effectiveness of counseling after rehabilitation in improving PA behavior [31, 53], this may explain the increase in PA behavior between T0 and T1. Since the period just after rehabilitation is a critical window of opportunity for intervening and important to assist people from being a patient to a participant in lifelong PA [54], a broader implementation of PA counseling not just in the Netherlands [55] but internationally seems a promising approach. However, our data and that of the RCT [31] is limited to one year after rehabilitation, and future research should investigate whether these counseling sessions are enough for adherence to lifelong PA.

Effects of personal characteristics and diagnosis

We found a large diversity in individual PA behavior over time, as seen by the large interquartile ranges for all dose characteristics of PA. Part of this diversity in PA can be explained by age, sex, BMI and diagnosis. The effects of age and sex on PA are also found in the general population and in people with disabilities, with older people being less active and males being more active than females [24, 25, 46, 48]. In contrast, we found that females were more active than males, which may be explained by the household PA as these were reported much more by females than males. As household PA were mostly of light intensity, we also found that males were more active than females in MVPA, which is in line with previous literature [24, 46].

Interestingly, we found that older people were more active in MVPA than younger people. One explanation could be that for people older than 55 years, MVPA is reached with a lower MET-value [56]. Because the Adapted-SQUASH has predefined MET-values for each activity, it could be that the same activity is categorized as light intensity for people younger than 55 years, but as moderate intensity for people older than 55 years.

Only education had a significant interaction effect on PA over time, with people with a higher education increasing their PA behavior more than people with a lower education. Previous research also found that people with higher education were more active, but to the best of our knowledge, the association between education and longitudinal change of PA behavior was not studied before [24, 57].

Combining the knowledge about dose characteristics of PA behavior and the influence of personal characteristics on PA behavior could help health professionals and PA promoting programs to give more individually tailored recommendations. This could be beneficial for getting adults with physical disabilities/chronic diseases more active, as it is known from goal setting literature that more specificity is better [58].

Strengths and limitations

A strength of the current study is that we study people with a broad range of physical disabilities/chronic diseases, who underwent rehabilitation in different rehabilitation centers and hospitals departments across the Netherlands. This, together with the pragmatic measurement setting, improves generalizability of the results. However, as the ReSpAct cohort is probably a positive sample regarding PA, results should also be generalized with some caution.

This study used an observational study design, in which all participants received personalized PA counseling as part of the RSE program. Without a control group, we cannot study the effectiveness of the RSE program. As such, we do not know whether participating in the RSE program contributed to the increased levels of PA after rehabilitation. However, the primary aim of this study was to explore the dose characteristics of PA in adults with physical disabilities/chronic diseases up to one year after rehabilitation, for which an observational study lends it design. Furthermore, the RSE program was developed based on the results of an RCT that showed the effectiveness of counseling during and after rehabilitation in increasing overall PA behavior [31, 53].

PA was measured with a self-reported questionnaire. Questionnaires are prone to recall bias and social desirability, and therefore lead to overestimation of PA [32, 59, 60]. Intensity outcomes of the Adapted-SQUASH are mostly based on MET-values from the Ainsworth compendium of physical activities, based on a general population [33], which might not be as valid for people with disabilities. However, as the test-retest reliability was high for the Adapted-SQUASH, the increase of PA behavior found in this study is fairly robust.

Lastly, possible effects of characteristics (i.e., age, sex, BMI, smoking behavior, alcohol use and education level) and diagnosis on PA were tested univariable and not multivariable. It is possible that effects of characteristics are influenced by other characteristics. Multivariable testing would correct for this. However, because our main aim was to explore the dose characteristics and the studied characteristics were based on previous literature [24-27], we currently limited the study ambitions to univariate testing.

Future research

This study gives detailed information on the dose characteristics of PA behavior in adults with physical disabilities/chronic diseases, which is a first step in the dose-response relationship of PA and health. Due to lack of research on this relationship in adults with physical disabilities/chronic diseases, evidence of the current WHO PA guidelines for this population is mostly derived from research in non-disabled populations [11]. This makes it questionable how applicable these guidelines are, and perhaps making disability specific guidelines more suitable [15, 61]. However, the current PA guidelines for people with disabilities does have its merits, as it exposed the lack of systematic research on PA in this population [62], inspiring new studies, such as the current study, to bridge this gap. Future research should now focus on the dose-response relationships between PA and health.

Closely related to the need for more research on the dose-response relationship of PA and health, is the need for more research on PA measurement instruments in adults with physical disabilities/chronic diseases. Both self-reported and device-based instruments have limitations in this population, and future research should find out which types of instruments are most appropriate for dose/dose-response studies.

The effect of personal characteristics and diagnosis on PA behavior overall and over time found in this study, helps to inform readers to points of attention when promoting PA behavior. Although most characteristics examined in this study cannot be intervened at, theoretical models underlying PA promotion, such as the Physical Activity for people with a Disability (PAD) model [63], suggest personal factors (e.g. motivation, self-efficacy) and environmental factors (e.g. barriers and facilitators, social support) that can be intervened at, also influence PA behavior. Future research should investigate how these modifiable factors influence the development of PA behavior during and after rehabilitation. This could help improve PA promotion interventions and gear them more to individualized therapy.

Conclusion

Both PA level, and change of PA over time are highly variable among adults with physical disabilities/chronic diseases, in terms of different PA dimensions and in the context of personal and diagnosis characteristics. The findings of this study help to understand the construct of PA behavior among a diverse population of persons with a physical disability and/or chronic disease what potentially can be used to improve PA promotion activities among this population during and after rehabilitation.

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Author contribution
PB conceptualized the current study, analyzed the data, interpreted the data and drafted the manuscript. FH, LAK, LHVVDW and RD aiding in the conceptualization, interpretation and drafting of the manuscript. FH and BLS collected the data. LHVVDW, RD and FJH designed the overarching ReSpAct study. TH and LAK helped with statistical analysis. All authors provided critical feedback. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests
The authors declare that they have no competing interests

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Chapter 1 - Appendix 1.

Results of longitudinal multilevel analysis of physical activity behavior over time in table

Appendix 1. Results of longitudinal multilevel analysis of physical activity behavior over time.

	Baseline to T1				Baseline to T2				Baseline to T3			
	β	95% CI		p-value	β	95% CI		p-value	β	95% CI		p-value
Total PA	218.6	142.9	294.3	**<.001**	242.2	162.6	321.7	**<.001**	153.8	70.9	236.6	**<.001**
Leisure Time	57.9	15.0	100.8	**.008**	19.3	-25.7	64.3	.400	19.8	-27.2	66.7	.409
Household	34.2	-6.7	75.0	.101	44.1	1.2	86.9	**.044**	-25.5	-70.1	19.0	.262
Work	100.3	59.2	141.4	**<.001**	151.7	108.5	195.0	**<.001**	137.6	92.6	182.5	**<.001**
Commuting	24.5	6.1	43.0	**.009**	26.5	7.2	45.8	**.007**	24.0	3.9	44.1	**.019**
MVPA	105.0	57.8	152.3	**<.001**	138.4	88.7	188.1	**<.001**	112.9	61.1	164.6	**<.001**

PA = Physical activity, MVPA = moderate to vigorous physical activity

Bold = statistically significant

Chapter 2 - Appendix 2.

Descriptive statistics and PA behavior of each diagnosis groups separately.

Brain disease

Appendix 1.1 Descriptive statistics of participants with a brain disease.

	Population at T0	Population at T1	Population at T2	Population at T3
N	341	299	256	236
Age (years)	52.7 ± 12.3	53 ± 12.2	53.3 ± 11.8	53.5 ± 11.9
Sex (% male)	56.6	57.9	56.6	58.9
BMI (kg/m2)	27 ± 10.7	27.1 ± 11.3	27 ± 11.9	27 ± 12
Smoking				
% Yes	12.6	12	10.2	11
% No	73.6	77.3	78.9	78
Alcohol use				
% No	51	54.2	52.3	53.8
% Light	12.9	13.4	14.5	14
% Moderate	20.5	19.7	20.7	19.5
% Excessive	1.5	1.7	1.2	1.3
Marital status				
% Single	23.8	25.1	25.1	25.1
% Married/living with partner	65.1	66.2	66.2	66.2
Education level				
% Low	65.1	66.2	66	66.9
% High	23.5	24.7	24.2	24.6
Work status				
% School	1.5	1.3	0.8	1.3
% Employed	36.1	37.5	35.9	37.7
% Unemployed	9.7	10.4	9	9.7
% Retired	17.3	18.7	18	18.6
% unable to work	15.8	15.7	17.2	15.7
% Other	7.3	7.4	9	8.1
Rehabilitation context				
% Rehabilitation center	76.2	75.6	78.1	78.8
% Hospital	23.8	24.4	21.9	21.2
Rehabilitation form				
% Inpatient	3.8	3.7	3.5	2.5
% Outpatient	89.7	90	88.7	90.3
% Consultancy	6.5	6.4	7.8	7.2
Number of counseling moments				
% 0	11.4	10.7	10.9	9.3
% 1-3	52.5	53.5	52.3	52.1
% 4 or more	36.1	35.8	36.7	38.6

Data presented as mean ± SD or %

Note: For some participants information was missing, leading to not all percentages adding up to a 100%.

Appendix 1.2 Physical activity behavior of people with a brain disease per measurement occasion.

	T0	T1	T2	T3
Total PA				
N	341	299	256	236
Total (min/week)	1410 (760 - 2400)	1620 (930 - 2685)	1568 (952 - 2604)	1680 (960 - 2604)
Light (min/week)	790 (240 - 1440)	840 (308 - 1650)	750 (243 - 1642)	780 (240 - 1538)
Moderate (min/week)	160 (0 - 540)	180 (30 - 615)	195 (1 - 788)	230 (3 - 750)
Vigorous (min/week)	120 (0 - 300)	150 (40 - 360)	140 (0 - 312)	120 (29 - 360)
Leisure time				
N	341	295	256	232
Total (min/week)	450 (240 - 805)	520 (288 - 878)	510 (240 - 840)	480 (296 - 908)
% 0 min/week	3.2	3.4	4.7	3
Light (min/week)	30 (0 - 250)	30 (0 - 270)	0 (0 - 246)	0 (0 - 240)
% 0 min/week	49.9	49.2	51.2	51.3
Moderate (min/week)	120 (0 - 300)	120 (0 - 360)	120 (0 - 338)	120 (0 - 360)
% 0 min/week	33.1	28.1	31.2	32.3
Vigorous (min/week)	120 (0 - 270)	120 (42 - 300)	120 (0 - 289)	120 (30 - 300)
% 0 min/week	27	21	29.7	23.3
Frequency of leisure time activities (mean ± sd days per week)				
Walking	3.6 ± 2.7	3.3 ± 2.5	3.3 ± 2.5	3.2 ± 2.6
Bicycling	1.8 ± 2.2	1.9 ± 2.3	1.7 ± 2.2	1.9 ± 2.2
wheelchair riding	0.2 ± 1.2	0.3 ± 1.2	0.2 ± 1	0.2 ± 1
Handbiking	0 ± 0	0 ± 0.2	0 ± 0.5	0 ± 0.3
Gardening	0.6 ± 1.1	0.6 ± 1.2	0.5 ± 1.1	0.6 ± 1.1
Odd jobs	0.7 ± 1.4	0.6 ± 1.2	0.6 ± 1.2	0.5 ± 0.9
Fitness	0.6 ± 0.9	0.7 ± 1.2	0.6 ± 1.1	0.5 ± 1.1
Swimming	0.3 ± 0.7	0.3 ± 0.7	0.1 ± 0.5	0.1 ± 0.4
Household				
N	333	293	253	236
Total (min/week)	480 (140 - 855)	420 (150 - 960)	525 (180 - 870)	472 (148 - 878)
% 0 min/week	17.1	11.3	13	13.1
Light (min/week)	450 (120 - 840)	420 (150 - 900)	450 (180 - 840)	420 (135 - 840)
% 0 min/week	17.4	12.3	14.2	14.8

Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	87.7	80.2	81	80.9
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Work				
N	321	296	247	231
Total (min/week)	0 (0 - 480)	0 (0 - 900)	0 (0 - 1020)	0 (0 - 960)
% 0 min/week	62.9	51.4	51	55
Light	0 (0 - 0)	0 (0 - 300)	0 (0 - 120)	0 (0 - 0)
% 0 min/week	76.9	68.9	73.3	76.2
Moderate (min/week)	0 (0 - 0)	0 (0 - 60)	0 (0 - 120)	0 (0 - 90)
% 0 min/week	80.4	73	70.4	71.4
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Commuting				
N	340	296	253	231
Total (min/week)	0 (0 - 36)	0 (0 - 30)	0 (0 - 50)	0 (0 - 60)
% 0 min/week	70.3	71.6	66.8	68.4
Light (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	90.9	88.9	88.5	90.9
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	94.4	94.3	93.3	93.5
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	80.6	80.7	79.1	80.5

Data presented as median (interquartile range), mean ± SD or %

Musculoskeletal disease

Appendix 1.3 Descriptive statistics of participants with a musculoskeletal disorder.

	Population at T0	Population at T1	Population at T2	Population at T3
N	234	201	170	149
Age (years)	47 ± 14.9	47.5 ± 15	47.6 ± 14.8	46.4 ± 14.5
Sex (% male)	35.9	36.3	37.1	35.6
BMI (kg/m2)	27.5 ± 6.1	27.2 ± 5.8	27.7 ± 6.4	27.7 ± 6.2
Smoking				
% Yes	20.5	21.9	20.6	22.1
% No	66.7	66.7	71.2	68.5
Alcohol use				
% No	52.6	52.7	56.5	57
% Light	10.7	10.4	11.2	11.4
% Moderate	22.6	24.4	22.9	21.5
% Excessive	1.3	1	1.2	0.7
Marital status				
% Single	26.5	25.9	25.9	25.9
% Married/living with partner	61.5	63.7	63.7	63.7
Education level				
% Low	64.1	64.7	66.5	69.1
% High	24.4	25.4	26.5	22.1
Work status				
% School	2.6	3	1.8	2
% Employed	31.2	32.3	31.2	33.6
% Unemployed	12.8	13.9	12.9	15.4
% Retired	12	13.4	12.4	12.1
% unable to work	19.7	18.4	21.8	18.1
% Other	10.7	9.5	12.4	10.7
Rehabilitation context				
% Rehabilitation center	65.4	65.2	67.6	63.8
% Hospital	34.6	34.8	32.4	36.2
Rehabilitation form				
% Inpatient	1.3	1.5	0.6	1.3
% Outpatient	87.2	89.1	88.2	88.6
% Consultancy	11.5	9.5	11.2	10.1
Number of counseling moments				
% 0	13.7	13.4	12.4	12.8
% 1-3	62	60.2	62.9	62.4
% 4 or more	24.4	26.4	24.7	24.8

Data presented as mean ± SD or %

Note: For some participants information was missing, leading to not all percentages adding up to a 100%.

Appendix 1.4 Physical activity behavior of participants with a musculoskeletal disorder.

	T0	T1	T2	T3
Total PA				
N	234	201	170	149
Total (min/week)	1728 (1042 - 2918)	2055 (1200 - 3070)	1935 (1011 - 3270)	1898 (1085 - 3270)
Light (min/week)	1140 (450 - 2124)	1260 (600 - 2370)	1145 (600 - 2248)	1050 (555 - 2290)
Moderate (min/week)	120 (0 - 472)	150 (15 - 510)	128 (0 - 600)	120 (0 - 540)
Vigorous (min/week)	120 (0 - 268)	120 (0 - 310)	120 (0 - 300)	120 (0 - 300)
Leisure time				
N	233	199	168	145
Total (min/week)	420 (243 - 770)	450 (252 - 765)	420 (204 - 750)	375 (185 - 660)
% 0 min/week	4.3	2	5.4	5.5
Light (min/week)	120 (0 - 360)	90 (0 - 352)	90 (0 - 278)	60 (0 - 271)
% 0 min/week	38.2	35.2	39.9	40
Moderate (min/week)	60 (0 - 195)	90 (0 - 220)	60 (0 - 214)	30 (0 - 180)
% 0 min/week	42.5	32.2	42.9	48.3
Vigorous (min/week)	100 (0 - 240)	120 (0 - 285)	110 (0 - 241)	105 (0 - 240)
% 0 min/week	27.9	28.1	29.2	36.6
Frequency of leisure time activities (mean ± sd days per week)				
Walking	3.6 ± 2.6	3.6 ± 2.4	3.4 ± 2.6	3.2 ± 2.6
Bicycling	2.1 ± 2.3	1.8 ± 2.2	1.7 ± 2.2	1.4 ± 1.9
wheelchair riding	0.3 ± 1.5	0.3 ± 1.3	0.2 ± 1.2	0.2 ± 1.1
Handbiking	0.1 ± 0.5	0.1 ± 0.6	0.1 ± 0.5	0 ± 0.3
Gardening	0.5 ± 1.1	0.4 ± 0.7	0.4 ± 0.8	0.3 ± 0.6
Odd jobs	0.5 ± 1.2	0.4 ± 1.1	0.5 ± 1.1	0.4 ± 1
Fitness	0.7 ± 1.1	0.6 ± 1.1	0.5 ± 1.1	0.3 ± 0.8
Swimming	0.4 ± 0.8	0.4 ± 0.7	0.3 ± 0.7	0.2 ± 0.6

Appendix 1.4 Continued.

	T0	T1	T2	T3
Household				
N	232	199	166	147
Total (min/week)	630 (236 - 1099)	630 (300 - 1140)	600 (278 - 1012)	585 (248 - 900)
% 0 min/week	9.5	8	7.2	6.1
Light (min/week)	615 (210 - 1080)	600 (282 - 1140)	600 (270 - 960)	585 (240 - 900)
% 0 min/week	9.9	9	7.2	6.1
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	90.1	89.9	88	90.5
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Work				
N	223	197	166	148
Total (min/week)	0 (0 - 960)	300 (0 - 1200)	390 (0 - 1440)	360 (0 - 1710)
% 0 min/week	50.7	44.2	41.6	42.6
Light	0 (0 - 600)	0 (0 - 840)	0 (0 - 1005)	0 (0 - 1200)
% 0 min/week	64.6	58.4	57.2	57.4
Moderate (min/week)	0 (0 - 0)	0 (0 - 180)	0 (0 - 285)	0 (0 - 120)
% 0 min/week	77.1	68.5	64.5	70.3
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Commuting				
N	232	200	169	149
Total (min/week)	0 (0 - 52)	0 (0 - 82)	0 (0 - 30)	0 (0 - 60)
% 0 min/week	68.1	63.5	67.5	61.7
Light (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	87.5	80	84	82.6
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	96.6	94.5	95.3	95.3
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	78.9	81	81.7	77.2

Data presented as median (interquartile range), mean ± SD or %

Chronic pain

Appendix 1.5 Descriptive statistics of participants with chronic pain.

	Population at T0	Population at T1	Population at T2	Population at T3
N	198	176	144	128
Age (years)	45.4 ± 11.6	45.8 ± 11.8	47.4 ± 10.8	46.6 ± 11.2
Sex (% male)	24.2	25.6	23.6	25
BMI (kg/m2)	27.9 ± 6.1	28 ± 6.2	27.8 ± 5.7	27.6 ± 5.9
Smoking				
% Yes	16.2	17	16	14.8
% No	70.7	72.7	73.6	76.6
Alcohol use				
% No	51	51.1	52.8	54.7
% Light	8.6	9.1	7.6	9.4
% Moderate	24.7	26.7	25.7	25
% Excessive	2.5	2.8	3.5	2.3
Marital status				
% Single	28.3	30.7	30.7	30.7
% Married/living with partner	59.1	59.7	59.7	59.7
Education level				
% Low	72.2	73.3	74.3	76.6
% High	15.7	17.6	16.7	15.6
Work status				
% School	2	2.3	0.7	1.6
% Employed	30.3	32.4	32.6	33.6
% Unemployed	16.2	15.3	13.2	14.1
% Retired	3.5	4	3.5	2.3
% unable to work	25.3	26.7	28.5	27.3
% Other	10.1	9.7	12.5	12.5
Rehabilitation context				
% Rehabilitation center	63.1	63.6	62.5	64.1
% Hospital	36.9	36.4	37.5	35.9
Rehabilitation form				
% Inpatient	2.5	2.8	0.7	1.6
% Outpatient	92.4	92	94.4	94.5
% Consultancy	5.1	5.1	4.9	3.9
Number of counseling moments				
% 0	9.1	8.5	7.6	3.1
% 1-3	52.5	49.4	51.4	55.5
% 4 or more	38.4	42	41	41.4

Data presented as mean ± SD or %
Note: For some participants information was missing, leading to not all percentages adding up to a 100%.

Appendix 1.6 Physical activity behavior of participants with chronic pain.

	T0	T1	T2	T3
Total PA				
N	198	176	144	128
Total (min/week)	1710 (1051 - 2520)	1845 (972 - 2770)	1868 (1080 - 2771)	1598 (1080 - 2771)
Light (min/week)	1260 (652 - 2032)	1338 (630 - 2250)	1308 (606 - 2280)	1192 (770 - 1989)
Moderate (min/week)	60 (0 - 300)	112 (0 - 360)	94 (0 - 424)	112 (0 - 300)
Vigorous (min/week)	90 (2 - 210)	120 (0 - 240)	90 (0 - 240)	95 (0 - 240)
Leisure time				
N	198	171	143	125
Total (min/week)	435 (240 - 735)	525 (282 - 792)	445 (240 - 752)	450 (210 - 710)
% 0 min/week	1.5	0.6	3.5	3.2
Light (min/week)	150 (30 - 420)	180 (0 - 480)	150 (0 - 360)	120 (0 - 360)
% 0 min/week	24.2	28.1	31.5	32.8
Moderate (min/week)	30 (0 - 180)	60 (0 - 210)	45 (0 - 188)	15 (0 - 180)
% 0 min/week	46.5	40.9	44.8	48
Vigorous (min/week)	60 (0 - 191)	120 (5 - 210)	90 (0 - 180)	90 (0 - 225)
% 0 min/week	26.3	25.1	30.1	25.6
Frequency of leisure time activities (mean ± sd days per week)				
Walking	4.5 ± 2.5	4.3 ± 2.5	4.1 ± 2.6	4.1 ± 2.6
Bicycling	2 ± 2.2	1.9 ± 2.2	1.7 ± 2	2.1 ± 2.2
wheelchair riding	0.2 ± 1.2	0.2 ± 0.8	0.2 ± 1	0.2 ± 1
Handbiking	0 ± 0.5	0 ± 0	0 ± 0.2	0 ± 0.3
Gardening	0.6 ± 1.1	0.5 ± 1.1	0.4 ± 1.1	0.6 ± 1.3
Odd jobs	0.8 ± 1.6	0.5 ± 1.1	0.5 ± 1.1	0.3 ± 0.8
Fitness	0.6 ± 1.1	0.6 ± 1.1	0.5 ± 1	0.3 ± 0.8
Swimming	0.3 ± 0.6	0.2 ± 0.4	0.2 ± 0.5	0.2 ± 0.5
Household				
N	196	171	141	128
Total (min/week)	690 (270 - 1080)	720 (300 - 1245)	680 (315 - 1260)	702 (300 - 1059)
% 0 min/week	6.6	4.1	5	7
Light (min/week)	690 (270 - 1058)	660 (300 - 1245)	680 (300 - 1260)	702 (300 - 1050)
% 0 min/week	6.6	4.7	5.7	7

Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	92.9	91.8	90.1	89.1
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Work				
N	190	175	141	126
Total (min/week)	0 (0 - 720)	0 (0 - 900)	0 (0 - 960)	0 (0 - 930)
% 0 min/week	55.3	52.6	53.2	55.6
Light	0 (0 - 480)	0 (0 - 600)	0 (0 - 540)	0 (0 - 480)
% 0 min/week	62.6	60.6	63.1	63.5
Moderate (min/week)	0 (0 - 0)	0 (0 - 30)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	83.7	74.9	75.2	77
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Commuting				
N	197	174	143	127
Total (min/week)	0 (0 - 50)	0 (0 - 40)	0 (0 - 14)	0 (0 - 8)
% 0 min/week	68.5	70.7	72.7	74
Light (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	85.3	85.6	86	86.6
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	96.4	94.8	95.8	97.6
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	79.2	82.8	83.9	84.3

Data presented as median (interquartile range), mean ± SD or %

Neurologic disease

Appendix 1.7 Descriptive statistics of participants with a neurologic disease.

	Population at T0	Population at T1	Population at T2	Population at T3
N	188	173	156	145
Age (years)	49.6 ± 12	49.7 ± 12.1	50.2 ± 11.8	51.1 ± 11.5
Sex (% male)	43.6	42.8	42.9	46.9
BMI (kg/m2)	27 ± 6.6	27 ± 6.7	26.4 ± 5.8	26.2 ± 5.3
Smoking				
% Yes	19.7	20.2	19.9	17.2
% No	67.6	68.8	69.9	72.4
Alcohol use				
% No	53.2	53.2	57.1	55.9
% Light	8	8.1	7.1	8.3
% Moderate	23.9	25.4	23.1	23.4
% Excessive	2.1	2.3	2.6	2.1
Marital status				
% Single	30.3	31.2	31.2	31.2
% Married/living with partner	59.6	60.1	60.1	60.1
Education level				
% Low	60.6	61.3	60.3	59.3
% High	29.3	30.1	30.8	31
Work status				
% School	0.5	0.6	0	0.7
% Employed	28.2	30.1	28.8	28.3
% Unemployed	11.7	12.7	11.5	11.7
% Retired	9	8.7	10.3	9.7
% unable to work	32.4	31.2	31.4	32.4
% Other	8	8.1	9	7.6
Rehabilitation context				
% Rehabilitation center	69.7	69.9	68.6	70.3
% Hospital	30.3	30.1	31.4	29.7
Rehabilitation form				
% Inpatient	1.1	1.2	1.3	0.7
% Outpatient	93.1	93.1	92.9	94.5
% Consultancy	5.9	5.8	5.8	4.8
Number of counseling moments				
% 0	13.3	13.9	13.5	13.1
% 1-3	59	59	57.1	60.7
% 4 or more	27.7	27.2	29.5	26.2

Data presented as mean ± SD or %

Note: For some participants information was missing, leading to not all percentages adding up to a 100%.

Appendix 1.8 Physical activity behavior of participants with a neurologic disease.

	T0	T1	T2	T3
Total PA				
N	188	173	156	145
Total (min/week)	1478 (709 - 2268)	1500 (900 - 2625)	1770 (840 - 2280)	1450 (735 - 2280)
Light (min/week)	870 (311 - 1669)	930 (420 - 1890)	952 (412 - 1744)	840 (360 - 1635)
Moderate (min/week)	120 (0 - 480)	155 (0 - 510)	120 (0 - 458)	95 (0 - 420)
Vigorous (min/week)	48 (0 - 210)	90 (0 - 210)	90 (0 - 281)	45 (0 - 210)
Leisure time				
N	186	171	153	143
Total (min/week)	420 (200 - 686)	405 (219 - 690)	450 (218 - 840)	360 (178 - 600)
% 0 min/week	5.9	2.9	3.3	6.3
Light (min/week)	60 (0 - 225)	30 (0 - 270)	60 (0 - 330)	60 (0 - 270)
% 0 min/week	44.1	46.8	39.9	42
Moderate (min/week)	60 (0 - 210)	90 (0 - 240)	60 (0 - 225)	60 (0 - 140)
% 0 min/week	34.4	35.1	36.6	39.9
Vigorous (min/week)	45 (0 - 180)	75 (0 - 198)	90 (0 - 240)	45 (0 - 180)
% 0 min/week	40.9	33.3	30.7	44.1
Frequency of leisure time activities (mean ± sd days per week)				
Walking	3 ± 2.8	3.2 ± 2.8	3 ± 2.7	2.8 ± 2.7
Bicycling	1.6 ± 2.1	1.6 ± 2.1	1.7 ± 2.1	1.3 ± 1.9
wheelchair riding	0.4 ± 1.5	0.5 ± 1.6	0.6 ± 1.7	0.6 ± 1.7
Handbiking	0 ± 0.1	0.1 ± 0.5	0 ± 0.3	0.1 ± 0.5
Gardening	0.8 ± 1.5	0.6 ± 1.2	0.4 ± 1	0.5 ± 1.1
Odd jobs	0.5 ± 1.2	0.4 ± 1	0.4 ± 1	0.4 ± 1.1
Fitness	0.7 ± 1.1	0.7 ± 1	0.7 ± 1.2	0.5 ± 0.8
Swimming	0.3 ± 0.6	0.3 ± 0.6	0.2 ± 0.4	0.2 ± 0.5

Appendix 1.8 Continued.

	T0	T1	T2	T3
Household				
N	186	171	155	143
Total (min/week)	570 (180 - 1020)	540 (240 - 1020)	540 (240 - 1065)	420 (180 - 988)
% 0 min/week	13.4	12.3	11	15.4
Light (min/week)	540 (180 - 956)	480 (232 - 960)	480 (232 - 1065)	420 (165 - 900)
% 0 min/week	13.4	12.3	11.6	15.4
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	87.1	87.1	83.9	90.2
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Work				
N	175	167	153	145
Total (min/week)	0 (0 - 600)	0 (0 - 750)	0 (0 - 540)	0 (0 - 600)
% 0 min/week	66.3	61.7	62.1	62.8
Light	0 (0 - 0)	0 (0 - 150)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	78.9	73.7	77.1	76.6
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	85.1	79.6	77.8	79.3
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Commuting				
N	186	173	155	144
Total (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 10)	0 (0 - 0)
% 0 min/week	80.6	80.3	74.2	75.7
Light (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	90.9	90.8	89	88.9
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	95.7	96	94.2	95.1
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	90.3	90.2	88.4	88.9

Data presented as median (interquartile range), mean $\pm$ SD or %

Organ disease

Appendix 1.9 Descriptive statistics of participants with an organ disease.

	Population at T0	Population at T1	Population at T2	Population at T3
N	152	141	123	107
Age (years)	59.9 ± 10.3	60.4 ± 10.1	60 ± 10.5	61.1 ± 10.9
Sex (% male)	68.4	68.8	65.9	68.2
BMI (kg/m2)	28.6 ± 4.9	28.5 ± 4.9	28.4 ± 4.8	28.1 ± 4.9
Smoking				
% Yes	13.2	13.5	13	12.1
% No	78.9	80.1	80.5	81.3
Alcohol use				
% No	48	48.9	49.6	46.7
% Light	11.2	9.9	12.2	11.2
% Moderate	30.3	31.9	29.3	33.6
% Excessive	2	2.1	1.6	0.9
Marital status				
% Single	25	26.2	26.2	26.2
% Married/living with partner	69.1	68.1	68.1	68.1
Education level				
% Low	76.3	76.6	75.6	76.6
% High	17.1	17	18.7	18.7
Work status				
% School	0.7	0.7	0.8	0.9
% Employed	28.3	27.7	28.5	26.2
% Unemployed	11.8	12.1	14.6	12.1
% Retired	34.2	35.5	35	41.1
% unable to work	17.1	17	13.8	13.1
% Other	2.6	2.1	3.3	1.9
Rehabilitation context				
% Rehabilitation center	82.2	83	84.6	86
% Hospital	17.8	17	15.4	14
Rehabilitation form				
% Inpatient	2	2.1	1.6	1.9
% Outpatient	90.1	90.1	88.6	89.7
% Consultancy	7.9	7.8	9.8	8.4
Number of counseling moments				
% 0	10.5	9.9	10.6	10.3
% 1-3	61.8	61.7	63.4	60.7
% 4 or more	27.6	28.4	26	29

Data presented as mean ± SD or %
Note: For some participants information was missing, leading to not all percentages adding up to a 100%.

2

Appendix 1.10 Physical activity behavior of participants with an organ disease.

	T0	T1	T2	T3
Total PA				
N	152	141	123	107
Total (min/week)	1500 (840 - 2370)	1560 (870 - 2775)	1950 (870 - 3112)	1740 (904 - 3112)
Light (min/week)	600 (180 - 1489)	600 (180 - 1260)	600 (211 - 1770)	600 (165 - 1260)
Moderate (min/week)	300 (0 - 795)	390 (90 - 1080)	420 (60 - 1150)	385 (60 - 1042)
Vigorous (min/week)	120 (0 - 270)	180 (0 - 360)	124 (0 - 360)	180 (0 - 385)
Leisure time				
N	152	139	120	105
Total (min/week)	505 (224 - 848)	605 (300 - 990)	570 (326 - 960)	690 (360 - 990)
% 0 min/week	2	2.2	2.5	5.7
Light (min/week)	0 (0 - 120)	0 (0 - 45)	0 (0 - 120)	0 (0 - 0)
% 0 min/week	67.8	71.2	67.5	77.1
Moderate (min/week)	180 (0 - 450)	180 (20 - 480)	180 (0 - 480)	240 (30 - 615)
% 0 min/week	31.6	23.7	26.7	24.8
Vigorous (min/week)	120 (0 - 270)	140 (0 - 352)	120 (0 - 300)	180 (20 - 360)
% 0 min/week	27.6	26.6	30	24.8
Frequency of leisure time activities (mean ± sd days per week)				
Walking	3.7 ± 2.6	3.5 ± 2.5	3.4 ± 2.6	3.7 ± 2.6
Bicycling	1.7 ± 2.1	1.5 ± 1.9	1.5 ± 1.9	1.9 ± 2.1
wheelchair riding	0.1 ± 0.7	0.1 ± 0.6	0.1 ± 0.9	0.1 ± 1
Handbiking	0 ± 0.1	0 ± 0	0 ± 0	0 ± 0
Gardening	0.9 ± 1.4	0.7 ± 1.4	0.7 ± 1	0.7 ± 1.2
Odd jobs	0.9 ± 1.5	0.7 ± 1.5	0.8 ± 1.3	0.9 ± 1.6
Fitness	0	0.7 ± 1.1	0.4 ± 0.8	0.4 ± 1
Swimming	0.2 ± 0.5	0.1 ± 0.4	0.1 ± 0.4	0.1 ± 0.5
Household				
N	147	138	121	106
Total (min/week)	455 (142 - 930)	540 (169 - 960)	525 (240 - 1080)	525 (180 - 1005)
% 0 min/week	15.6	14.5	12.4	15.1
Light (min/week)	420 (128 - 840)	465 (150 - 840)	420 (150 - 900)	435 (139 - 840)
% 0 min/week	17.7	15.2	14.9	15.1

Moderate (min/week)	0 (0 - 0)	0 (0 - 60)	0 (0 - 60)	0 (0 - 84)
% 0 min/week	75.5	63	63.6	59.4
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Work				
N	142	137	120	102
Total (min/week)	0 (0 - 480)	0 (0 - 480)	0 (0 - 765)	0 (0 - 705)
% 0 min/week	65.5	59.9	60.8	61.8
Light	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	84.5	84.7	84.2	85.3
Moderate (min/week)	0 (0 - 0)	0 (0 - 300)	0 (0 - 120)	0 (0 - 120)
% 0 min/week	78.2	67.9	70	71.6
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Commuting				
N	148	141	122	102
Total (min/week)	0 (0 - 0)	0 (0 - 8)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	78.4	74.5	78.7	75.5
Light (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	93.2	94.3	94.3	94.1
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	94.6	89.4	91.8	92.2
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	85.8	85.8	86.9	86.3

Data presented as median (interquartile range), mean ± SD or %

Amputation

Appendix 1.11 Descriptive statistics of participants with an amputation.

	Population at T0	Population at T1	Population at T2	Population at T3
N	57	52	47	40
Age (years)	56.8 ± 12.6	56.6 ± 13	55.9 ± 13.3	57.4 ± 12.2
Sex (% male)	77.2	78.8	76.6	82.5
BMI (kg/m2)	27.1 ± 5.9	26.7 ± 5.8	26.7 ± 5.8	27.3 ± 6.1
Smoking				
% Yes	22.8	21.2	19.1	25
% No	70.2	73.1	76.6	72.5
Alcohol use				
% No	59.6	59.6	59.6	62.5
% Light	5.3	5.8	6.4	2.5
% Moderate	21.1	21.2	23.4	25
% Excessive	7	7.7	6.4	7.5
Marital status				
% Single	31.6	32.7	32.7	32.7
% Married/living with partner	61.4	61.5	61.5	61.5
Education level				
% Low	77.2	76.9	80.9	82.5
% High	14	15.4	12.8	12.5
Work status				
% School	0	0	0	0
% Employed	19.3	19.2	23.4	20
% Unemployed	8.8	7.7	10.6	7.5
% Retired	31.6	30.8	29.8	30
% unable to work	28.1	30.8	25.5	32.5
% Other	3.5	3.8	4.3	5
Rehabilitation context				
% Rehabilitation center	71.9	71.2	68.1	70
% Hospital	28.1	28.8	31.9	30
Rehabilitation form				
% Inpatient	7	5.8	8.5	7.5
% Outpatient	87.7	88.5	85.1	85
% Consultancy	5.3	5.8	6.4	7.5
Number of counseling moments				
% 0	17.5	19.2	19.1	20
% 1-3	42.1	42.3	40.4	45
% 4 or more	40.4	38.5	40.4	35

Data presented as mean ± SD or %
Note: For some participants information was missing, leading to not all percentages adding up to a 100%.

Appendix 1.12 Physical activity behavior of participants with an amputation.

	T0	T1	T2	T3
Total PA				
N	57	52	47	40
Total (min/week)	1294 (615 - 2130)	1942 (1260 - 2565)	1920 (1276 - 2925)	1918 (1130 - 2925)
Light (min/week)	840 (360 - 1680)	1238 (702 - 1732)	1200 (420 - 2070)	840 (420 - 1680)
Moderate (min/week)	210 (0 - 420)	190 (60 - 600)	210 (19 - 840)	330 (60 - 855)
Vigorous (min/week)	30 (0 - 180)	30 (0 - 278)	45 (0 - 240)	60 (0 - 278)
Leisure time				
N	56	51	47	39
Total (min/week)	745 (311 - 1215)	690 (415 - 1290)	585 (262 - 1200)	660 (420 - 1122)
% 0 min/week	7.1	3.9	10.6	2.6
Light (min/week)	88 (0 - 725)	180 (0 - 540)	60 (0 - 420)	90 (0 - 472)
% 0 min/week	48.2	35.3	44.7	43.6
Moderate (min/week)	139 (0 - 375)	180 (0 - 450)	120 (0 - 480)	90 (0 - 480)
% 0 min/week	39.3	27.5	34	30.8
Vigorous (min/week)	30 (0 - 184)	30 (0 - 255)	30 (0 - 240)	60 (0 - 270)
% 0 min/week	46.4	47.1	46.8	46.2
Frequency of leisure time activities (mean ± sd days per week)				
Walking	2.9 ± 3.1	2.9 ± 3	2.7 ± 2.8	3 ± 3
Bicycling	0.7 ± 1.8	0.7 ± 1.6	0.8 ± 1.7	0.7 ± 1.6
wheelchair riding	2.8 ± 3.3	2.2 ± 3.1	1.9 ± 2.9	2.3 ± 3.2
Handbiking	0.2 ± 0.8	0.4 ± 1.3	0.4 ± 1.1	0.3 ± 0.9
Gardening	0.5 ± 1.3	0.5 ± 0.9	0.5 ± 1.1	0.7 ± 1.4
Odd jobs	0.7 ± 1.6	0.9 ± 1.6	0.7 ± 1.3	1.1 ± 1.8
Fitness	0.8 ± 1.2	0.8 ± 1.4	0.5 ± 1	0.5 ± 0.9
Swimming	0.5 ± 0.9	0.3 ± 0.5	0.2 ± 0.5	0.2 ± 0.4

Appendix 1.12 Continued.

	T0	T1	T2	T3
Household				
N	54	52	47	40
Total (min/week)	225 (0 - 652)	485 (202 - 840)	650 (225 - 1050)	420 (105 - 840)
% 0 min/week	29.6	19.2	21.3	22.5
Light (min/week)	225 (0 - 630)	485 (188 - 840)	630 (225 - 1005)	390 (105 - 840)
% 0 min/week	29.6	19.2	21.3	22.5
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 1)	0 (0 - 0)
% 0 min/week	90.7	86.5	74.5	82.5
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Work				
N	53	49	46	38
Total (min/week)	0 (0 - 0)	0 (0 - 540)	0 (0 - 315)	0 (0 - 660)
% 0 min/week	75.5	59.2	69.6	52.6
Light	0 (0 - 0)	0 (0 - 240)	0 (0 - 0)	0 (0 - 315)
% 0 min/week	84.9	73.5	82.6	73.7
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 150)
% 0 min/week	84.9	77.6	76.1	65.8
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Commuting				
N	57	52	47	39
Total (min/week)	0 (0 - 0)	0 (0 - 1)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	87.7	75	85.1	76.9
Light (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	91.2	90.4	89.4	89.7
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	96.5	86.5	95.7	87.2
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	96.2	93.6	92.3

Data presented as median (interquartile range), mean ± SD or %

Spinal cord injury

Appendix 1.13 Descriptive statistics of participants with SCI.

	Population at T0	Population at T1	Population at T2	Population at T3
N	38	30	27	24
Age (years)	48.2 ± 15.4	48.2 ± 15.6	49.4 ± 14.2	50 ± 16.2
Sex (% male)	42.1	36.7	44.4	45.8
BMI (kg/m2)	31 ± 23.8	32.4 ± 26.3	31.8 ± 28.3	31.5 ± 29.6
Smoking				
% Yes	18.4	20	14.8	16.7
% No	68.4	73.3	74.1	75
Alcohol use				
% No	42.1	43.3	44.4	41.7
% Light	2.6	3.3	3.7	0
% Moderate	34.2	36.7	33.3	41.7
% Excessive	7.9	10	7.4	8.3
Marital status				
% Single	44.7	43.3	43.3	43.3
% Married/living with partner	50	53.3	53.3	53.3
Education level				
% Low	60.5	56.7	55.6	66.7
% High	34.2	40	37	29.2
Work status				
% School	5.3	3.3	3.7	8.3
% Employed	26.3	26.7	25.9	16.7
% Unemployed	10.5	10	11.1	8.3
% Retired	18.4	20	18.5	25
% unable to work	26.3	26.7	25.9	29.2
% Other	7.9	10	7.4	8.3
Rehabilitation context				
% Rehabilitation center	89.5	86.7	88.9	91.7
% Hospital	10.5	13.3	11.1	8.3
Rehabilitation form				
% Inpatient	13.2	6.7	11.1	16.7
% Outpatient	73.7	76.7	70.4	66.7
% Consultancy	13.2	16.7	18.5	16.7
Number of counseling moments				
% 0	2.6	0	0	4.2
% 1-3	71.1	73.3	70.4	66.7
% 4 or more	26.3	26.7	29.6	29.2

Data presented as mean ± SD or %
Note: For some participants information was missing, leading to not all percentages adding up to a 100%.

2

Appendix 1.14 Physical activity behavior of participants with SCI.

	T0	T1	T2	T3
Total PA				
N	38	30	27	24
Total (min/week)	1515 (885 - 2059)	2018 (915 - 3008)	2100 (924 - 2599)	1700 (1061 - 2599)
Light (min/week)	885 (555 - 1582)	1185 (555 - 1642)	1185 (720 - 2115)	1203 (390 - 1779)
Moderate (min/week)	52 (0 - 240)	142 (0 - 465)	30 (0 - 225)	150 (0 - 484)
Vigorous (min/week)	42 (0 - 195)	120 (0 - 377)	90 (0 - 270)	120 (0 - 210)
Leisure time				
N	38	30	26	23
Total (min/week)	435 (188 - 825)	604 (398 - 1155)	540 (375 - 862)	495 (370 - 955)
% 0 min/week	5.3	3.3	3.8	8.7
Light (min/week)	135 (0 - 442)	240 (0 - 555)	195 (1 - 465)	60 (0 - 375)
% 0 min/week	36.8	36.7	26.9	39.1
Moderate (min/week)	52 (0 - 240)	128 (0 - 285)	0 (0 - 232)	90 (0 - 321)
% 0 min/week	34.2	33.3	53.8	39.1
Vigorous (min/week)	42 (0 - 195)	120 (0 - 311)	75 (0 - 225)	120 (0 - 210)
% 0 min/week	44.7	33.3	30.8	30.4
Frequency of leisure time activities (mean ± sd days per week)				
Walking	2.1 ± 2.6	2.2 ± 2.6	1.5 ± 2.1	2 ± 2.5
Bicycling	1.2 ± 2.1	1.6 ± 2.4	0.8 ± 1.8	1.6 ± 2.6
wheelchair riding	1.6 ± 2.6	1.7 ± 2.9	2.6 ± 3.4	2.5 ± 3.3
Handbiking	0.3 ± 1.3	0.3 ± 0.9	0.7 ± 1.4	0.4 ± 1.2
Gardening	0.4 ± 0.9	0.2 ± 0.5	0.2 ± 0.5	0.3 ± 0.7
Odd jobs	0.8 ± 1.6	0.4 ± 1	0.3 ± 0.6	0.7 ± 1.3
Fitness	0	0.7 ± 0.8	0.5 ± 0.9	0.6 ± 1
Swimming	0.5 ± 0.8	0.4 ± 0.8	0.2 ± 0.5	0.2 ± 0.5
Household				
N	38	30	27	22
Total (min/week)	450 (38 - 840)	510 (135 - 998)	360 (180 - 1125)	322 (120 - 630)
% 0 min/week	21.1	13.3	11.1	13.6
Light (min/week)	450 (38 - 840)	510 (135 - 998)	360 (180 - 880)	278 (120 - 604)
% 0 min/week	21.1	13.3	11.1	13.6

Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	97.4	86.7	92.6	86.4
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Work				
N	36	30	27	23
Total (min/week)	0 (0 - 495)	0 (0 - 720)	180 (0 - 930)	0 (0 - 1110)
% 0 min/week	61.1	53.3	48.1	56.5
Light	0 (0 - 300)	0 (0 - 360)	0 (0 - 810)	0 (0 - 840)
% 0 min/week	69.4	70	55.6	65.2
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	86.1	83.3	88.9	82.6
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Commuting				
N	38	30	27	24
Total (min/week)	0 (0 - 90)	0 (0 - 71)	0 (0 - 52)	0 (0 - 0)
% 0 min/week	63.2	70	66.7	79.2
Light (min/week)	0 (0 - 22)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	73.7	86.7	92.6	91.7
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	92.1	90	81.5	100
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	94.7	90	85.2	87.5

Data presented as median (interquartile range), mean ± SD or %

Other diseases

Appendix 1.15 Descriptive statistics of participants with other diseases.

	Population at T0	Population at T1	Population at T2	Population at T3
N	48	42	43	31
Age (years)	46.4 ± 13.8	47.4 ± 14.1	46.4 ± 13.9	46.9 ± 14.9
Sex (% male)	47.9	47.6	51.2	45.2
BMI (kg/m2)	26 ± 4.6	25.7 ± 4.4	26.1 ± 4.6	26.8 ± 5
Smoking				
% Yes	10.4	9.5	11.6	6.5
% No	72.9	81	72.1	77.4
Alcohol use				
% No	35.4	40.5	34.9	35.5
% Light	18.8	19	20.9	22.6
% Moderate	27.1	28.6	25.6	22.6
% Excessive	2.1	2.4	2.3	3.2
Marital status				
% Single	14.6	16.7	16.7	16.7
% Married/living with partner	75	78.6	78.6	78.6
Education level				
% Low	62.5	64.3	69.8	71
% High	25	28.6	20.9	22.6
Work status				
% School	6.2	7.1	7	9.7
% Employed	39.6	40.5	41.9	41.9
% Unemployed	4.2	2.4	4.7	6.5
% Retired	12.5	14.3	11.6	12.9
% unable to work	20.8	23.8	18.6	16.1
% Other	6.2	7.1	7	6.5
Rehabilitation context				
% Rehabilitation center	62.5	66.7	60.5	61.3
% Hospital	37.5	33.3	39.5	38.7
Rehabilitation form				
% Inpatient	0	0	0	0
% Outpatient	93.8	92.9	95.3	93.5
% Consultancy	6.2	7.1	4.7	6.5
Number of counseling moments				
% 0	4.2	2.4	2.3	6.5
% 1-3	52.1	50	55.8	51.6
% 4 or more	43.8	47.6	41.9	41.9

Data presented as mean ± SD or %
Note: For some participants information was missing, leading to not all percentages adding up to a 100%.

Appendix 1.16 Physical activity behavior of participants with other diseases.

	T0	T1	T2	T3
Total PA				
N	48	42	43	31
Total (min/week)	1996 (1282 - 2535)	1715 (1402 - 3205)	2050 (1380 - 2960)	2135 (1560 - 2960)
Light (min/week)	1305 (652 - 2018)	1260 (562 - 2205)	1265 (731 - 2160)	1320 (530 - 2075)
Moderate (min/week)	132 (0 - 615)	172 (8 - 788)	240 (0 - 690)	180 (68 - 780)
Vigorous (min/week)	60 (0 - 188)	125 (40 - 251)	60 (0 - 205)	100 (60 - 240)
Leisure time				
N	48	42	42	31
Total (min/week)	415 (216 - 735)	405 (285 - 889)	412 (259 - 630)	450 (312 - 810)
% 0 min/week	2.1	2.4	2.4	3.2
Light (min/week)	120 (0 - 315)	90 (0 - 288)	120 (0 - 348)	120 (0 - 300)
% 0 min/week	27.1	38.1	31	32.3
Moderate (min/week)	60 (0 - 225)	30 (0 - 285)	60 (0 - 202)	105 (0 - 352)
% 0 min/week	41.7	42.9	40.5	35.5
Vigorous (min/week)	60 (0 - 180)	120 (40 - 232)	60 (0 - 172)	75 (22 - 150)
% 0 min/week	33.3	23.8	35.7	22.6
Frequency of leisure time activities (mean ± sd days per week)				
Walking	3.9 ± 2.6	3.9 ± 2.7	3.7 ± 2.6	3.9 ± 2.7
Bicycling	1.8 ± 2	1.7 ± 1.8	1.2 ± 1.9	1.6 ± 1.7
wheelchair riding	0 ± 0	0 ± 0.3	0.1 ± 0.8	0 ± 0
Handbiking	0 ± 0.1	0 ± 0	0 ± 0	0 ± 0
Gardening	1 ± 1.5	0.8 ± 1.5	0.5 ± 0.8	1.3 ± 1.9
Odd jobs	0.7 ± 1.4	0.6 ± 1.1	0.4 ± 0.8	0.7 ± 1.3

Appendix 1.16 Continued.

	T0	T1	T2	T3
Household				
N	48	42	43	31
Total (min/week)	740 (349 - 1060)	515 (188 - 982)	802 (480 - 1050)	720 (390 - 915)
% 0 min/week	6.2	7.1	2.3	6.5
Light (min/week)	660 (349 - 1028)	510 (188 - 945)	742 (420 - 960)	720 (360 - 915)
% 0 min/week	6.2	7.1	2.3	6.5
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	81.2	85.7	83.7	77.4
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Work				
N	46	42	43	31
Total (min/week)	240 (0 - 810)	660 (0 - 1245)	480 (0 - 1440)	360 (0 - 1440)
% 0 min/week	43.5	33.3	37.2	41.9
Light	0 (0 - 450)	120 (0 - 900)	0 (0 - 690)	0 (0 - 840)
% 0 min/week	58.7	50	58.1	58.1
Moderate (min/week)	0 (0 - 105)	0 (0 - 285)	0 (0 - 450)	0 (0 - 150)
% 0 min/week	71.7	61.9	65.1	71
Vigorous (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	100	100	100	100
Commuting				
N	48	42	43	31
Total (min/week)	0 (0 - 45)	0 (0 - 79)	0 (0 - 60)	0 (0 - 110)
% 0 min/week	64.6	57.1	65.1	54.8
Light (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	83.3	88.1	86	83.9
Moderate (min/week)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)	0 (0 - 0)
% 0 min/week	97.9	90.5	95.3	93.5
Vigorous (min/week)	0 (0 - 0)	0 (0 - 22)	0 (0 - 0)	0 (0 - 25)
% 0 min/week	77.1	73.8	79.1	71

Data presented as median (interquartile range), mean ± SD or %

Chapter 2 - Appendix 3. Effect modification of personal characteristics and diagnosis on the development of physical activity behavior.

		Total PA			Leisure time		
		β	SE	P-value	β	SE	P-value
Diagnosis	(Intercept)	1676.4	76.2	**>.001**	63.3	37.2	**>.001**
Brain disease (ref)	t1	223.9	74.2	**.003**	67.6	41.9	.107
	t2	211.7	78.3	**.007**	-23.7	44.0	.590
	t3	144.1	80.6	.074	29.9	45.5	.512
	Musculoskeletal disorder	307.5	109.6	**.005**	-62.1	55.9	.267
	Chronic pain	164.6	114.8	.152	-79.4	58.6	.176
	Neurologic disease	12.9	117.0	.913	-29.8	59.9	.618
	Organ disease	129.3	128.1	.313	43.7	64.9	.501
	Amputation	-122.4	184.0	.506	344.3	94.5	**>.001**
	Spinal cord injury	27.8	219.6	.899	19.5	112.2	.862
	Other diseases	392.7	197.8	**.047**	15.9	101.1	.875
	t1 * Musculoskeletal disorder	38.1	116.8	.744	15.4	66.0	.815
	t2 * Musculoskeletal disorder	36.5	123.6	.768	5.4	69.6	.470
	t3 * Musculoskeletal disorder	70.5	128.6	.584	27.9	72.8	.702
	t1 * Chronic pain	6.6	122.0	.957	-1.1	69.2	.987
	t2 * Chronic pain	-20.1	130.1	.877	66.7	73.2	.363
	t3 * Chronic pain	-118.9	135.0	.379	-43.8	76.4	.566
	t1 * Neurologic disease	-114.5	123.1	.352	-73.0	69.7	.295
	t2 * Neurologic disease	-11.6	128.4	.928	121.0	72.6	.096
	t3 * Neurologic disease	-176.5	131.8	.181	-105.8	74.6	.156
	t1 * Organ disease	-94.0	131.9	.476	5.0	74.6	.947
	t2 * Organ disease	76.0	138.5	.583	49.4	78.3	.528
	t3 * Organ disease	181.2	144.4	.209	96.5	81.6	.237
	t1 * Amputation	365.9	193.8	.059	-36.5	11.3	.741
	t2 * Amputation	317.9	201.1	.114	-129.2	113.6	.255
	t3 * Amputation	359.5	211.7	.090	-114.4	12.5	.343
	t1 * Spinal cord injury	-18.7	242.1	.938	86.9	136.3	.524
	t2 * Spinal cord injury	271.2	252.1	.282	304.2	143.4	**.034**
	t3 * Spinal cord injury	113.3	262.6	.666	142.8	149.6	.340
	t1 * Spinal cord injury	10.7	211.3	.960	-67.1	119.0	.573
	t2 * Spinal cord injury	-83.8	211.5	.692	-113.2	119.8	.345
	t3 * Spinal cord injury	96.1	234.1	.681	-44.0	131.5	.738
	Type III ANOVA Diagnosis			**.001**			**>.001**
	*Type III ANOVA Time * Diagnosis*			.612			.263

Household			Work			Commuting			MVPA		
β	SE	P-value	β	SE	P-value	β	SE	P-value	β	SE	P-value
626.7	37.7	**>.001**	373.9	43.0	**>.001**	64.5	13.5	**>.001**	654.7	44.9	**>.001**
-6.3	4.2	.876	144.5	4.1	**>.001**	17.5	18.0	.332	132.7	46.4	**.004**
7.4	42.2	.861	172.2	42.7	**>.001**	59.8	18.9	**.002**	147.5	49.0	**.003**
-29.2	43.2	.500	128.7	43.7	**.003**	7.5	19.5	.701	105.0	5.4	**.037**
181.4	58.9	**.002**	20.4	67.4	**.003**	-7.1	21.2	.736	-54.6	7.4	.438
169.0	61.9	**.006**	75.6	7.8	.285	4.3	22.3	.845	-246.1	74.1	**.001**
45.5	63.0	.470	36.8	72.3	.611	-19.7	22.7	.385	-104.7	75.4	.165
73.3	68.0	.281	38.2	77.6	.622	-19.0	24.5	.438	127.1	8.9	.116
-205.0	10.4	**.041**	-201.0	114.1	.078	-45.6	35.6	.201	-137.5	118.7	.247
-118.7	118.1	.315	67.9	135.8	.617	3.6	42.6	.472	-165.4	141.9	.244
244.9	106.5	**.021**	106.7	121.9	.382	1.6	38.4	.783	-2.6	127.9	.984
35.0	62.9	.578	-54.5	63.1	.388	4.2	28.3	.157	-39.0	73.0	.593
-32.2	66.6	.629	66.7	67.2	.321	-44.5	29.8	.136	-6.6	77.3	.433
-63.0	69.1	.362	71.6	69.3	.302	4.6	3.9	.189	-3.5	8.4	.965
114.3	66.0	.084	-69.0	65.6	.293	-15.0	29.7	.613	-6.7	76.2	.426
72.7	7.2	.300	-71.1	7.5	.314	-81.0	31.4	**.010**	-8.2	81.4	.919
17.3	72.4	.811	-52.6	73.0	.471	-28.4	32.5	.383	-21.9	84.4	.796
66.7	66.3	.315	-99.8	66.9	.136	-18.0	29.9	.548	-12.9	76.9	.116
35.0	69.0	.612	-141.7	69.9	**.043**	-36.8	31.1	.236	-4.5	8.3	.614
-2.4	7.8	.973	-75.6	71.5	.290	13.2	31.9	.679	-8.7	82.4	.327
-3.8	71.6	.957	-134.6	71.8	.061	2.7	32.1	.520	28.7	82.4	.728
24.3	74.9	.745	-9.6	75.5	.899	-5.8	33.6	.862	111.6	86.5	.197
2.6	77.8	.792	5.5	78.8	.522	38.2	35.3	.279	154.0	9.3	.088
162.9	105.2	.122	16.4	107.1	.134	85.2	47.0	.070	84.4	121.1	.486
319.9	108.7	**.003**	121.6	109.7	.268	-2.6	48.6	.671	44.6	125.7	.722
203.2	114.4	.076	165.1	115.8	.154	115.8	51.3	**.024**	156.8	132.4	.236
99.0	129.4	.445	-197.9	129.8	.128	-22.0	58.4	.706	-26.9	151.3	.859
171.0	134.8	.205	-152.5	136.6	.264	-44.9	6.5	.458	-74.2	157.7	.638
126.4	144.5	.382	2.7	143.2	.985	-62.1	62.8	.323	49.2	164.3	.765
-86.2	112.9	.446	179.4	113.4	.114	-17.6	51.1	.731	32.1	132.0	.808
67.9	113.0	.548	45.8	113.7	.687	-88.1	51.2	.085	-122.4	132.1	.354
-54.1	125.0	.665	91.6	125.5	.465	97.4	56.2	.083	-73.8	146.4	.614
		>.001			**.001**			.311			**>.001**
		.493			.105			**.041**			.860

Chapter 2 - Appendix 3. Continued.

		Total PA			Leisure time		
		β	SE	P-value	β	SE	P-value
Age	(Intercept)	2429.2	142.5	**>.001**	446.2	73.9	**>.001**
	t1	436.5	152.0	**.004**	84.4	86.4	.329
	t2	589.1	164.0	**>.001**	69.4	93.0	.455
	t3	416.5	169.0	**.014**	-16.7	96.5	.863
	Age	-12.7	2.7	**>.001**	3.5	1.4	**.012**
	t1 * Age	-4.2	2.9	.143	-.5	1.6	.750
	t2 * Age	-6.7	3.1	**.031**	-1.0	1.8	.567
	t3 * Age	-5.1	3.2	.113	0.7	1.8	.708
	*Type III ANOVA Time * Age*			.145			.839
Sex	(Intercept)	1642.7	59.1	**>.001**	619.5	25.7	**>.001**
Male (ref)	t1	265.0	55.9	**>.001**	61.9	25.6	**.016**
	t2	285.5	58.8	**>.001**	29.6	26.7	.268
	t3	235.0	60.5	**>.001**	4.8	27.8	.142
	Female	273.9	73.0	**>.001**	-22.4	51.6	.665
	t1 * Female	-87.6	77.3	.257	17.0	6.0	.776
	t2 * Female	-81.9	81.2	.313	-8.0	63.9	.901
	t3 * Female	-155.2	84.5	.066	-78.5	66.9	.241
	*Type III ANOVA Time * Sex*			.314			.633
BMI	(Intercept)	2008.8	135.0	**>.001**	668.2	68.1	**>.001**
	t1	346.7	133.3	**.009**	101.3	75.6	.180
	t2	204.6	137.1	.136	87.2	77.5	.260
	t3	62.4	140.5	.657	96.6	79.5	.224
	BMI	-8.8	4.5	**.049**	-1.9	2.3	.403
	t1 * BMI	-4.0	4.6	.384	-1.4	2.6	.605
	t2 * BMI	1.9	4.7	.692	-2.1	2.7	.441
	t3 * BMI	3.4	4.9	.490	-2.5	2.7	.356
	*Type III ANOVA Time * BMI*			.457			.800
Smoking behavior	(Intercept)	1758.6	59.7	**>.001**	619.5	25.7	**>.001**
No (ref)	t1	244.3	44.9	**>.001**	61.9	25.6	**.016**
	t2	278.6	46.8	**>.001**	29.6	26.7	.268
	t3	194.5	48.6	**>.001**	4.8	27.8	.142
	Yes	9.9	99.4	.921	-22.4	51.6	.665
	t1 * Yes	26.7	104.3	.798	17.0	6.0	.776
	t2 * Yes	-113.2	111.8	.311	-8.0	63.9	.901
	t3 * Yes	-190.8	116.6	.102	-78.5	66.9	.241
	*Type III ANOVA Time * Smoking behavior*			.231			.546

Household			Work			Commuting			MVPA		
β	SE	P-value	β	SE	P-value	β	SE	P-value	β	SE	P-value
846.2	77.6	**>.001**	1006.4	87.5	**>.001**	115.2	27.7	**>.001**	-96.0	91.7	.296
85.6	81.7	.295	258.6	81.9	**.002**	66.1	37.0	.074	21.9	95.0	.818
104.4	88.1	.236	428.8	88.9	**>.001**	23.1	39.7	.560	78.2	102.6	.446
4.1	9.8	.964	441.2	91.4	**>.001**	34.8	4.9	.395	-2.2	105.7	.983
-2.9	1.5	**.049**	-11.4	1.6	**>.001**	-1.1	.5	**.033**	13.5	1.7	**>.001**
-1.0	1.6	.529	-3.1	1.6	**.046**	-0.8	.7	.250	1.6	1.8	.372
-1.1	1.7	.492	-5.4	1.7	**.001**	0.1	.8	.919	1.1	1.9	.556
-0.6	1.7	.728	-5.9	1.7	**.001**	-0.2	.8	.797	2.2	2.0	.271
		.894			**.002**			.618			.696
461.8	27.6	**>.001**	453.3	39.9	**>.001**	54.7	1.3	**>.001**	69.9	39.4	**>.001**
48.9	3.2	.105	113.8	3.4	**>.001**	36.5	13.6	**.007**	172.0	34.8	**>.001**
93.6	31.7	**.003**	147.8	32.1	**>.001**	4.1	14.3	**.005**	183.8	36.7	**>.001**
32.5	32.5	.318	138.9	32.9	**>.001**	51.1	14.7	**.001**	195.5	37.8	**>.001**
45.4	37.9	**>.001**	-45.7	45.4	.314	6.2	14.2	.664	-203.1	46.9	**>.001**
-24.6	41.7	.555	-25.9	42.0	.537	-22.8	18.8	.225	-128.3	48.2	**.008**
-93.6	43.7	**.032**	7.7	44.2	.862	-25.9	19.7	.189	-86.1	5.7	.089
-107.9	45.4	**.018**	-2.7	45.9	.953	-53.0	2.5	**.010**	-161.9	52.7	**.002**
		.045			.887			.080			**.009**
768.1	71.9	**>.001**	553.0	81.9	**>.001**	5.2	24.2	**.038**	643.7	86.8	**>.001**
55.3	71.9	.442	155.6	7.9	**.028**	31.1	31.4	.322	131.2	82.7	.113
-72.7	74.0	.326	139.3	73.3	.058	54.8	32.2	.089	116.8	85.1	.170
-173.9	75.8	**.022**	146.5	74.9	.051	12.7	33.0	.700	72.3	87.2	.407
-2.4	2.4	.331	-4.8	2.7	.079	0.2	.8	.816	-2.5	2.9	.398
-0.8	2.5	.760	-1.6	2.5	.518	-0.4	1.1	.742	-0.8	2.9	.771
4.3	2.6	.093	0.4	2.5	.861	-1.1	1.1	.338	0.8	2.9	.791
5.4	2.6	**.038**	-0.4	2.6	.875	0.2	1.1	.859	1.4	3.0	.651
		.042			.870			.703			.898
689.0	27.3	**>.001**	422.9	33.9	**>.001**	55.3	8.2	**>.001**	589.3	35.3	**>.001**
38.9	24.2	.107	114.5	24.4	**>.001**	21.3	1.7	**.047**	111.1	28.0	**>.001**
47.4	25.2	.060	162.3	25.6	**>.001**	3.0	11.1	**.007**	172.7	29.2	**>.001**
-14.8	26.1	.570	143.8	26.5	**>.001**	19.6	11.6	.091	129.1	3.4	**>.001**
42.8	54.2	.430	-14.2	61.6	.817	2.4	18.8	.898	-89.4	64.1	.163
41.5	56.3	.461	-21.9	56.6	.699	2.4	24.9	.925	1.4	65.1	.983
25.1	6.2	.677	-87.0	6.5	.150	-3.5	26.5	.250	-212.3	69.8	**.002**
-21.9	62.8	.728	-53.6	63.5	.398	-9.5	27.6	.730	-98.2	72.8	.178
		.759			.516			.621			**.008**

Chapter 2 - Appendix 3. Continued.

		Total PA			Leisure time		
		β	SE	P-value	β	SE	P-value
Alcohol use	(Intercept)	1764.2	63.9	**>.001**	594.5	28.8	**>.001**
No (ref)	t1	239.0	53.1	**>.001**	56.5	3.4	.063
	t2	206.2	55.5	**>.001**	18.7	31.7	.555
	t3	93.8	57.6	.103	-12.4	33.0	.706
	Light	-89.9	122.9	.465	-3.0	63.5	.962
	Moderate	86.8	89.8	.334	107.4	46.5	**.021**
	Excessive	-614.7	247.9	**.013**	-291.6	128.0	**.023**
	t1 * Light	134.5	129.4	.299	11.0	73.9	.882
	t2 * Light	360.2	134.1	**.007**	124.6	76.6	.104
	t3 * Light	331.1	139.7	**.018**	202.3	8.5	**.012**
	t1 * Moderate	-31.8	93.5	.734	14.9	53.7	.781
	t2 * Moderate	42.0	99.0	.671	-21.7	56.6	.701
	t3 * Moderate	56.8	102.9	.581	34.8	58.7	.553
	t1 * Excessive	147.2	254.5	.563	119.4	145.1	.411
	t2 * Excessive	78.4	272.9	.774	68.6	155.2	.658
	t3 * Excessive	716.7	298.2	**.016**	347.4	169.3	**.040**
	Type III ANOVA Alcohol use			.064			**.001**
	*Type III ANOVA Time * Alcohol use*			.074			.157
Education level	(Intercept)	1758.9	61.4	**>.001**	634.4	27.4	**>.001**
Low (ref)	t1	216.2	46.9	**>.001**	63.5	26.6	**.017**
	t2	197.8	49.1	**>.001**	16.8	27.8	.546
	t3	90.2	50.8	.076	6.0	28.9	.834
	High	13.4	88.3	.879	-77.9	45.7	.088
	t1 * High	100.0	92.6	.280	-1.1	52.6	.984
	t2 * High	220.5	97.3	**.024**	55.1	55.2	.318
	t3 * High	260.9	102.1	**.011**	84.1	58.0	.147
	*Type III ANOVA Time * Education level*			**.038**			.375

Household			Work			Commuting			MVPA		
β	SE	P-value	β	SE	P-value	β	SE	P-value	β	SE	P-value
727.2	31.2	**>.001**	409.9	37.3	**>.001**	58.6	9.6	**>.001**	533.2	37.8	**>.001**
53.1	28.6	.064	9.8	28.9	**.002**	29.7	12.7	**.019**	103.9	33.2	**.002**
37.8	29.9	.206	13.0	3.3	**>.001**	1.6	13.2	.423	96.5	34.6	**.005**
-24.3	3.9	.433	105.6	31.3	**.001**	19.2	13.7	.161	63.8	36.0	.076
-138.1	66.8	**.039**	59.2	76.7	.441	-23.7	23.5	.312	-25.4	79.1	.748
-39.9	48.9	.415	33.6	55.8	.547	0.2	17.0	.992	175.0	57.8	**.002**
-85.4	136.1	.530	-244.3	155.4	.116	-13.3	47.6	.780	-164.1	159.4	.304
88.1	69.6	.206	81.5	7.4	.247	-24.9	31.0	.422	-19.6	8.7	.808
82.9	72.4	.252	105.5	73.2	.149	82.3	32.0	**.010**	174.9	83.7	**.037**
49.0	75.0	.514	128.5	76.9	.095	18.2	33.4	.586	13.0	87.2	.136
-65.7	5.5	.193	33.8	5.8	.505	-11.1	22.4	.619	25.9	58.4	.658
25.7	53.2	.629	4.9	53.9	.928	17.3	23.5	.462	67.5	61.8	.275
-9.7	55.3	.861	32.4	55.8	.562	-12.5	24.5	.608	85.6	64.2	.183
0.4	137.7	.998	84.2	141.3	.551	-62.3	61.4	.310	11.9	158.8	.485
-116.3	148.7	.434	202.6	149.4	.175	-0.8	65.9	.990	169.6	17.4	.319
121.5	163.3	.457	311.3	167.9	.064	6.6	71.9	.927	586.4	186.2	**.002**
		.308			.112			.847			**>.001**
		.514			.586			.145			**.040**
723.4	27.9	**>.001**	373.2	34.5	**>.001**	55.3	8.2	**>.001**	584.8	37.8	**>.001**
35.2	25.3	.164	95.3	25.5	**>.001**	22.5	1.9	**.038**	114.0	29.1	**>.001**
34.8	26.5	.190	13.4	26.8	**>.001**	16.5	11.3	.147	127.8	3.6	**>.001**
-36.6	27.3	.181	112.1	27.6	**>.001**	14.0	11.7	.234	104.7	31.6	**.001**
-94.2	48.2	.051	187.1	54.5	**.001**	1.3	16.4	.935	-43.7	57.3	.446
24.1	5.0	.629	66.9	49.9	.180	-4.7	21.5	.826	-24.7	57.6	.668
46.7	52.4	.374	78.9	52.7	.134	23.4	22.4	.297	34.6	6.6	.568
53.1	55.0	.335	94.9	55.1	.085	15.6	23.5	.506	21.7	63.5	.733
		.749			.284			.581			.791

3

Psychosocial factors of physical activity among people with disabilities: Prospective cohort study

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Abstract

Purpose/objective: This study aimed to 1) explore the associations between psychosocial factors and physical activity behavior in people with physical disabilities and/or chronic diseases, both between and within persons over time; and 2) examine whether these associations differ for people initiating and people maintaining physical activity behavior.

Research methods/design: Data of 1256 adults with physical disabilities and/or chronic diseases enrolled in the prospective cohort study Rehabilitation, Sports and Active lifestyle (ReSpAct) were analyzed. Self-reported physical activity and four main psychosocial factors (i.e. self-efficacy, attitude, motivation, social support) were measured with questionnaires 3-6 weeks before discharge (T0) and 14 (T1), 33 (T2) and 52 (T3) weeks after discharge from rehabilitation. Hybrid multilevel regression models (corrected for age, sex, education level, diagnosis, counseling support) were used.

Results: Multivariable significant between-subject associations were found for self-efficacy (std β=.094 [95%CI .035 – .153]) and intrinsic motivation (std β=.114 [95%CI .036 – .192]). Multivariable significant within-subject associations were found for identified regulation (std β=-.038 [95%CI -.072 – -.005]) and intrinsic motivation (std β=.049 [95%CI .016 – .082]). Effect modification of initiating or maintaining physical activity was found for the between-subject association of attitude (p=.035). No significant associations were found for social support, amotivation, external regulation, and introjected regulation.

Conclusion/implications: This study is the first that explored the between- and within-subject associations between psychosocial factors and physical activity over time in a large cohort of adults with physical disabilities and/or chronic diseases. The findings indicate the importance of intrinsic motivation, identified regulation, and self-efficacy in initiating and maintaining physical activity behavior.

Keywords: Physical activity, Behavior change, Psychosocial factors, Hybrid multilevel regression analysis

Impact

- The theoretical framework Physical Activity for people with Disabilities (PAD) model emphasizes the importance of psychosocial factors, including motivation, self-efficacy, attitude, and social support, on physical activity behavior of people with physical disabilities and/or chronic diseases.
- Informed by the PAD model, the ReSpAct (Rehabilitation, Sports and Active Lifestyle) study is the largest multicenter prospective cohort study including self-reported physical activity data from a diverse group of adults with physical disabilities or chronic diseases during and after rehabilitation care.
- This study is the first that disentangles the between- and within-subject associations between these key psychosocial factors and physical activity behavior in a large group of adults with physical disabilities and/or chronic diseases. Disentangling these associations helps better understand the relationships between psychosocial factors and physical activity, which in turn can help improve physical activity counseling and promoting activities during and after rehabilitation.
- Increasing intrinsic motivation within participants is associated with improvements in physical activity behavior after rehabilitation. These findings indicate the value of integrating physical activity counseling support activities focusing on increasing intrinsic motivation during and after rehabilitation.
- Providing tailored physical activity counseling during and after rehabilitation is a promising approach to improve physical activity in people with disabilities.

Introduction

Despite the numerous health benefits of physical activity (PA) in people with physical disabilities and/or chronic diseases [1, 2], many tend to have an inactive lifestyle. To illustrate, around 50% of people with physical disabilities and/or chronic diseases are inactive, defined as less than 10 minutes per week of moderate to vigorous activities [3, 4]. People with physical disabilities and/or chronic diseases are also 16-62% less likely to meet PA recommendations than people without disabilities (such as the 150-300 minutes of moderate to vigorous activities per week guideline of the World Health Organization) [1, 5]. People with physical disabilities and/or chronic diseases are particularly at risk of developing an inactive lifestyle after rehabilitation [6]. However, when PA is supported and promoted during and after rehabilitation, an active lifestyle can be maintained [7-9]. These findings illustrate the importance of PA promotion and counseling during and after rehabilitation to increase PA in people with physical disabilities and/or chronic diseases.

Behavior change theories can help understand PA behavior and inform and improve PA promotion interventions and programs. There are numerous behavior change theories [10], such as Health Action Process Approach (HAPA)) [11] and Self-determination theory [12]. The Physical Activity for people with a Disability (PAD) model is a disability-specific theoretical framework, developed to describe and understand the relationship between PA, its determinants and functioning of people with disabilities [13]. The PAD model integrates the Attitude, Social influence and self-Efficacy model [14] with the International Classification of Functioning, Disability and Health model [15].

According to the PAD model, psychosocial factors are important determinants for improving PA; four of which are self-efficacy, motivation, social support, and attitude [13]. First, self-efficacy is defined as one's belief in their capabilities to exercise control over challenging demands and their own function [16]. Various literature reviews reported positive associations between self-efficacy and PA behavior in both people with disabilities [17] and people without disabilities [18, 19]. Second, motivation can be divided into amotivation, more controlled forms of extrinsic motivation (i.e. external regulation, introjected regulation), more autonomous forms of extrinsic motivation (identified regulation), and intrinsic motivation [12]. To engage in behavior, amotivation is considered as a lack of any intention, external regulation to avoid punishment or for external rewards, introjected regulation to maintain self-approval or avoid guilt, identified regulation as leading to personally valued outcomes, and intrinsic motivation for enjoyment and satisfaction itself [12]. Literature reviews found consistent associations between motivation and PA, with more autonomous forms of motivation positively associated with exercise [18-20]. Third, social support is social relationships that give people emotional and practical resources they need and can encourage healthier behavioral patterns [21]. Literature reviews found social support to be positively associated with PA behavior in older adults and students [22, 23], positively associated with leisure time PA participation in people with physical disabilities [24] and an effective element of PA interventions for people with physical disabilities [17]. Finally, attitude is considered to be an important determinant of the intention to be physically active according to behavior change theory [14, 25]. In people with physical disabilities, literature reviews found moderate effects of attitude on intention to PA [26], and attitude to be positively associated with leisure time PA participation [24].

A major limitation of the existing literature on associations between psychosocial factors and PA is that most of the studies have a cross-sectional design [17-19, 22, 27]. Prospective studies assessing the associations between psychosocial factors and PA in people with various physical disabilities/chronic diseases are scarce. Prospective studies provide opportunities to study changes in psychosocial factors and PA behavior over time, both between persons and within a person [28]. Such prospective data are important to improve our understanding of behavior change in PA and to improve PA promotion interventions and programs in people with disabilities.

An important aspect in the PA behavior change literature is the distinction between PA initiation and PA maintenance [29-32]. PA maintenance is recently conceptualized as "a process marked by a shift in the mechanisms of action determining behavioral performance" [33]. Behavior change theories applying a stage model typically support this conceptualization, as these stage models theorize that certain determinants are more important during initiation and others more important during maintenance [11, 34-36]. Indeed, studies have shown that the effects of psychosocial factors may be different for people with physical disabilities and/or chronic diseases initiating PA behavior compared with those maintaining PA behavior [11, 37-39]. However, it is currently unknown if adults with physical disabilities and/or chronic diseases initiating PA have different associations between the development of PA after rehabilitation and changes in psychosocial factors compared with people maintaining PA. This might be relevant information to further tailor PA promotion and counseling.

Using the PAD model as theoretical basis, the evidence-based Rehabilitation, Sport and Exercise program (RSE; Dutch: Revalidatie, Sport en Bewegen) was developed to promote initiating and maintaining PA using tailored counseling in people with physical disabilities and/or chronic diseases during and after rehabilitation [7, 8, 40, 41]. And even though the randomized controlled trial underlying the RSE program showed promising results, there was a large variability in the extent to which participants benefitted from the PA counseling [7], suggesting need and opportunities to further improve the PA counseling support [42, 43].

Therefore this study aimed to 1) explore the between- and within-subject associations between psychosocial factors (motivation, self-efficacy, social support, attitude) and PA behavior in people with physical disabilities and/or chronic diseases over time during and up to one year after rehabilitation; and 2) explore whether the associations between psychosocial factors and PA differ between people initiating and people maintaining PA behavior. We expect that people with more positive outcomes on the psychosocial factors are more physically active, and that improving psychosocial factors within a person leads to an increase in PA. We expect the associations between psychosocial factors and PA behavior to be different between people initiating and people maintaining PA behavior, although we do not have specific expectations regarding the directions of these associations.

Methods

Study design and participants

This study is part of the Rehabilitation, Sports and Active lifestyle (ReSpAct) study, a multicenter prospective cohort study designed to evaluate the PA and sports stimulation program RSE [9, 40, 41]. Participants were included between May 2013 and August 2015, and followed over time with a set of questionnaires: 3-6 weeks before discharge of rehabilitation (Baseline: T0), and at 14 (T1), 33 (T2), and 52 (T3) weeks after discharge of rehabilitation. Participants included in the ReSpAct study: 1) were 18 years or older; 2) were diagnosed with a physical disability and/or chronic disease; 3) received inpatient, outpatient, or consultancy rehabilitation treatment; and 4) participated in the RSE program. People were excluded from participation in the ReSpAct study when they: 1) were unable to complete questionnaires, even with help; or 2) participated in a PA program other than RSE. The study was approved by the Ethical Committee of the Center for Human Movement Sciences of the University Medical Center Groningen (reference: ECB/2013.02.28_1). All participants signed an informed consent and participated voluntarily.

Self-reported PA

Self-reported PA behavior was measured using the Adapted version of the Short Questionnaire to ASsess Health enhancing physical activity (Adapted-SQUASH) [44], a 19-item recall questionnaire to assess PA among adults with disabilities based on an average week of the past month. Participants had to report the frequency (number of days), duration (hours and minutes per day), and perceived intensity of activities, pre-structured in four settings (commuting activities, activities at work and school, household activities, and leisure time activities). The Adapted-SQUASH is reliable (ICC = .67 for total activity score and ICC = .76 for total minutes of activity per week), and has comparable validity to other PA questionnaires when compared to accelerometer-derived PA (ρ = .40 for total activity score and ICC = .22 for total minutes of activity per week) [44].

Using a custom-created syntax (SPSS statistics 26, IBM), raw Adapted-SQUASH data was processed into the total activity score, to include the intensity of PA behavior. Total activity score was calculated by multiplying duration by intensity of each activity, and then adding this together. Intensity was based on self-reported intensity combined with a set metabolic equivalent of task (MET) value based on the Ainsworth compendium of physical activities [45] and a compendium of energy costs of physical activities for wheelchair-dependent individuals [46]. Adapted-SQUASH data of a measurement occasion was invalid when more than one of the pre-structured settings was missing, when total minutes PA per week was higher than 6720 minutes (on average 16 hours/day) or when the total activity score was higher than 60480.

Psychosocial factors

Motivation for PA was measured using the Behavioral Regulation in Exercise Questionnaire (BREQ-2) [47], a 19-item questionnaire with a five-point Likert scale. It consists of five subscales (amotivation, external regulation, introjected regulation, identified regulation, and intrinsic motivation), being the dimensions of motivation according to the Self-determination theory [48]. Since there is debate on whether the use of the combined Relative Autonomy Index score does justice to the multi-dimensionality of motivation [49], we used the scores of each subscale separately.

We assessed self-efficacy towards PA using five items developed by Marcus et al. [50] which showed good internal consistency (Cronbach's α = .82), to which we added two items to assess a more comprehensive self-efficacy construct. The addition of the two items improved the internal consistency of the questionnaire assessed in the ReSpAct cohort (n = 1719). More information on the internal consistency of this 7-item questionnaire can be found on Open Science Framework (https://osf.io/9e3pw). Scoring ranged from 0 (not at all confident) to 10 (very confident) for the individual items, and the total score was the sum of the seven items.

Attitude toward PA was assessed with three items, which were based on previous research [51, 52]. On a five-point Likert scale, participants were asked if they believe being regularly active was 1) very good to very bad, 2) very important to totally not important and 3) very fun to totally no fun. A lower score represents a more positive attitude towards PA. For better interpretability in further analysis, items were recoded so that higher scores indicate better attitude towards PA. A sum score of the recoded items was used as the final attitude score.

Perceived social support was measured using seven items with strong factor loadings from the Social Support for Exercise Behavior questionnaire [53], partly based on a previous selection of Papandonatos et al. [54]. Items were scored on a 5 point ordinal scale, ranging from 1 "never" to 5 "very often". The final score was calculated as the sum score of the 7 items.

Personal factors and diagnosis

Personal factors included age, sex, body mass index (BMI), education level, and stage of change regarding PA. Education level was dichotomized into high (university and higher) and low, for international comparability. Stage of change was assessed with one question with 5 answer options corresponding with the precontemplation, contemplation, preparation, action, and maintenance stage [50]. We dichotomized the stages of change for two reasons. First, a pragmatic reason, as using the full five stages would decrease the interpretability of the results. Second, there is discussion on the demarcation of the different stages of change based on the passage of time [16]. In line with previous research [37, 55] and behavior change theories [11, 30], the stages of change were dichotomized into two meaningful groups representing initiating PA behavior and maintaining PA behavior. Participants scoring precontemplation, contemplation or preparation were categorized as initiating PA behavior. Participants scoring action or maintenance were categorized as maintaining PA behavior. Diagnoses were grouped according to diagnosis groups of the Dutch Diagnose-Treatment Combinations, which are based on the International Classification of Diseases (ICD-10) structure: amputation (both upper and lower extremities), brain disease (e.g. stroke, congenital brain disease), chronic pain, musculoskeletal disease (e.g. conditions of upper-, lower extremities and spine, rheumatic conditions), neurologic disease (e.g. multiple sclerosis, Parkinson's disease), organ disease (e.g. chronic obstructive pulmonary disease, heart disease), spinal cord injury (SCI), and other (e.g. medically unexplained symptoms, chronic fatigue syndrome) [56]. Age, sex, and diagnosis were reported by the RSE counselor, and BMI, education level, and initiating or maintaining were self-reported by the participant.

Statistical analysis

Participants of the ReSpAct study were included in the analysis of the current study when there was availability of data on the diagnosis of the participants, together with availability of valid data of the Adapted-SQUASH at baseline and at least one follow-up measurement of the participants. Descriptive information of the population is shown in mean $\pm$ standard deviation or median (interquartile range) for continuous variables, and percentages for categorical variables. Differences in baseline characteristics between participants included and excluded in the analysis were tested with independent samples t-test or Mann-Whitney U test for continuous variables (depending on normality of data) and Pearson chi^2 test for categorical variables.

Besides the overall longitudinal relationship between psychosocial factors and PA, hybrid multilevel regression models were also used to disentangle the between- and within-subject effects of psychosocial factors on PA [28]. To do so, for each psychosocial factor, for each participant we created a mean score over the four measurement occasions (time independent) and a deviation score for each measurement occasion (time dependent), calculated as the deviation between the score on the measurement occasion and the individual mean score. Both (time independent) mean score and (time dependent) deviation score were inserted as independent variables in the hybrid multilevel regression models. The standardized regression coefficient of the mean score then describes the between-subject effect, indicating the effect of a difference in a certain psychosocial factor on PA between persons. The standardized regression coefficient of the deviation score describes the within-subject effect, indicating the effect of a change in the psychosocial factor on PA within a person over time. Random intercepts were included in all models to adjust for correlated observations within participants and within rehabilitation institutes.

'Univariable' models

For each of the four psychosocial factors, we first applied 'univariable' overall models with the PA total activity score as dependent variable and the psychosocial factors as independent variables. This was followed by the 'univariable' hybrid models, with the PA total activity score as dependent variable and the mean and deviation score of the psychosocial factors as independent variables. All 'univariable' models were corrected for age, sex, BMI, education level, diagnosis group, and number of counseling sessions.

Multivariable model

To correct for potential overlapping effects of the psychosocial factors, a multivariable overall model and multivariable hybrid model were then applied. All psychosocial factors were included in the multivariable models, as there was no multicollinearity among the psychosocial factors. The multivariable model was corrected for age, sex, BMI, education level, diagnosis group, and number of counseling sessions

Effect modification

To analyze whether the effect of the psychosocial factors differs between people initiating or maintaining PA, i.e. effect modification, we added initiators and maintainers and an interaction term between both mean and deviation score of a psychosocial factor and initiators and maintainers to the 'univariable' hybrid models.

Transparency and openness

The ReSpAct study was preregistered in the Dutch Trial Register (NTR3961/NL3788). All analyses and data processing codes are available on Open Science Framework (https://osf.io/f4myq/). De-identified data supporting the findings of this study are available from the corresponding author upon reasonable request. Analyses were performed in R and R studio [57], using the lmerTest package for multilevel regression analyses [58], and ggpot2 and sjPlot packages for graphics [59, 60]. As there is no obvious gain to address missing values using multiple imputations when using multilevel longitudinal regression models [61], this was not done in the current study. A table with the number of available data points per measurement occasion for the dependent and independent variables is presented in appendix 1. Significance level was set at .05.

Results

Of the 1719 participants who participated in the ReSpAct study, 1256 participants were included in the analysis of the current study. Participants were on average 50.7 ± 13.4 years old, 47.3 % were male, and had a median PA score of 4560 (range: 2600-7380) at baseline. The three largest diagnosis groups were brain disease (27.1%), musculoskeletal disease (18.6%), and chronic pain (15.8%) (table 1). Excluded participants were significantly younger and received fewer counseling sessions at baseline (table 1). A descriptive analysis of PA over time can be found in a previously published study [9], and a descriptive analysis of the different psychosocial factors over time can be found on OSF (https://osf.io/s8u7r).

'Univariable' models

Results of the corrected 'univariable' multilevel regression models are shown in table 2. We found significant overall associations for intrinsic motivation (standardized regression coefficient (std β) = .123 [95% CI .073 – .172]), self-efficacy (std β = .087 [95% CI .052 – .122]), and attitude (std β = .045 [95% CI .012 – .078]). Disentangling these overall associations, we found significant within-subject associations for two subscales of motivation: identified regulation (std β = -.033 [95% CI -.065 – -.002]) and intrinsic motivation (std β = .049 [95% CI .018 – .080]). Significant between-subject associations were found for intrinsic motivation (std β = .113 [95% CI .041 – .184]), self-efficacy (std β = .141 [95% CI .095 – .186]) and attitude (std β = .110 [95% CI .063 – .156]). Figures of the significant corrected 'univariable' associations can be found in appendix 3.

Multivariable model

Table 2 shows the results of the multivariable hybrid multilevel regression analysis. In the corrected multivariable model, the between-subject association of attitude was not significant anymore. The between-subject association of self-efficacy and intrinsic motivation, as well as the within-subject association of identified regulation and intrinsic motivation, remained statistically significant.

Effect modification

We found significant effect modification of initiating vs maintaining PA behavior for the 'univariable' between-subject effect of attitude (p=.035). The between-subject effect of attitude on PA, with people with a more positive attitude being more physically active, was more pronounced in people initiating their PA behavior (see figure 1). No other significant effect modification was found (appendix 2).

Table 1. Baseline characteristics of in- and excluded participants.

	Included (N=1256)	Excluded (N=463)
Personal factors		
Age (years)	50.7 ± 13.4	47.5 ± 14.3 *
Sex (% male)	47.3	42.1
BMI (kg/m2)	27.5 ± 8.6	27 ± 5.9
Education level (% High)[a]	25.1	21.1
Physical activity score	4560 (2600 - 7380)	4320 (2055 - 7552)[b]
Initiation vs maintaining		
% Initiation	40.8	42.7
% Maintaining	59.2	57.3
Rehabilitation factors		
Diagnosis group		
% Brain disease	27.1	25.7
% Musculoskeletal disease	18.6	19.1
% Chronic pain	15.8	19.1
% Neurologic disease	15.0	13.2
% Organ disease	12.1	10.5
% Amputation	4.5	4.5
% Spinal cord injury	3.0	4.5
% Other diseases	3.8	3.4
Rehabilitation context		
% Rehabilitation center	71.6	75.4
% Hospital	28.4	24.6
Rehabilitation form		
% Inpatient	2.8	3.7
% Outpatient	89.8	90.1
% Consultancy	7.4	6.3
Number of counseling sessions		*
0%	11.4	21.0
% 1-3	56.4	55.3
% 4 or more	32.2	23.8
Psychosocial factors		
Motivation		
Amotivation	0 (0 - 0.2)	0 (0 - 0.5)
External regulation	0.2 (0 - 0.8)	0.2 (0 - 1)
Introjected regulation	1 (0.3 - 1.7)	1 (0.3 - 1.7)
Identified regulation	3 (2.2 - 3.5)	3 (2.2 - 3.5)
Intrinsic motivation	3 (2.2 - 3.5)	3 (2.2 - 3.8)
Self-efficacy	42 (34 - 49)	41 (33 - 49)
Attitude	13 (11 - 15)	13 (11 - 15)
Social support	19 (14 - 23)	18 (14 - 23)

Note: Data presented as mean ± standard deviation, median (interquartile range) or percentage.
[a] Completed higher education
[b] Based on data of 344 excluded participants, as 119 participants were excluded due to no physical activity data.
* Significant difference on baseline between in- and excluded participants based on independent sample t-tests for normally distributed continuous variables, Mann-Whitney U tests for non-normally distributed continuous variables, and Chi-square tests for categorical variables (*significant result, p<.001)

3

Table 2. Standardized associations between psychosocial factors and PA using 'univariable' and multivariable hybrid (multilevel) models corrected for age, sex, body mass index, education level, diagnosis, and number of counseling sessions.

	Overall effect				Between-subjects effect				Within-subjects effect			
	Std β	95% CI		p-value	Std β	95% CI		p-value	Std β	95% CI		p-value
'Univariable' models												
Motivation												
Amotivaton	.003	-.034	.040	.878	-.003	-.060	.054	.916	.006	-.020	.032	.662
External regulation	-.013	-.052	.025	.497	-.009	-.062	.045	.747	-.002	-.028	.024	.855
Introjected regulation	-.001	-.039	.037	.957	-.013	-.066	.040	.635	.001	-.025	.027	.941
Identified regulation	-.030	-.079	.020	.246	.025	-.053	.104	.530	-.033	-.065	-.002	**.037**
Intrinsic motivation	.123	.073	.172	**.000**	.113	.041	.184	**.002**	.049	.018	.080	**.002**
Self-efficacy	.087	.052	.122	**.000**	.141	.095	.186	**.000**	.017	-.007	.041	.168
Attitude	.045	.012	.078	**.008**	.110	.063	.156	**.000**	.001	-.024	.026	.927
Social support	.012	-.023	.046	.516	.022	-.024	.068	.347	.001	-.023	.025	.949
Multivariable models												
Motivation												
Amotivaton	.019	-.020	.057	.341	.004	-.056	.063	.906	.017	-.011	.044	.240
External regulation	-.018	-.059	.022	.377	-.004	-.061	.054	.902	-.008	-.036	.020	.567
Introjected regulation	.006	-.034	.046	.769	.005	-.051	.061	.855	.002	-.025	.029	.872
Identified regulation	-.049	-.103	.005	.076	-.016	-.102	.070	.716	-.038	-.072	-.005	**.024**
Intrinsic motivation	.125	.071	.179	**.000**	.114	.036	.192	**.004**	.049	.016	.082	**.003**
Self-efficacy	.065	.023	.107	**.002**	.094	.035	.153	**.002**	.015	-.013	.043	.283
Attitude	.002	-.036	.040	.908	.003	-.060	.065	.934	-.004	-.031	.023	.767
Social support	-.006	-.044	.032	.753	-.008	-.059	.042	.740	-.001	-.028	.026	.924

Note: The regression coefficient of the overall association is a weighted average of the within and between regression coefficient.
Std = standardized, CI = confidence intervals

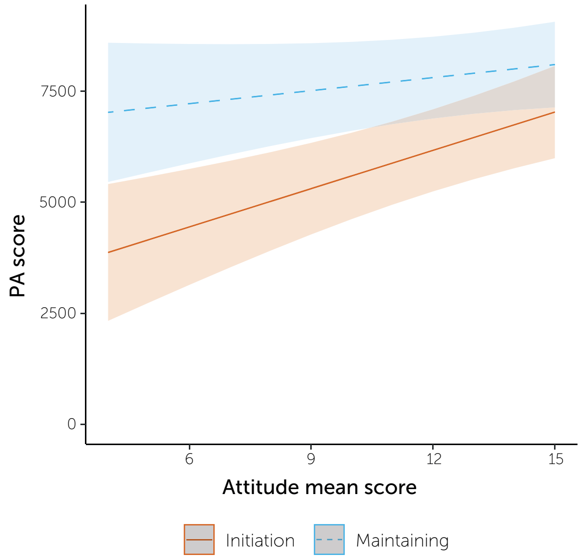

Figure 1. Effect modification of initiating or maintaining PA behavior on the association between the mean score of attitude and PA behavior.

Discussion

To our knowledge, this is the first study to explore the associations between psychosocial factors and PA behavior over time, both between and within participants, in a large cohort of people with various physical disabilities and/or chronic diseases. In this relatively physically active cohort, we found that participants with higher intrinsic motivation and higher self-efficacy scores were more physically active than those with lower scores in these psychosocial factors during and after rehabilitation. We found that an increase in intrinsic motivation after rehabilitation within a person was associated with an increase in PA, whereas an increase in identified regulation after rehabilitation was associated with a decrease in PA. There was a significant effect modification between people initiating or maintaining for the between-subject effect of attitude. No other significant effect modification was found for the studied psychosocial factors.

In line with our hypothesis, we found significant between-subject and within-subject associations between intrinsic motivation and between-subject associations between self-efficacy and PA during and after rehabilitation. This aligns with various behavior change theories [11, 12, 62] and previous studies among persons with physical disabilities and/or chronic diseases [17, 20]. These results highlight the potential value of focusing on self-efficacy and intrinsic motivation in the rehabilitation context.

Contrary to what we expected and what previous research has shown [18, 20, 22], we found a small negative association between identified regulation and PA and no associations between other motivation aspects, attitude or social support. Additionally, the significant associations of intrinsic motivation and self-efficacy had small effect sizes. We suggest three potential reasons explaining the lack of significant, strong associations between psychosocial factors and PA behavior in our cohort. First, participants had on average high baseline scores on the psychosocial factors. Scores on social support were much higher compared to a previous study using the same scale [54] and BREQ-2 results were comparable with previous studies in populations that followed PA programs [47, 63]. The median attitude on baseline was 13 on a scale of 3 to 15, suggesting a positive attitude towards PA. These high baseline scores in the psychosocial factors could indicate a decreased potential for further improvement in these psychosocial factors, explaining the lack of significant relationships with changes in PA. Additionally, our cohort is a relatively active cohort compared to a typical population of people with physical disabilities and/or chronic diseases [5, 9]. Together, this indicates the importance of these psychosocial factors in initiating and maintaining PA during and after rehabilitation. Second, there was a large variability in PA behavior in our cohort, both between participants and within participants. A study on the validity and reliability of the Adapted-SQUASH showed that although the questionnaire had good reproducibility, the questionnaire had wide limits of agreement [44]. Wide limits of agreement for reliability mean a large variability within a person between two measurement occasions, which reduce the chance of detecting relationships between PA and measures of health [64]. Third, there may be determinants that are of influence on PA behavior in people with physical disabilities and/or chronic diseases other than psychosocial factors (e.g. barriers regarding PA, implicit attitudes towards PA, rehabilitation processes) [1, 65, 66]. For example, previous studies showed that people with physical disabilities and/or chronic diseases experience many barriers regarding PA that differ from the barriers that people without physical disabilities and/or chronic diseases experience [24, 65]. Furthermore, previous research showed that reducing barrier beliefs in primary care patients is related to an increase in PA behavior [67, 68]. It could be that changes in barriers regarding PA are equally or more impactful on a person's PA behavior compared with changes in psychosocial factors. Future research should further investigate how changes in barriers regarding PA, and in other determinants, affect PA behavior, especially in people with physical disabilities and/or chronic diseases.

In contrast to our hypotheses, we did not find effect modification between people initiating or maintaining PA behavior and the studied psychosocial factors of PA. The exception being the finding that a better attitude is more positively associated with PA behavior in people initiation compared to people maintaining PA behavior. Previous cross-sectional studies did find differences in psychosocial factors between people in different stages of behavior change [11, 37-39] . However, these studies looked at specific components of the psychosocial factors related to different stages, as theorized by the HAPA model [11]. We did not measure the psychosocial factors in such detail, but in a more general manner. Future research is needed to explore the differences in effect of changing these specificcomponents of psychosocial factors on PA behavior between people initiating or people maintaining their PA behavior.

Scientific and practical implications

For improving PA counseling support, and PA promotion in general, it is important to advance our understanding of how changes in psychosocial factors within a person are associated with changes in their PA behavior over time. This study adds to existing PA behavior change and rehabilitation literature, by providing insights into associations between key psychosocial factors and PA behavior, both *between* and *within* persons over time. Changes within a person are particularly important for improving PA counseling support intervention. The contradictory findings of the overall-, between- and within-associations reported in our study highlight the potential relevance of disentangling these associations to advance our understanding of how psychosocial factors influence PA behavior in people with and without disabilities. We encourage researchers to use similar techniques to provide both between- and within-subject effects in future prospective research on determinants of PA.

The findings of this study suggest the importance of increasing intrinsic motivation for PA behavior in people with physical disabilities and/or chronic diseases during and after rehabilitation. Motivational interviewing is a technique where the recipient rather than the counselor is encouraged to voice the arguments for change, eliciting intrinsic motivation for change [69]. Providing tailored PA counseling support using this technique is a promising approach to substantially improve PA behavior in people with physical disabilities and/or chronic diseases during and after rehabilitation.

Strengths and Limitations

An important strength of this study is the inclusion of a large, diverse group of adults with physical disabilities and/or chronic diseases who were followed over time during and up to one year after discharge from rehabilitation. Uniquely, participants in the study took part in an evidence-based PA promotion intervention (RSE) that was offered as part of their regular rehabilitation treatment [41]. Another strength of the study is the strong disability-specific theoretical foundation (PAD model) of the PA promotion intervention that was used to inform the design and measures of our study [40]. Furthermore, this study is the first that used a rigorous statistical method to disentangle the between- and within-subject associations between psychosocial factors and PA in adults with physical disabilities and/or chronic diseases.

Some limitations should be acknowledged. First, there is potential bias in the ReSpAct cohort. The cohort is on average relatively active compared to a typical population of people with disabilities and/or chronic diseases [5, 9]. This might indicate that the ReSpAct cohort consists of people who were most engaged in and benefited the most from the rehabilitation treatment. Therefore, it is questionable if the results can be translated to a less active group of adults with physical disabilities or chronic disease. This study, however, does give a unique insight into adults with physical disabilities and/or chronic diseases who are physically active. Second, we did not control for severity of disability in the analyses. As the severity of disability could potentially influence the results, it is important to take this into consideration for future research. Third, this study used self-reported questionnaires to assess PA behavior. Questionnaires are subjected to bias, most notably recall bias and social desirable answers [70]. In the case of PA, questionnaires mostly overestimate actual PA behavior. However, for practical reasons (i.e. costs, logistics) PA was self-reported in this prospective cohort study. Fourth, we only focused on four key psychosocial factors. Future research is needed to explore associations between other determinants and PA behavior. Fifth, we dichotomized participants into those initiating PA and those maintaining PA based on the five stages of change of the transtheoretical model, which is not supported by the model. The dichotomization does not make a distinction between people ready and people not ready to change their behavior, as proposed by the transtheoretical model. However, we studied participants of a PA promotion rehabilitation program, suggesting that participants were ready to become more active. Indeed, only 1.2% of the participants self-reported being in the precontemplation stage. Furthermore, the dichotomization was informed by previous literature and other behavior change theories (e.g. HAPA). Lastly, aligning with behavior change theory, we hypothesized that changes in psychosocial factors of PA would result in changes in PA behavior. It is possible that these associations are bidirectional [71]. Future research is needed to improve our understanding on the working mechanisms of the associations between psychosocial factors and PA behavior.

Conclusion

This is the first large-scale, multicenter cohort study that explored the between- and within-subject associations between psychosocial factors and PA behavior over time in people with physical disabilities and/or chronic diseases. The study demonstrates the variability and complexity of how psychosocial factors affect PA levels in people with disabilities and/or chronic diseases during and after rehabilitation. We found small significant associations of intrinsic motivation and self-efficacy between persons and small significant associations of intrinsic motivation and identified regulation within a person. This may suggest the importance of motivation and self-efficacy in counseling people with physical disabilities and/or chronic diseases initiating or maintaining PA during or after rehabilitation.

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Chapter 3 - Appendix 1.

Appendix 1. Number of available datapoints per measurement occasion for dependent and independent variables.

	T0	T1	T2	T3
Physical activity score	1256	1124	973	876
Self-efficacy	1172	1052	916	837
Amotivation	1205	1035	908	826
External regulation	1202	1043	905	826
Introjected regulation	1205	1041	908	828
Identified regulation	1205	1042	908	826
Intrinsic motivation	1193	1031	901	825
Social support	1182	1043	915	836

Chapter 3 - Appendix 2.

Appendix 2. Univariable effect modification of stages of change on the psychosocial factor using hybrid multilevel models.

	Std β	95% CI		p-value
Self-efficacy				
Initiation vs maintaining				
Initiation [ref]				
Maintaining	0.176	0.052	0.301	0.006
Between	0.099	0.037	0.162	0.002
Within	-0.028	-0.068	0.011	0.164
Interaction				
Initiation*Between [ref]				
Maintaining*Between	-0.036	-0.182	0.109	0.624
Initiation*Within [ref]				
Maintaining*Within	0.027	-0.013	0.068	0.184
Attitude				
Initiation vs maintaining				
Initiation [ref]				
Maintaining	0.388	0.172	0.604	0.000
Between	0.110	0.051	0.169	0.000
Within	-0.034	-0.075	0.007	0.100
Interaction				
Initiation*Between [ref]				
Maintaining*Between	-0.248	-0.478	-0.017	0.035
Initiation*Within [ref]				
Maintaining*Within	0.027	-0.015	0.068	0.211
Social support				
Initiation vs maintaining				
Initiation [ref]				
Maintaining	0.090	-0.013	0.193	0.086
Between	-0.019	-0.081	0.042	0.533
Within	0.000	-0.041	0.042	0.986
Interaction				
Initiation*Between [ref]				
Maintaining*Between	0.084	-0.030	0.198	0.147
Initiation*Within [ref]				
Maintaining*Within	-0.016	-0.058	0.027	0.474

Appendix 2. Continued.

	Std β	95% CI		p-value
Motivation				
Initiation vs maintaining				
Initiation [ref]				
Maintaining	0.186	0.023	0.349	0.025
Amotivation Between	0.013	-0.054	0.080	0.708
Amotivation Within	0.020	-0.019	0.059	0.315
External regulation Between	0.007	-0.060	0.073	0.840
External regulation Within	-0.004	-0.044	0.036	0.841
Internal regulation Between	0.011	-0.062	0.084	0.772
Internal regulation Within	0.015	-0.030	0.060	0.514
Identified regulation Between	-0.002	-0.106	0.102	0.967
Identified regulation Within	-0.020	-0.072	0.032	0.456
Intrinsic motivation Between	0.104	0.011	0.197	0.028
Intrinsic motivation Within	0.021	-0.030	0.073	0.422
Interaction				
Initiation*Amotivation Between [ref]				
Maintaining*Amotivation Between	0.000	-0.055	0.054	0.986
Initiation*Amotivation Within[ref]				
Maintaining*Amotivation Within	-0.011	-0.051	0.030	0.600
Initiation*External regulation Between [ref]				
Maintaining*External regulation Between	-0.008	-0.067	0.050	0.786
Initiation*External regulation Within [ref]				
Maintaining*External regulation Within	0.005	-0.036	0.046	0.810
Initiation*Internal regulation Between [ref]				
Maintaining*Internal regulation Between	-0.022	-0.101	0.057	0.578
Initiation*Internal regulation Within[ref]				
Maintaining*Internal regulation Within	-0.016	-0.062	0.030	0.488
Initiation*Identified regulation Between [ref]				
Maintaining*Identified regulation Between	-0.039	-0.281	0.202	0.749
Initiation*Identified regulation Within [ref]				
Maintaining*Identified regulation Within	-0.027	-0.078	0.025	0.309
Initiation*Intrinsic motivation Between [ref]				
Maintaining*Intrinsic motivation Between	0.024	-0.162	0.210	0.800
Initiation*Intrinsic motivation Within [ref]				
Maintaining*Intrinsic motivation Within	0.018	-0.033	0.070	0.491

Models are corrected for age, sex, body mass index, education level, diagnosis and number of counseling sessions
std = standardized

Chapter 3 - Appendix 3.

Figures of significant associations

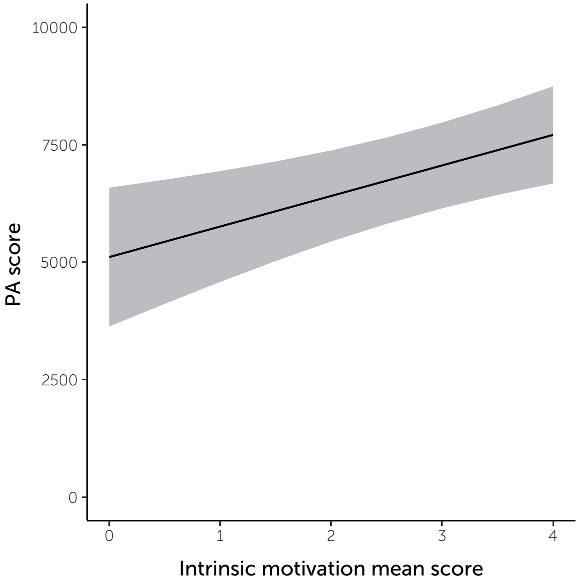

Figure A3.1. Corrected 'univariable' between-subject association between intrinsic motivation and PA behavior.

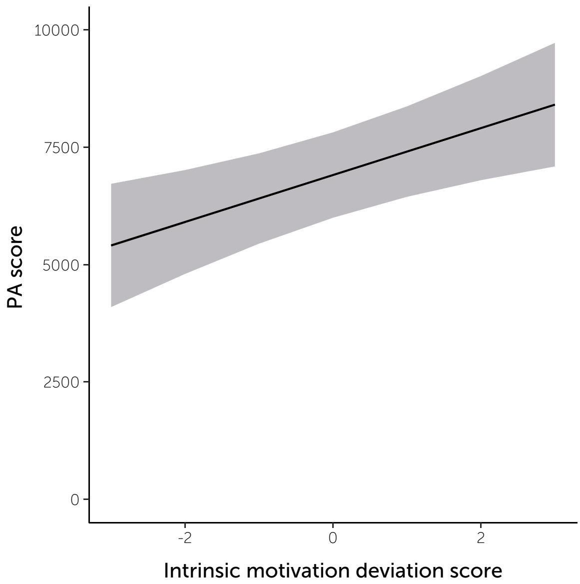

Figure A3.2. Corrected 'univariable' within-subject association between intrinsic motivation and PA behavior.

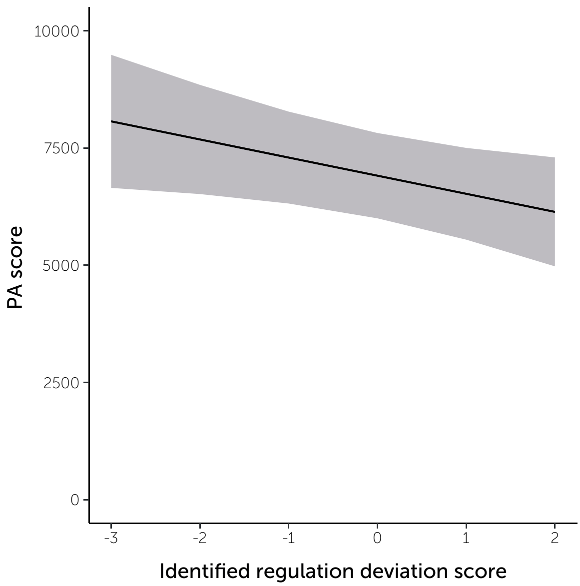

Figure A3.3. Corrected 'univariable' within-subject association between identified regulation and PA behavior.

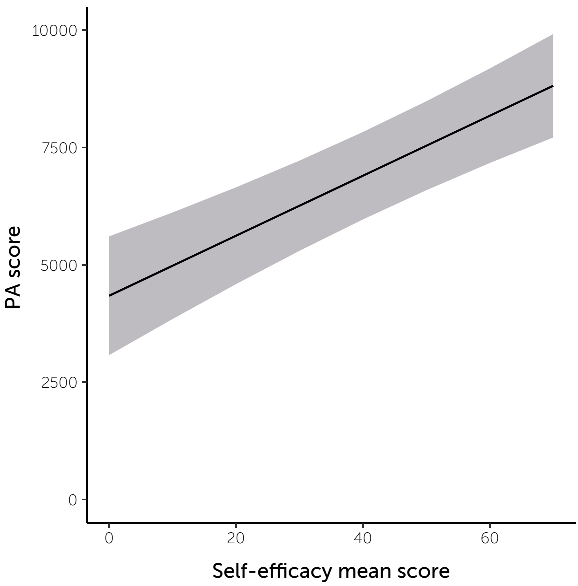

Figure A3.4. Corrected 'univariable' between-subject association between self-efficacy and PA behavior.

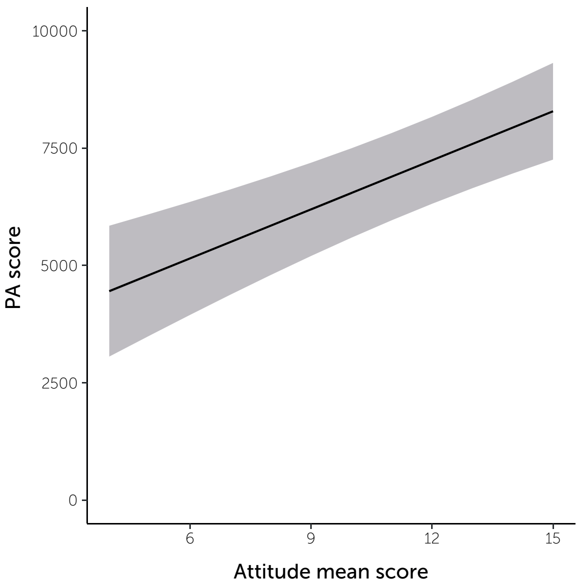

Figure A3.5. Corrected 'univariable' between-subject association between attitude and PA behavior.

4

Long-term trajectories of physical activity behavior in adults with physical disabilities and/or chronic diseases following rehabilitation: the prospective cohort study ReSpAct 2.0.

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Abstract

Purpose: This study aimed to identify trajectories of physical activity behavior from discharge up to 6-8 years after rehabilitation among adults with physical disabilities and/or chronic diseases, and to determine modifiable determinants associated with trajectory membership.

Material and methods: 390 Adults with physical disabilities and/or chronic diseases participated in the Rehabilitation, Sports and Active lifestyle (ReSpAct) 2.0 study with measurements at 3-6 weeks before discharge (T0), and 14 (T1), 33 (T2), and 52 weeks (T3), and 6-8 years (T4) after discharge from rehabilitation. Physical activity behavior and its determinants were assessed using questionnaires. Latent class growth modeling was used to identify trajectories of physical activity behavior. Associations between determinants at T0 and trajectory membership were analyzed using logistic regression analyses.

Results: Three trajectories of physical activity behavior were identified: a moderately active (n=297; baseline total physical activity: 1370 (770:2070) min/week), highly active (n=71; baseline total physical activity: 2950 (1945:3475) min/week), and increasingly active (n=22; baseline total physical activity: 1755 (461:2415) min/week) trajectory. Barriers regarding physical activity (OR=0.71, 95%CI 0.53–0.95) and perceived fatigue (OR=0.75, 95%CI 0.57–0.98) were significantly associated with trajectory membership in univariable models, corrected for age and sex.

Conclusions: Targeting barriers regarding physical activity and perceived fatigue early in rehabilitation seem crucial for membership of a trajectory resulting in a more favorable development of physical activity behavior after rehabilitation.

Keywords: Physical activity, Chronic disease, Physical disability, Long-term follow-up, Cohort study, Rehabilitation

Introduction

Despite many health benefits of physical activity (PA) for people with physical disabilities and/or chronic diseases [1], this population tends to have an inactive lifestyle [2]. Promoting PA in people with physical disabilities and/or chronic diseases has been a focus of numerous studies, but most of these studies investigate short-term effects on PA behavior [3]. Most health benefits of PA diminish over time when an active lifestyle is not sustained [4], while increases in PA behavior typically decrease after the intervention is finished [5]. Therefore, more attention should be placed on long-term (i.e. >12 months) PA adherence.

PA recommendations for optimal health benefits in people with physical disabilities and/or chronic diseases are defined as "at least 150 minutes of moderate-intensity PA, 75 minutes of vigorous-intensity PA, or an equivalent combination of both per week", but added that every increase in PA is meaningful [6]. For some diagnoses, diagnosis-specific PA recommendations are available, recommending lower minimum levels of moderate to vigorous intensity PA [7, 8]. People with physical disabilities and/or chronic diseases experience multiple barriers to PA [9]. This might put them more at risk of staying at or relapsing into an inactive lifestyle, especially when barriers are magnified. For example, during the COVID-19 pandemic, many people with disabilities reported lower levels of PA, which may have been due to the magnified barriers to PA in that period (e.g. closing of exercise facilities) [10, 11].

The period during and after rehabilitation offers a critical and promising window to promote long-term PA adherence [12, 13]. The Rehabilitation, Sports and Exercise program (RSE, Dutch: Revalidatie, Sport en Bewegen) is an evidence-based program that targets this period by providing tailored PA counseling using motivational interviewing [14, 15]. The Rehabilitation, Sports and Active lifestyle (ReSpAct) study evaluates the RSE program [14, 15] and showed that participants of the RSE program improved their PA behavior up to one year after rehabilitation [16]. However, it is unclear whether this increase in PA behavior can be sustained on the long-term.

The development of PA behavior over time is highly variable among people with physical disabilities and/or chronic diseases [3, 16]. Data-driven approaches such as latent class growth modeling (LCGM) assume that there are subpopulations that each follow their unique development [17]. Information on different trajectories of PA development can provide information on modifiable determinants (e.g. acceptance of disability) [18] that predict a more favorable development of PA behavior long term, which can help the rehabilitation setting by specifically tuning treatment to these determinants early on.

Previous research in people with physical disabilities and/or chronic diseases has shown that lifestyle (e.g. smoking), health-related factors (e.g. fatigue) and psychosocial factors (e.g. self-efficacy) are predictors for longer-term PA adherence

[19-22]. However, existing literature on the predictors for longer-term PA adherence only studied disease-specific populations [21, 22], or used a priori defined PA groups instead of data-driven trajectories.

Therefore, this study aimed to (1) identify trajectories of PA behavior from discharge up to 6-8 years after rehabilitation among adults with physical disabilities and/or chronic diseases who followed a tailored PA counseling rehabilitation program, and (2) determine modifiable determinants measured during rehabilitation that are associated with PA trajectory membership.

Materials and methods

Study setting

The ReSpAct study is a prospective cohort study designed to evaluate the RSE program in 18 rehabilitation institutes (rehabilitation centers and hospital departments) across the Netherlands [14, 15]. In The Netherlands, rehabilitation treatment is provided in an in- or outpatient setting, with the majority of patients receiving outpatient rehabilitation treatment. The duration is highly variable among diagnoses and settings, and individually adjusted, with outpatient rehabilitation having a typical duration of 12-16 weeks. Inpatient rehabilitation generally lasts up to 16 weeks. In the RSE program, sport and exercise are made an integrated part of the rehabilitation treatment. Shortly before discharge from the rehabilitation treatment, a first tailored PA counseling session is provided to participants of the RSE program. Then in the 13 weeks after discharge from rehabilitation, four additional counseling sessions are provided. In ReSpAct 1.0, participants of the study were followed over time from just before the first counseling session of the RSE program up to one year after discharge from rehabilitation [14]. ReSpAct 2.0 includes a long-term follow-up measurement among the same individuals, 6-8 years after discharge from rehabilitation. This resulted in a cohort that was followed using a stable set of questionnaires at a total of 5 measurement occasions: baseline (T0, 3-6 weeks before discharge), and 14 weeks (T1), 33 weeks (T2) 52 weeks (T3) and 6-8 years (T4) after discharge from rehabilitation. ReSpAct 1.0 and 2.0 were approved by the Ethical Committee of the Center for Human Movement Sciences and the Central Ethics Committee of the University Medical Center Groningen (reference: ECB/2013.02.28_1 and 201900645). All participants signed informed consent and participated voluntarily. For additional information on the RSE program and ReSpAct study, see appendix 1.

Participants

Participants were eligible for inclusion for ReSpAct 1.0 when they (1) were aged 18 years or older; (2) were diagnosed with a physical disability and/or chronic disease that is treated within rehabilitation and impaired physical activity (e.g. cardiopulmonary diseases); (3) received inpatient, outpatient, or consultancy rehabilitation treatment; and (4) participated in the RSE program. Participants were excluded when they (1) were unable to complete questionnaires, even with help; or (2) participated in another PA program besides RSE. The participants of ReSpAct 1.0 were enrolled between May 2013 and August 2015. Participants of ReSpAct 1.0 were invited to participate in ReSpAct 2.0 in March 2021 when they (1) had not withdrawn consent for participation in the ReSpAct study and (2) were not deceased during the ReSpAct 1.0 study period. Data collection for ReSpAct 2.0 took place between March 2021 and August 2021, during the COVID-19 pandemic.

Self-reported PA behavior

The Adapted version of the Short Questionnaire to Assess Health-enhancing physical activity (Adapted-SQUASH) was used to measure self-reported PA behavior at all measurement occasions [23]. The Adapted-SQUASH is a valid and reliable 19-item recall questionnaire to assess PA behavior among adults with physical disabilities and/or chronic diseases based on an average week of the past month [23]. To provide a measure of PA closest to the total dose of PA (i.e. duration * setting * intensity * mode * frequency) [16] , raw Adapted-SQUASH data were processed into the total PA score using a custom-created syntax (SPSS statistics 26, IBM). Adapted-SQUASH data of a measurement occasion was considered invalid when more than one of the pre-structured settings was missing, when the total minutes PA per week was higher than 6720 minutes (on average 16 hours/day) or when the total PA score was higher than 60480 (6720 minutes at maximum intensity score of 9). More information on the procedure and processing of the Adapted-SQUASH is provided in appendix 2.

Determinants

Based on the Physical Activity for people with a Disability (PAD) model and previous research [19-21, 24], we included the determinants described below. As certain determinants could be classified as both environmental as well as personal determinants (the terminology of the PAD model), we categorized determinants into: demographic, lifestyle, psychosocial, health-related and rehabilitation variables.

Demographic and lifestyle variables

Demographic variables included were age and sex. Lifestyle variables included were body mass index (BMI), smoking behavior (smokers and non-smokers), and alcohol consumption. Alcohol consumption was dichotomized into light or no alcohol consumption (≤3 glasses per week for males, ≤2 glasses per week for females) and moderate to excessive alcohol consumption (>3 glasses per week for males, >2 glasses per week for females).

Psychosocial variables

Based on the PAD model, intention to participate in PA, attitude towards PA, self-efficacy towards PA, intrinsic motivation for PA, and barriers regarding PA were included as psychosocial determinants. Intention was assessed with a single question to what extent participants were planning to be regularly active in the coming 6 months, with answers ranging from 0 (“not at all”) to 10 (“very”). Attitude toward PA was assessed with three items, which were based on previous research [25, 26]. On a 5-point Likert scale, participants were asked if they believe that being regularly active was (a) very good to very bad, (b) very important to totally not important, and (c) very much fun to totally no fun. For better interpretability, the item was recoded so that higher scores indicate a more positive attitude. Self-efficacy towards PA was assessed with five items developed by Marcus et al. [27] that showed good internal consistency (Cronbach’s α = .82). The ReSpAct research group added two items to assess a more comprehensive self-efficacy construct, which improved the internal consistency of the questionnaire (see: https://osf.io/mneqr). The total self-efficacy score was the sum of the seven items, each scored 0 to 10, in which a higher score indicates higher self-efficacy. Intrinsic motivation for PA was assessed using the intrinsic motivation subscale of the Behavioral Regulation in Exercise Questionnaire (BREQ)-2 questionnaire [28]. The subscale consists of 4 items with a 5-point scale (range 0 = “not true for me” to 4 = “very true for me”), and the overall score is the mean of those 4 items. In a previous study, we found that only the intrinsic motivation subscale of the BREQ-2 was related to PA behavior [24]. Barriers regarding PA were measured with 11 items, based on research of Sallis et al. [29] and Van der Ploeg et al. [30]. Items were scored on a five-point Likert scale (“never” to “very often”). The items were summed, to create a combined score for barriers ranging from 0 to 44.

Health-related variables

Based on the PAD model, health-related variables studied were acceptance of disability and/or disease, perceived fatigue, perceived pain, and diagnosis group. Participants were asked to complete these questions specifically for the diagnosis for which they received rehabilitation. Acceptance of disability and/or disease was assessed using a four-point Likert scale (ranging from 1 = “no acceptance” to 4 = “complete acceptance”). Thereafter, acceptance was dichotomized into no (no or little acceptance) and yes (acceptance to a large extent or complete acceptance).

Perceived fatigue was assessed using the Fatigue Severity Scale (FSS), a valid and reliable questionnaire to determine the impact of perceived fatigue in different disability populations [31]. Scores range from 1 to 7, with higher scores indicating more severe perceived fatigue [31]. Perceived pain was assessed with one item on a 6-point scale, with a higher score indicating more perceived pain (0-6, "no pain" to "severe pain") [32]. Perceived pain was dichotomized into no (no to light pain) and yes (moderate to severe pain). Dichotomization of the variables was done because the odds ratios did not linearly increase/decrease when entering these variables as categorical variables in the logistic regression, being one of the assumptions of logistic regression. Reported diagnoses were the primary reason for rehabilitation, and were grouped according to diagnosis groups of the Dutch Diagnose-Treatment Combinations, which are based on the International Classification of Diseases (ICD-10) structure [33]: amputation (both upper and lower extremities), brain disease (e.g. stroke, congenital brain disease), chronic pain, musculoskeletal disease (e.g. conditions of upper-, lower extremities and spine, rheumatic conditions), neurologic disease (e.g. multiple sclerosis, Parkinson's disease), organ disease (e.g. chronic obstructive pulmonary disease, heart disease), spinal cord injury, and other (e.g. medically unexplained symptoms, chronic fatigue syndrome). A complete overview of the items, in Dutch (original) and English (translated), can be found on Open Science Framework (https://osf.io/fwkqx).

Rehabilitation variables

Rehabilitation variables were the rehabilitation form (inpatient, outpatient, or consultancy rehabilitation), the rehabilitation context (rehabilitation center or hospital), and the number of tailored active lifestyle counseling sessions. The counseling sessions were part of the RSE program, with a maximum number of 5 sessions. All rehabilitation variables were reported by the physical activity counselor.

Statistical analysis

For the statistical analysis, we only included participants of the ReSpAct 2.0 cohort who met the following criteria: (1) data available on the diagnosis that was the primary reason for rehabilitation treatment; and (2) valid data on the Adapted-SQUASH at baseline and T4. Differences in baseline characteristics between in- and excluded participants were tested with independent samples t-test or Mann-Whitney U test for continuous variables (depending on normality of data) and Pearson chi^2 test for categorical variables.

To study both aims, the statistical analyses were conducted in two steps. First, we used LCGM to identify trajectories of PA behavior over the five measurement occasions during and up to 6-8 years after rehabilitation, using the total PA score. We considered linear growth models and linear and quadratic growth mixture models, following the common stepwise modeling strategies [34] and the Guidelines for Reporting on Latent Trajectory Studies [35]. First, a one-class model was determined, followed by sequentially adding up to four classes to investigate if model fit improved. As model fit criteria to determine the optimal number of classes, we used (1) a lower Bayesian Information Criterion (BIC) (a decrease of 10 points is regarded as sufficient improvement [36]); (2) a higher entropy, which is a standardized measure representing the accuracy of classification of individuals' trajectories with a range from 0 to 1 (higher values indicate better classification) [37]; and (3) average posterior probabilities of $\geq$.80 [34]. Furthermore, clinical interpretation and class size were taken into consideration when selecting the optimal number of classes. Participants were classified into the class to which they had the highest posterior probability (trajectory membership). Current literature suggests a sample size of at least 300 participants is needed for this type of analysis [38].

Second, to assess the predictive potential of modifiable baseline determinants (i.e. lifestyle, psychosocial, health-related and rehabilitation variables) of participants on trajectory membership, we performed logistic regression analyses. Trajectory membership resulting from the LCGM analysis was used as the dependent variable, with the modifiable baseline determinants as independent variables. We performed univariable and multivariable logistic regressions, both unadjusted and adjusted for age and sex. The continuous independent variables age, BMI, intention, attitude, self-efficacy, intrinsic motivation, perceived barriers, fatigue, and number of counseling sessions were standardized before adding to the analyses. Ninety-nine participants had missing data on the determinants at baseline, with in a total six percent missingness in these variables. We used multiple imputation following the Multiple Imputation by Chained Equations method to handle missingness [39]. Ten Imputations were performed on item level using parcel summary score multiple imputation [40]. All variables used in the analysis, with the addition of PA score, were used for multiple imputation, except trajectory membership (due to high correlation with baseline PA).

All statistical analyses were performed using R and Rstudio [41]. The LCMM package was used for the LCGM analyses [42]. The MICE package was used for multiple imputation [39], and the PSFMI package for the pooled logistic regression [43]. The ggplot2 package was used to create figures [44]. Significance level was set at $\alpha<0.05$. Scripts containing the data processing and analysis code, as well as additional information concerning the LCGM, are available on Open Science Framework (https://osf.io/xr5pe/).

Results

Characteristics of the study population

390 Participants of the ReSpAct 1.0 cohort (n=1719) completed the additional T4 questionnaire, and were included in the current study. Figure 1 illustrates a flowchart of inclusion. Included participants were on average 50.4 (12.1) years old and 50.0% were male. The three most common diagnosis groups were brain disease (27.9%, n=109), chronic pain (16.9%, n=66), and musculoskeletal disease (16.4%, n=64). Additionally, 35.9% of the participants reported to have one or more comorbidities at T0, and 29.7% reported having acquired one or more additional comorbidities in the year before T4. Participants had a median total PA score of 4555 (Q1:Q3: 2552 : 7418) (table 1). Missing PA scores over the five measurement occasions ranged from 0% (at T0 and T4) to 21%. Participants excluded from the analysis reported, on average, a higher education, a higher BMI, more often being a smoker, a lower intention to be active, more perceived barriers, and they received less counseling compared to participants included in the current analysis.

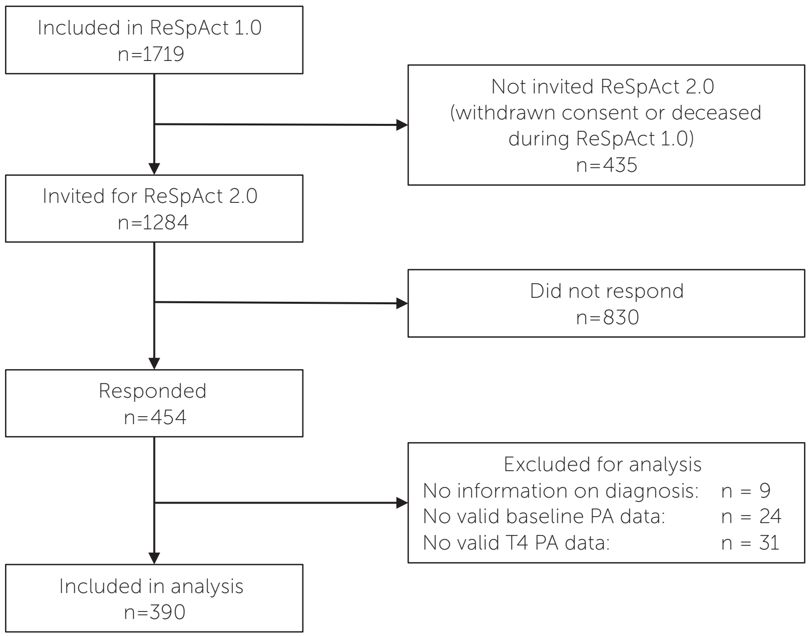

Figure 1. Flow chart of inclusion in the ReSpAct 2.0 study.

Table 1. Baseline characteristics (T0) of the included and excluded participants of ReSpAct 2.0.

	Participants	Non-participants	p-value
N	390	1329	
Demographics			
Age (years)	50.4 ± 12.1	49.7 ± 14.2	.339
Sex (% male)	50.0	44.7	.073
Education level			**<.001**
% Low	61.0	62.0	
% High	32.1	16.3	
% Missing	*6.9*	*21.7*	
Lifestyle			
Total PA score	4555 (2552 - 7418)	4560 (2495 - 7440)	.857
% Missing	*0*	*9.0*	
BMI (kg/m2)	26.8 ± 5	27.6 ± 9	**.035**
% Missing	*7.9*	*24.2*	
Smoking			**.001**
% Yes	12.6	16.3	
% No	78.5	58.2	
% Missing	*9.0*	*25.6*	
Alcohol consumption			.118
% No or light	60.8	53.3	
% Moderate or Excessive	29.0	20.4	
% Missing	*9.2*	*26.0*	
Psychosocial			
Intention	8 (7 - 10)	8 (7 - 9)	**<.001**
% Missing	*2.6*	*6.2*	
Attitude	13 (12 - 15)	13 (11 - 15)	.084
% Missing	*8.2*	*15.3*	
Self-efficacy	42 ± 11.3	41.2 ± 11.6	.237
% Missing	*6.2*	*9.0*	
Intrinsic motivation	3 (2.2 - 3.8)	3 (2.2 - 3.5)	.190
% Missing	*5.1*	*7.6*	
Barriers	14.5 ± 6.1	15.4 ± 6.5	**.012**
% Missing	*2.3*	*5.4*	
Health-related			
Diagnosis group			.081
% Brain disease	27.9	26.0	
% Musculoskeletal disease	16.4	19.1	
% Chronic pain	16.9	16.3	
% Neurologic disease	15.4	14.0	
% Organ disease	11.5	11.5	
% Amputation	4.1	4.6	
% Spinal cord injury	1.8	3.8	
% Other diseases	5.9	3.0	
Comorbidities			.813
% Yes	35.9	36.7	
% No	64.1	63.3	

Table 1. Continued.

	Participants	Non-participants	p-value
Health-related			
Acceptance of disability			.063
% Yes	56.7	41.5	
% No	35.9	36.6	
% Missing	*7.4*	*21.9*	
Perceived fatigue	4.4 ± 1.4	4.3 ± 1.5	.305
% Missing	*2.3*	*5.6*	
Pain			.076
% Yes	41.5	38.0	
% No	44.9	32.5	
% Missing	*13.6*	*29.5*	
Rehabilitation			
Rehabilitation context			.412
% Rehabilitation center	74.4	72.1	
% Hospital	25.6	27.9	
Rehabilitation form			.117
% Inpatient	1.5	3.5	
% Outpatient	92.1	89.2	
% Consultancy	6.4	7.3	
Number of counseling sessions	2.6 ± 1.4	2.3 ± 1.5	**.001**

PA = physical activity, BMI = body mass index, FSS = Fatigue Severity Scale.
Results shown as mean ± sd, median (Q1 – Q3), or percentage.
Non-participants are people who participated in ReSpAct 1.0, but did not fill in the T4 measurement questionnaire

Trajectories of PA behavior

The results of the fit indices for the linear growth, and linear and quadratic growth mixture models with one to four trajectories of PA behavior are shown in table 2. Based on the model fit criteria (table 2) and clinical interpretation, we considered the three-trajectory quadratic mixture model as the optimal model. The three-trajectory model consisted of one large and stable trajectory of moderate PA (labeled "moderately active"; n = 297, 76.2%), a smaller and mostly stable trajectory of high PA with a slightly decreasing trend from one year after rehabilitation to 6-8 years after rehabilitation (labeled "highly active"; n = 71, 18.2%) and a small trajectory of increasing PA (labeled "increasingly active"; n = 22. 5.6%) (see figure 2). Estimated mean trajectories for each model, estimated means with individual trajectories for each latent class, and estimated with observed means for the final model can be found on Open Science Framework (https://osf.io/96ypr).

Table 2. Fit indices for latent class growth mixture models with 1–4 trajectories of physical activity (total PA score) in people with physical disabilities and/or chronic diseases

N classes	BIC	Entropy	posterior probability				N participants per class			
			1	2	3	4	1	2	3	4
Latent class growth linear										
1	35362.3	1	-				390			
2	34988.0	0.86	0.98	0.92			313	77		
3	34906.7	0.88	0.92	0.95	0.93		79	302	9	
4	34875.0	0.9	0.88	0.96	0.91	0.82	6	298	16	17
Mixture Linear										
1	34958.5	1	-				390			
2	34883.9	0.95	0.87	0.99			14	376		
3	34834.1	0.77	0.84	0.92	0.87		22	297	71	
4	34844.4	0.81	0.75	0.93	0.91	0.85	26	296	5	63
Mixture quadratic										
1	34950.7	1	-				390			
2	34874.6	0.95	0.99	0.83			374	16		
3	**34824.5**	**0.77**	**0.92**	**0.84**	**0.87**		**297**	**22**	**71**	
4	34835.3	0.77	0.91	0.75	0.92	0.86	5	26	296	63

PA = physical activity, N = number, BIC = bayesian information criterion
Bold = chosen model

Determinants of trajectories of PA behavior

Table 3 provides the descriptive statistics of the modifiable determinants (i.e. lifestyle, psychosocial, health-related and rehabilitation determinants) at baseline for the trajectories of PA behavior. As the “increasingly active” trajectory consisted of a small number of participants (n=22), this class was excluded from logistic regression analyses. Table 4 shows the results of the adjusted univariable, and adjusted multivariable logistic regression analysis. In the univariable models adjusted for age and sex, participants who reported more barriers regarding PA (OR = 0.71, 95% Confidence Interval (CI) 0.53 – 0.95) and more perceived fatigue (OR = 0.75, 95% CI 0.57 – 0.98) were more likely to belong to the “moderately active” trajectory as opposed to the “highly active trajectory”. In the corrected multivariable model, no baseline modifiable determinants were significantly associated with trajectory membership. A correlation plot of the variables in the multivariable model reveals

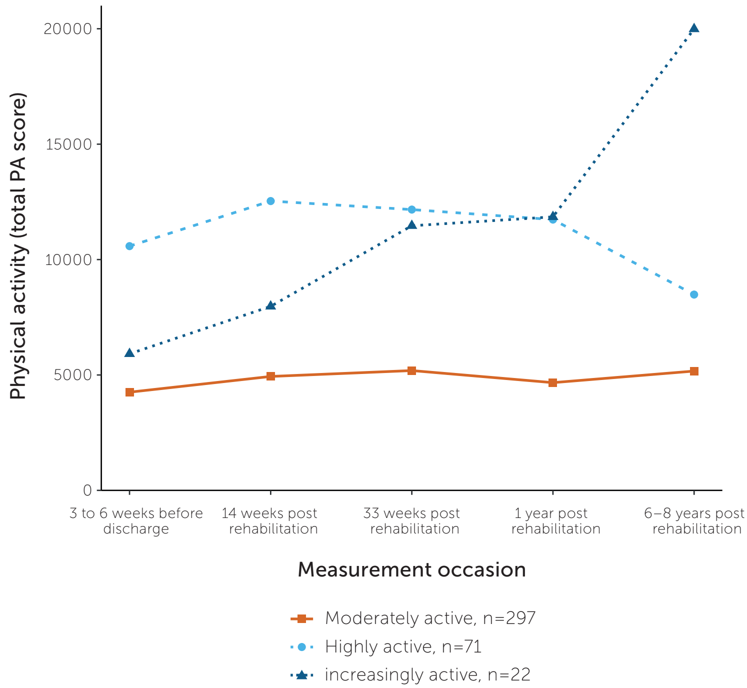

Figure 2. Three trajectory model of physical activity (total PA score) up to 6-8 years after rehabilitation in people with physical disabilities and/or chronic diseases, based on latent class growth mixture modeling.

no substantial multicollinearity. However, it did show correlations between .40 and .50 among some variable pairs. For example, the variable barriers regarding PA was moderately correlated with self-efficacy (Pearson r = -.49) as well as with perceived fatigue (Pearson r = .45) (see Open Science Framework: https://osf.io/bjds2). The results of the unadjusted models are presented and discussed in appendix 3.

Table 3. Demographics, lifestyle, psychosocial, health-related, and rehabilitation determinants at baseline (T0) for the three trajectories of physical activity behavior

	"Moderately active"	"Highly active"	"Increasingly active"
N	297	71	22
Demographics			
Age (years)	48.8 ± 12.2	55.2 ± 10.6	56.9 ± 8.3
Sex (% male)	44.4	64.8	77.3
Lifestyle			
Total PA score	3840 (2310 - 5850)	9960 (7560 - 12935)	5460 (2295 - 8272)
Total PA (min/week)	1370 (770 - 2070)	2950 (1945 - 3475)	1755 (461 - 2415)
MVPA (min/week)	230 (90 - 420)	1260 (590 - 1985)	480 (120 - 1095)
BMI (kg/m2)	26.9 ± 5.2	26.5 ± 4.2	27.2 ± 4.8
% Missing	*9.1*	*2.8*	*9.1*
Smoking			
% Yes	14.1	7.0	9.1
% No	75.4	87.3	90.9
% Missing	*10.4*	*5.6*	*0.0*
Alcohol consumption			
% No or light	63.0	50.7	63.6
% Moderate or Excessive	24.9	43.7	36.4
% Missing	*10.8*	*5.6*	*0.0*
Psychosocial			
Intention	8 (7 - 10)	8 (7 - 10)	8 (7 - 9)
% Missing	*2.4*	*2.8*	*4.5*
Attitude	13 (11.8 - 15)	13 (11 - 15)	14 (12 - 15)
% Missing	*7.1*	*12.7*	*9.1*
Self-efficacy	41.7 ± 11.2	43.4 ± 11.2	42.9 ± 12.4
% Missing	*5.1*	*11.3*	*4.5*
Intrinsic motivation	3 (2.2 - 3.8)	3.2 (2.6 - 3.8)	3.4 (3 - 4)
% Missing	*5.1*	*7.0*	*0.0*
Barriers	15 ± 6.1	12.5 ± 6.3	14.7 ± 4.9
% Missing	*2.4*	*2.8*	*0.0*
Health-related			
Acceptance of disability			
% Yes	54.5	67.6	50.0
% No	37.0	26.8	50.0
% Missing	*8.4*	*5.6*	*0.0*
Fatigue (FFS score)	4.5 ± 1.4	4.1 ± 1.3	3.8 ± 1.5
% Missing	*2.4*	*2.8*	*0.0*
Pain			
% Yes	41.1	42.3	45.5
% No	43.1	49.3	54.5
% Missing	*15.8*	*8.5*	*0.0*
Rehabilitation			
Number of counseling moments	2.6 ± 1.4	2.5 ± 1.4	2.5 ± 1.6

PA = physical activity, MVPA = moderate to vigorous physical activity BMI = body mass index, FFS = Fatigue Severity Scale.
Results shown as mean ± sd, median (Q1 – Q3), or percentage.

Table 4. Results of the pooled logistic regression analyses for the membership to the moderately or highly active trajectories. People belonging to the moderately active trajectory are the reference category.

	Univariable, adjusted for age and sex				Multivariable adjusted for age and sex			
	OR	95% CI		p-value	OR	95% CI		p-value
BMI	.88	.66	1.18	.389	.94	.68	1.31	.718
Smoking								
No [ref]	-	-	-	-	-	-	-	-
Yes	.50	.19	1.35	.171	.50	.17	1.46	.202
Alcohol use								
No to light [ref]	-	-	-	-	-	-	-	-
Moderate to excessive	1.77	.98	3.20	.056	1.75	.94	3.24	.075
Intention	1.17	.87	1.55	.296	1.07	.76	1.51	.700
Attitude	1.11	.83	1.48	.486	.94	.68	1.32	.739
Self-efficacy	1.11	.84	1.46	.468	.87	.58	1.32	.513
Intrinsic motivation	1.25	.93	1.66	.137	1.21	.85	1.72	.292
Barriers	**.71**	**.53**	**.95**	**.023**	.75	.49	1.14	.177
Acceptance of disability								
No [ref]	-	-	-	-	-	-	-	-
Yes	1.55	.83	2.88	.164	1.33	.68	2.57	.404
Fatigue	**.75**	**.57**	**.98**	**.035**	.83	.60	1.14	.247
Pain								
No [ref]	-	-	-	-	-	-	-	-
Yes	1.02	.56	1.85	.957	1.58	.80	3.13	.189
Number of counseling sessions	.95	.73	1.24	.702	.90	.68	1.19	.474

BMI = body mass index, OR = odds ratio, CI = confidence interval, ref = reference category

Discussion

In this long-term follow-up study in people with physical disabilities and/or chronic diseases, we eventually included 390 individuals. Among those, we identified three trajectories of total PA behavior from discharge to six to eight years after rehabilitation: moderately active, highly active, and increasingly active. Experiencing more barriers and perceiving more fatigue significantly reduced the odds of belonging to the highly active trajectory compared with the moderately active trajectory in the univariable models. In the multivariable model no modifiable baseline determinants were significantly associated with trajectory membership.

We found that the development of PA behavior after participating in a PA promoting rehabilitation program is heterogeneous, and is best described by multiple sub-populations as compared to one single population. This is consistent with previous diagnosis-specific studies that reported on trajectories of PA after rehabilitation in patients with COPD [45] and breast cancer [46]. Furthermore, studies in a community setting identified multiple trajectories of development of PA behavior over time, both in people with chronic spinal cord injury [47] and in the general population [48]. These studies commonly identified a trajectory considered to be inactive or low active (e.g. not meeting MVPA guidelines). In contrast, the trajectory with the lowest average PA in our study, the "moderately active" trajectory, had a median baseline MVPA level above the 150 minutes per week threshold of the aerobic guidelines of the World Health Organization [6]. These high PA levels reported in our cohort can possibly be explained by the fact that ReSpAct participants received tailored counseling just before and in the first three months after discharge from rehabilitation. Indeed, the ReSpAct population is on average relatively active compared to a typical population of people with physical disabilities and/or chronic diseases, and they showed an increase of PA on a group level in the first three months [16]. The important addition of this study is that on the longer-term PA behavior of people in the "moderately active" trajectory remained stable. People in the "highly active" trajectory were still highly active on the longer term, even though they showed a decrease in PA from one year post. And the PA behavior of people in the small "increasingly active" trajectory continued to increase on the longer term.

The data collection of the long-term follow-up was performed during the COVID-19 pandemic, which was found to negatively affect PA behavior in previous research, in particular in those with physical disabilities and/or chronic diseases [11]. This makes the results of our long-term follow-up even more promising; despite the pandemic, our participants remained relatively active. The pandemic might also be an explanation of the decrease in PA behavior of the "highly active" trajectory. However, the decrease of the "highly active" trajectory might also be a natural effect of aging [49]. The participants who adopted the "highly active" trajectory were older compared to the participants adopting the other trajectories, which might explain why we found this decrease only in this trajectory. All in all, the results of the current study may suggest that providing tailored PA counseling during and in the months following rehabilitation can be a promising approach to promote a long-term physically active lifestyle.

Barriers regarding PA and perceived fatigue were baseline determinants that were significantly associated with trajectory membership in the univariable models. People experiencing fewer barriers have higher odds of adopting a "highly active" trajectory. According to the barrier-belief approach these barriers are an individual's belief about obstructing factors regarding PA, and the reason why PA behavior cannot be achieved [50]. In primary care patients, reducing barrier beliefs was found to be effective for increasing PA behavior [51]. By providing tailored counseling, a person's goals for PA and possible barriers to achieve this PA goal can be identified [50]. By applying motivational interviewing [52], these barriers can be addressed using goal setting and problem solving strategies [50]. Therefore, it seems advisable to provide tailored counseling using motivational interviewing to reduce barriers regarding PA at an early stage in rehabilitation to open up the potential for long-term PA adherence.

People with disabilities commonly report high levels of perceived fatigue [53]. In our study, participants who reported less perceived fatigue had higher odds of adopting the "highly active" trajectory. Previous research in people with physical disabilities and/or chronic diseases found perceived fatigue to be associated with quality of life [54], depressive symptoms [55], and overall function in daily life [56]. Additionally, stroke survivors reported that being physically active reduced their perceived fatigue complaints [57]. This makes it clear that fatigue management is important in people with physical disabilities and/or chronic diseases, and should therefore be an important focus point in (early) rehabilitation. The rehabilitation setting might benefit from using strategies such as activity pacing, a strategy to manage daily activities by dividing energy over the day and planning rest periods [58, 59]. A meta-analysis has previously shown the beneficial effects of activity pacing interventions on perceived fatigue severity in people with chronic conditions [59]. Further research in this area may provide information on how to correctly implement advice on fatigue management in the rehabilitation setting.

When tested in the multivariable model, none of the modifiable baseline determinants were significantly associated with trajectory membership ("highly active" vs "moderately active" trajectory). This could be explained by the active nature of the ReSpAct population, as modifiable determinants are mostly considered to be differentiators between inactive and active persons [60]. Another explanation might be the interaction between the modifiable determinants, as theorized by PAD model [18]. We found certain baseline determinants to be moderately correlated to each other. Therefore, results of univariable models are also of relevance, as they provide an indication which determinants are the strongest predictors of PA behavior, and should therefore be targeted during rehabilitation.

The goal of PA promotion programs, either during rehabilitation or in the community, is to increase the PA behavior of its participants. We found a small group of our study participants to adopt an increasingly active trajectory over the six to eight year study period. Understanding why these participants are able to increase their PA behavior, even at the longer term, might be therefore be valuable for the optimalization of PA promotion programs. Although the descriptive information shows a tendency of people adopting an increasing active trajectory to be more intrinsically motivated and perceiving less fatigue than people adopting the other two trajectories, the group was too small to include in further statistical analyses. Future research should aim to further explore trajectories of increasing PA, and how determinants change within the members of such a trajectory over time.

Strengths and Limitations

An important strength of this study is the length of follow-up after rehabilitation and the consistent monitoring of this cohort, which is to the best of our knowledge, the longest existing follow-up on PA behavior among people with physical disability and/or chronic diseases after rehabilitation. This can help answering questions whether and how this population can achieve a life-long physically active lifestyle, improving long-term health and quality of life. Long-term longitudinal studies (>12 months) are essential to substantiate sustainability of health outcomes, especially in the field of rehabilitation, which focusses on improving long term health outcomes to improve participation and quality of life.

Another strength is that we included a large group of adults with a broad range of physical disabilities and/or chronic diseases, which provides a more generic view of the rehabilitation setting compared to studies with a disability-specific population. Therefore, our results can contribute to the development and improvement of PA promotion programs that are often applied diagnosis-overarching in rehabilitation.

Finally, we used LCGM models to unravel heterogeneity in the development of PA behavior. This data-driven technique categorized people based on their development pattern and formed homogenous subgroups of people following a similar development [34]. This approach fits with the research design (i.e. a prospective cohort study), and provides more information than when summarizing the data into the average participant described by means and standard deviations.

The study also has some limitations. First, only 23% of the original ReSpAct population was included in the current study. This is mainly due to non-response of participants at the last measurement occasion (T4). In part, this might be explained by the COVID-19 pandemic. Therefore, we must take into account the possibility of positive sampling, where only the participants most interested in the topic of research responded to the long-term follow-up, and thus were included in the current study. Indeed, the included participants had some more favorable baseline characteristics, such as a higher intention to be active, perceiving less barriers and being less often a smoker compared to the excluded participants. However, we still included a sufficiently large and diverse group of people with various physical disabilities and/or chronic diseases who were followed up to eight years after rehabilitation with a consistent set of reliable and valid measures. This makes this study an important addition to the current literature, helping understand PA behavior among people with physical disabilities and/or chronic diseases and the potential role of the rehabilitation setting. In that respect, we also welcome replication of the identified trajectories in other comparable datasets.

Second, the ReSpAct cohort might not be representative for an average group of people with physical disability and/or chronic diseases, as they participated in the tailored PA counseling rehabilitation program RSE. This focus on promoting a physically active lifestyle is common in the Dutch rehabilitation setting. This might make the results of this study an inspiration for other countries to adopt similar strategies in their rehabilitation settings.

Third, because of the large scale and nationwide approach of the ReSpAct cohort, we evaluated PA behavior by a questionnaire only, and were not able to additionally apply activity monitoring. Experienced PA (assessed by a recall questionnaire) and objectively measured PA (by an activity monitor) are two distinct complementary constructs, which are ideally evaluated both [61]. This was however not feasible in the current study. Despite the reliability of the Adapted-SQUASH, PA recall questionnaires are prone to overestimation [62], what possibly accounted for the high PA levels that were found in this study. Furthermore, we used a cumulative score to capture the complex multidimensional construct of PA among people with physical disabilities and/or chronic diseases. And even though the PA score is a measure closest to the total dose of PA, using it might have led to a loss in potential interesting differentiations of the different dose characteristics (i.e. setting, mode, frequency, duration, intensity) on, for example, identified trajectories. It might be interesting to study this in future research.

Fourth, the lack of information between measurement occasions at one year and at six to eight years after rehabilitation can be considered a limitation. In this large episode, a lot may have changed in the lives of the participants. As behavior change and behavior maintenance are continual processes, data of this episode would have been informative. However, the current study does provide valuable information for rehabilitation practitioners on the diversity of the rehabilitation population with regards to PA behavior and those factors that may have an impact here several years beyond the actual period of rehabilitation.

Last, to reduce participant burden, some determinants were measured by non-validated short or one-item questionnaires. Although the ReSpAct questionnaire was developed based on existing validated questionnaires [14], the results should therefore be interpreted with caution.

Conclusion

This prospective cohort study identified three long-term trajectories of PA behavior among a heterogenous cohort of people with physical disabilities and/or chronic diseases who participated in a tailored PA counseling rehabilitation program at the start of the study. More than three-quarter of our sample obtained a stable moderately active trajectory, a reasonable number of people obtained a trajectory which was highly active but showed a decline from one year to six to eight years post rehabilitation, while a small number of people obtained an increasingly active trajectory. Barriers regarding PA and perceived fatigue appear important determinants to target early on in rehabilitation for a more favorable development of PA after rehabilitation. Furthermore, providing tailored PA counseling during and just after discharge from rehabilitation may be a promising approach for a long-term physically active lifestyle.

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Declaration of interest
The authors report there are no potential conflict of interest to declare.

Data availability statement

Additional information can be found on Open Science Framework (https://osf.io/xr5pe/). This includes all analyses and data processing codes, additional information on the latent class growth analysis, the items of the barriers regarding physical activity questionnaire and an analysis of the reliability of the 7-item self-efficacy questionnaire. De-identified data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Chapter 4 - Appendix 1 - ReSpAct/RSE

The Rehabilitation, Sports and Exercise program (RSE, Dutch: Revalidatie, Sport en Bewegen) is an evidence-based program that targets this period among a wide population of people in rehabilitation by providing tailored PA counseling support during and after rehabilitation [1, 2]. The randomized controlled trial that offered the groundwork for the RSE program showed increased PA levels up to one year after the intervention [3].

The Physical Activity for people with a Disability (PAD) model was developed to describe the relationship between PA behavior and determinants in people with disabilities [4]. It formed the theoretical basis for the development of the RSE program [1]. Important determinants of PA according to the PAD model can be divided into environmental factors (e.g. social influence and environmental barriers) and personal factors (e.g. health condition, self-efficacy, and personal barriers) [4]. The Rehabilitation, Sports and Active lifestyle (ReSpAct) study is a prospective cohort study designed to evaluate the RSE program over time [1, 2].

Previous studies using latent class growth modeling in the ReSpAct cohort have shown that there are distinct trajectories in the development of quality of life among people with physical disability and/or chronic diseases [5] as well as in the development of perceived fatigue in people with stroke after rehabilitation [6].

4

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Chapter 4 - Appendix 2 - Adapted-SQUASH

The Adapted-SQUASH is a 19-item recall questionnaire to assess PA behavior among adults with physical disabilities and/or chronic diseases based on an average week of the past month [1]. Participants had to report on the frequency (number of days), duration (hours and minutes per week), and perceived intensity (light, moderate, vigorous) of different types of activities, which were pre-structured in four different settings (leisure time activities, household activities, commuting activities, and activities during work and school). When compared to accelerometer-derived PA among people with physical disabilities and/or chronic diseases, the Adapted-SQUASH has comparable validity to other PA questionnaires in this population (ρ = .40 for total PA score and ICC = .22 for total minutes of activity per week) [1]. Furthermore, the Adapted-SQUASH is considered reliable (ICC = .67 for total PA score and ICC = .76 for total minutes of activity per week) [1].

In the processing of the adapted-SQUASH, the intensity of activities is calculated based on a combination of three variables; (1) the self-reported intensity; (2) a fixed metabolic equivalent (MET) of the activity; and (3) the age of the participant [1, 2]. Based on these three variables, an activity will be classified with a number of 1 through 9. An activity will be classified as light, moderate or vigorous based on these numbers; where the numbers 1 and 2 stand for light activity, 3-6 for moderate activity and 7-9 for vigorous. See in the two tables below how these numbers are assigned to the activities.

Table 1. Norm intensity based on age

	Norm intensity		
	Light	Moderate	Vigorous
Age			
18-55	<4.0 MET	4.0 – 6.5 MET	≥6.5 MET
>55	<3.0 MET	3.0 – 5.0 MET	≥5.0 MET

Table 2. Activity number, based on norm intensity and self-reported intensity

	Self-reported intensity		
	Light	Moderate	Vigorous
Norm intensity			
Light	1	2	3
Moderate	4	5	6
Vigorous	7	8	9

As these tables show, activities with a MET value between 3 and 4 will be classified at different intensity based on age (i.e. 55 years old as cut-point). This cut-point was based on the Dutch Norm of Healthy physical activity from 2000 [3].

The activity score of an activity is calculated by multiplying the duration (in minutes) by the activity number. For example, the activity score of walking (3.0 MET) for 2 hours per week at a self-reported moderate intensity when younger than 55, results in an activity score of 240. The total PA score is the summation of the activity score of all activities reported by the participant.

When analyzing data from longitudinal studies with a long follow-up, it becomes important to specify with which age the adapted-SQUASH is processed in the different measurement occasions. This has to do with people who cross this age threshold during the study, as activities they participated with MET values between 3 and 4 are classified as light at baseline, will be classified as moderate when they crossed the age threshold of 55 years. This could lead to an increase of moderate to vigorous minutes of PA for a person who performs the same amount of the same activities. Furthermore, it will lead to an increase of the adapted-SQUASH score (which is the sum of all minutes of activities with their corresponding activity number). In the figures below, we show the effect of processing the adapted-SQUASH using the age at 6-8 years follow-up as compared to using the age at baseline.

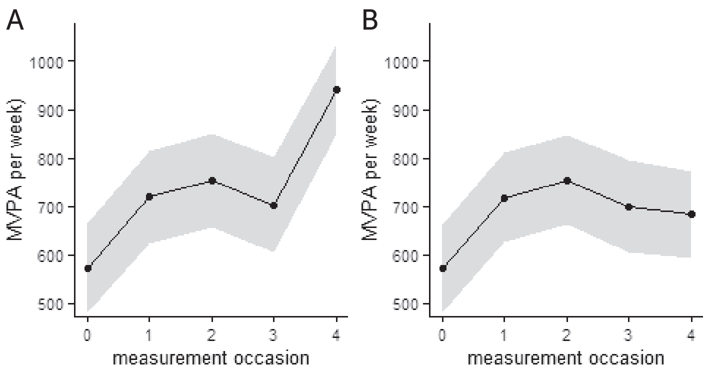

Figure 1. Minutes of moderate to vigorous physical activity (MVPA) per week, based on a multilevel model using physical activity as dependent variable and time as independent (with random intercepts for participants). A. adapted-SQUASH processed with age at measurement occasion. B. adapted-SQUASH processed with age at baseline.

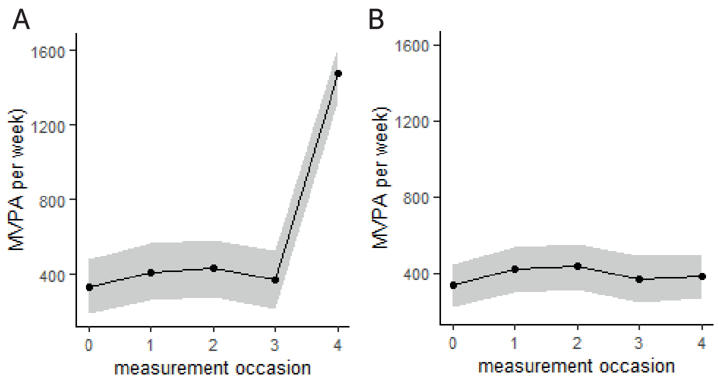

Figure 2. Minutes of moderate to vigorous physical activity (MVPA) per week for people who crossed the 55 years old threshold between T3 and T4, based on a multilevel model using physical activity as dependent variable and time as independent (with random intercepts for participants). A. adapted-SQUASH processed with age at measurement occasion. B. adapted-SQUASH processed with age at baseline.

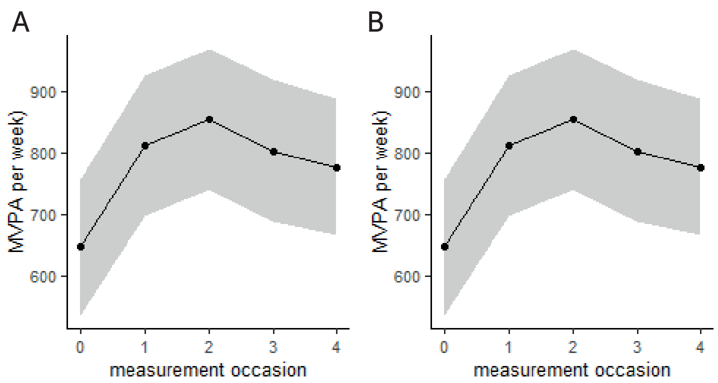

Figure 3. Minutes of moderate to vigorous physical activity (MVPA) per week for people who did not cross the 55 years old threshold between T3 and T4, based on a multilevel model using physical activity as dependent variable and time as independent (with random intercepts for participants). A. adapted-SQUASH processed with age at measurement occasion. B. adapted-SQUASH processed with age at baseline.

As these figures show, there is a large difference in the minutes of moderate to vigorous PA when the adapted-SQUASH is processed with the age at measurement occasion or the age at baseline. The increase in minutes of MVPA seen in figure 1.A is only caused by the by the 92 participants (of the 390 in total) who crossed the age threshold of 55 years between T3 and T4. Therefore, we have chosen to process the data for the adapted-SQUASH for all measurement occasions with age at baseline since it gives a more consistent representation of the development of PA behavior over time.

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Chapter 4 - Appendix 3 – Unadjusted logistic regression analyses

Results of unadjusted logistic regression analyses

In the unadjusted univariable logistic regression analysis, we found the following modifiable baseline determinants that could significantly distinguish the participants in the "highly active" trajectory from the participants in the "moderately active" trajectory: alcohol consumption (no to light alcohol consumption as reference: odds ratio (OR) = 2.14, 95% confidence interval (CI) 1.23 – 3.71), barriers regarding PA (OR = 0.64, 95% CI 0.48 – 0.84), and perceived fatigue (OR = 0.71, 95% CI 0.55 – 0.92). In the unadjusted multivariable logistic regression analysis, alcohol consumption is the only significant determinant for "highly active" trajectory membership (no alcohol consumption as reference: OR = 2.10, 95% CI 1.16 – 3.80). See supplemental table 1.

Supplemental table 1. Univarable logistic regression analyses for each possible predictor

	OR	95% CI		p-value
Age	1.05	1.03	1.08	0.000
Sex				
Male [ref]	-	-	-	
Female	0.43	0.25	0.74	0.002
BMI	0.99	0.93	1.04	0.627
Smoking				
No [ref]	-	-	-	
Yes	0.43	0.14	1.04	0.088
Alcohol use				
No to light [ref]	-	-	-	
Moderate to excessive	2.18	1.25	3.78	0.006
Intention	1.04	0.89	1.22	0.632
Attitude	1.08	0.94	1.24	0.300
Self-efficacy	1.01	0.99	1.04	0.264
Intrinsic motivation	1.33	0.96	1.87	0.092
Barriers	0.93	0.89	0.97	0.003
Acceptance of disability				
No [ref]	-	-	-	
Yes	1.72	0.97	3.14	0.070
Fatigue	0.79	0.66	0.95	0.012
Pain				
No [ref]	-	-	-	
Yes	0.90	0.52	1.55	0.704
Number of counseling sessions	0.93	0.77	1.12	0.442

BMI = body mass index, OR = odds ratio, CI = confidence interval,
ref = reference category

Discussion of unadjusted results

Our study shows that, uncorrected for age and sex, people who have a moderate or excessive alcohol usage had higher odds of following the highly active trajectory. This is consistent with previous studies, in which alcohol usage is found to be positively related with PA and to membership of trajectories of higher levels of PA in a general population (1-3) and in breast cancer survivors (4, 5). A possible explanation for this counterintuitive association could be the social aspects of both PA and alcohol. Social situations in which PA is performed, such as walking with peers or competing in team sports, could lead to social situations in which alcohol is consumed (e.g. a drink with the team after the game). It could also be hypothesized that PA is a compensatory behavior for the consumption of alcohol. Another explanation might be the confounding effect of sex, as males consume more alcohol (6) and report more minutes of MVPA (7). Our results are in line with this reasoning, as the association between alcohol consumption and trajectory membership became non-significant when corrected for age and sex, both in the univariable model as in the multivariable model. As it might be important to decouple the unhealthy behavior (alcohol consumption) from the healthy behavior (PA behavior), future research should focus on the explanations of the association between alcohol consumption and PA behavior.

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5

Measurement properties of device-based physical activity instruments in ambulatory adults with physical disabilities and/or chronic diseases: a scoping review

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Abstract

Background: People with physical disabilities and/or chronic diseases tend to have an inactive lifestyle. Monitoring physical activity levels is important to provide insight on how much and what types of activities people with physical disabilities and/or chronic diseases engage in. This information can be used as input for interventions to promote a physically active lifestyle. Therefore, valid and reliable physical activity measurement instruments are needed. This scoping review aims 1) to provide a critical mapping of the existing literature and 2) directions for future research on measurement properties of device-based instruments assessing physical activity behavior in ambulant adults with physical disabilities and/or chronic diseases.

Methods: Four databases (MEDLINE, CINAHL, Web of Science, Embase) were systematically searched from 2015 to April 16th 2023 for articles investigating measurement properties of device-based instruments assessing physical activity in ambulatory adults with physical disabilities and/or chronic diseases. For the majority, screening and selection of eligible studies were done in duplicate. Extracted data were publication data, study data, study population, device, studied measurement properties and study outcome. Data were synthesized per device.

Results: 103 of 21566 Studies were included. 55 Consumer-grade and 23 research-grade devices were studied on measurement properties, using 14 different physical activity outcomes, in 23 different physical disabilities and/or chronic diseases. ActiGraph (n=28) and Fitbit (n=39) devices were most frequently studied. Steps (n=68) was the most common used physical activity outcome. 97 studies determined validity, 11 studies reliability and 6 studies responsiveness.

Conclusion: This scoping review shows a large variability in research on measurement properties of device-based instruments in ambulatory adults with physical disabilities and/or chronic diseases. The variability highlights a need for standardization of and consensus on research in this field. The review provides directions for future research.

Keywords: Physical activity, device-based instruments, accelerometry, measurement properties, validity, reliability, responsiveness, physical disability, chronic disease, scoping review

Background

Physical activity (PA), defined as "any bodily movement produced by skeletal muscles that result in energy expenditure" [1], is a multidimensional construct with dimensions as setting (e.g. PA during leisure time, work), mode (e.g. walking, bicycling), frequency (e.g. times per week), duration (e.g. in hours) and intensity (e.g. light, moderate or vigorous) [2, 3]. PA has many health benefits across the lifespan, especially for people with physical disabilities and/or chronic diseases [4, 5]. Still, people with physical disabilities and/or chronic diseases tend to have an inactive lifestyle [6, 7]. Monitoring PA in this population is important, as it will provide insight in how much and what types of PA they engage in. Information on the amount and types of PA can help tailor PA promotion activities to individuals and uncover opportunities for improving PA for people with physical disabilities and/or chronic diseases. Furthermore, self-monitoring is one of the most effective behavior change techniques for improving PA, further stressing the importance of accurately measuring PA [8]. The need to measure and quantify PA in this varied population has also been emphasized by various research groups [9, 10], including the developers of the new World Health Organization's PA guidelines [11].

A variety of instruments exist to measure PA in people with physical disabilities and/or chronic diseases. Instruments for PA measurement can be classified into two main categories: device-based instruments (e.g. accelerometers and pedometers; later also mentioned as devices) and self-report instruments (e.g. questionnaires and diaries). Both types of instruments have advantages and disadvantages [12] and are believed to measure different aspects of the PA construct [13]. Self-report instruments are assumed to capture the perceived PA behavior, whereas device-based instruments aim to capture the continuous acceleration of the body above a certain threshold [13]. The consensus is currently that both types of instruments have their own value and should be used complementary to one another, depending on the research questions or clinical and/or practical goals [14].

Device-based instruments collect raw movement data (e.g. acceleration) from a variety of locations on the human body. These data are converted into different PA outcomes (e.g. energy expenditure, steps) often using dedicated algorithms [15]. These algorithms are commonly developed for a general (non-disabled) population [9]. People with physical disabilities and/or chronic diseases such as those with stroke, Parkinson's disease, and chronic obstructive pulmonary disorder, might have a different pattern of locomotion (e.g. slower and/or asymmetrical) [16-18]. Also, people with physical disabilities and/or chronic diseases could have a different energy expenditure during PA compared to people without physical disabilities and/or chronic diseases, due to a lower efficiency of walking or other motor actions in general [19-21] or due to an increased energy cost of daily activities [22]. This could be of influence on the validity of the algorithms used in device-based PA instruments when applied to people with physical disabilities and/or chronic diseases. Research already showed that slower walking speeds limit the validity of measuring steps using certain devices [23, 24]. Furthermore, energy expenditure estimations of devices had poor correlations with estimations of indirect calorimetry in people with stroke [25]. These findings warrant a critical mapping of the measurement properties of device-based instruments used to assess PA in people with physical disabilities and/or chronic diseases.

There have been reviews in the past on the measurement properties of device-based instruments in people with physical disabilities and/or chronic diseases. However, these are mostly either diagnosis- or PA-outcome specific [25-29]. Also, manual wheeled mobility involves a completely different class of bodily activities and their energetic consequences as opposed to individuals who walk. A recent systematic review gave an extensive overview of the measurement properties of device-based and self-reported instruments assessing PA in people using a wheelchair [30]. Therefore, the current review focused on the ambulatory population of adults with physical disabilities and/or chronic diseases.

This scoping review aims to provide a critical mapping of the existing literature on the measurement properties of device-based instruments assessing physical activity behavior in ambulant adults with various physical disabilities and/or chronic diseases. Using this critical mapping, we provide future directions to study the measurement properties of device-based instruments assessing PA in ambulatory adults with physical disabilities and/or chronic diseases.

Methods

Study design

This scoping review was guided by the methodological framework for scoping reviews [31, 32] and the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guideline [33]. A scoping review was chosen as it can be used to summarize research findings and potentially identify research gaps in the literature, which matches our aim. The study protocol is available at https://osf.io/c27xv/. During the review process, we deviated from the published protocol. In appendix 1 we report the reason and the nature of these deviations. In short, we deviated from the protocol in three main ways: 1) because of the large amount of research, we changed the scope of the review from all literature on both device-based and self-reported instruments into only device-based instruments in a set time period; 2) we therefore changed the review question accordingly; and 3) we changed the method from a systematic into a scoping review.

Following the aim and scope of the original protocol, we defined the following PICO criteria: *(P)* Adults (≥18 years old) with physical disabilities and/or chronic diseases. *Physical disability* was defined as a congenital disease, acquired illness, or trauma that causes an impairment, activity limitation and participation restriction that lasts at least 1 year [34, 35]. *Chronic disease* was defined broadly as conditions that last 1 year or more and require ongoing medical attention or limit activities of daily living or both [36]. *(I)* Physical activity measurement instrument. *Physical activity measurement instrument* was defined as a device-based or self-report instrument that assesses any bodily movement produced by the muscles that results in increased energy expenditure [1] in the activity domain of the International Classification of Function, Disability and Health (ICF) model [35]. *(C)* We did not use a comparison group, since this is not relevant for studies on measurement properties. *(O)* Measurement properties (e.g. reliability, validity, responsiveness). Operationalization of *Measurement properties* followed the definitions of COSMIN [37].

Search strategy and information sources

Together with an information specialist (KS), we combined the three different concepts of our PICO to create our search terms: physical activity measurement instrument, physical disability and/or chronic disease and measurement properties. We used a combination of both MeSH-terms and free text words for each concept, linked with Boolean operators. Literature was initially searched up to June 26th 2019, with a first update of the search up to November 20th 2020, and a second update of the search up to April 16th 2023 in four databases: Medline, Cinahl, Web of Science and Embase. We adapted the search strategy for each database using the same keywords and, where possible, MeSH-terms. The full search strategies for each of the four databases can be found in appendix 2.

Eligibility criteria

Articles were eligible for inclusion in the scoping review when 1) included participants were 18 years or older and had a physical disability or chronic disease, with having the physical disability or chronic disease a primary reason for rehabilitation treatment; 2) PA was measured as an amount or energy cost using a self-reported or device-based instrument; 3) measurement properties were a (primary or secondary) outcome measure of the studies; 4) articles were published in peer-reviewed journals and involved primary research. Articles were excluded when 1) studies were not in humans; 2) participants had an intellectual-, sensory-, cognitive- or mental disability; 3) all included participants were wheelchair users; 4) PA was measured as a functional or a performance outcome; 5) articles were not in English or Dutch. We excluded literature studying participants with intellectual-, sensory-, cognitive- or mental disabilities, as these studies may require different approaches and interpretations compared to studies involving people with physical disabilities and/or chronic diseases. As the authors are knowledgeable in Dutch and English, we excluded all non-English/Dutch articles.

Selection of sources of evidence

Before screening, duplicates were removed using Bramer et al.'s method [38] in EndNote. Two researchers independently screened titles (PB & LAK) and subsequently abstracts (PB & IB) on eligibility using custom Excel spreadsheets. Disagreement was resolved by including those articles to the next phase. For the title and abstract phase, pilot tested checklists with specific instructions for in- and exclusion were used. During the abstract screening phase, regular meetings were held to ensure equal interpretation of the abstracts between both researchers and to discuss uncertainties. Before full text screening, articles were removed that used self-reported PA instruments or were published before 2015. We did this due to the change of focus (on devise-based instruments only) of the review after the abstract phase (see appendix 1).

Eligibility of full texts was screened by two researchers independently (PB & IB), using a checklist for full text eligibility and a custom Excel spreadsheet. Disagreements were discussed, and if necessary, a third assessor (LAK) was consulted. Cohen's Kappa statistics were calculated to assess the agreement between the two screeners for the title, abstract and full text phase [39]. For feasibility reasons, the second update was performed by one researcher (PB) only. A second researcher (LAK) was consulted in case of questions and doubt with respect to the interpretation of the study. The PICO, in- and exclusion criteria and complete checklists per phase can be found in appendix 3. The used custom Excel spreadsheets can be found on Open Science Framework (https://osf.io/c27xv/).

Data charting process

The first author (PB) extracted data using an extraction form in Excel (available at Open Science Framework: https://osf.io/c27xv/). The data extraction form included the following information: 1) publication data (author, year of publication, land of origin); 2) study data (design, setting, sample size, and protocol tasks); 3) study population (diagnosis group(s), age, gender, and walking speed); 4) device (name, type, placement, unit of measurement, epoch length, sampling rate, and algorithm used); 5) studied measurement properties (validity, reliability, or responsiveness) and criterion measure (name, type, unit of measurement, algorithm used); and 6) study outcomes.

Synthesis of results
We synthesized the data based on device. For each device, the available measurement properties were presented using the following ordering: 1) PA outcome; 2) diagnosis group; 3) study; 4) device placement; and 5) algorithm. We separated research-grade devices from consumer-grade devices.

Results

Figure 1 shows a flowchart of the screening and review process. A total of 21566 records were identified through the search. After removing duplicates and publications categorized as non-primary research, 13219 records were screened on title. Based on title, we excluded 10752 records. We screened the remaining records on abstract, and excluded 1725 records. A further 403 records were excluded, as they were published before 2015 or used self-report measurement instruments for physical activity. The remaining 287 records were read in full. Of these, we excluded 184 records that did not meet the eligibility criteria, which resulted in a total of 103 studies included in this review. Agreement of the initial search and first update for title, abstract and full text screening was moderate (title phase: Cohen's Kappa = 0.68, agreement = 78%; abstract phase: Cohen's Kappa = 0.55, agreement = 82%; full text phase: Cohen's Kappa = 0.57, agreement = 78%).

Characteristics of the included studies are shown in table 1. In total, 23 different physical disabilities and/or chronic diseases were included in the studies. Most studies included people with stroke (n=27) [40-66], chronic obstructive pulmonary disease (n=11) [67-77] and multiple sclerosis (n=10) [78-87]. Six studies included a mixed population of people with different physical disabilities and/or chronic diseases [24, 75, 77, 88-90]. Sample sizes ranged from 4 to 176, with a median of 28. The majority of studies were performed in Northern America (USA, n=28 [51, 64, 69, 70, 72, 74, 76, 83-85, 91-107]; Canada, n=10 [40, 47, 50, 52, 53, 89, 108-111]) and Western Europe (UK, n=11 [78, 80, 82, 86, 112-118]; France, n=8 [42-45, 55, 119]; the Netherlands, n=6 [48, 75, 77, 120-122]; Germany, n=4 [68, 87, 123, 124]; Switzerland, n=4 [66, 81, 125, 126]; Denmark, n=3 [127-129]; Belgium, n=2 [67, 88]; Italy, n=2 [56, 130]; Sweden, n=2 [71, 79]; Ireland, n=1 [131]; Portugal, n=1 [132]). Only 14 studies were performed in other countries (Brazil, n=6 [46, 49, 57, 62, 63, 133]; Japan, n=4 [59, 73, 134, 135]; Australia, n=3 [60, 90, 136]; Czech Republic, n=1 [65]). Of the 103 included studies, 65 were performed in a laboratory setting with protocolled activities [24, 40-46, 49, 51-59, 61-66, 70, 72, 75, 78-80, 83, 86, 88-90, 92, 93, 95-97, 101, 103, 104, 107, 109, 111-115, 119, 120, 122, 123, 125, 126, 128-133, 137-139], 28 during free-living (activities of own choice) [50, 60, 67, 68, 71, 73, 76, 82, 87, 91, 94, 98-100, 102, 105, 106, 108, 110, 121, 124, 127, 134-136, 140-142], nine in a

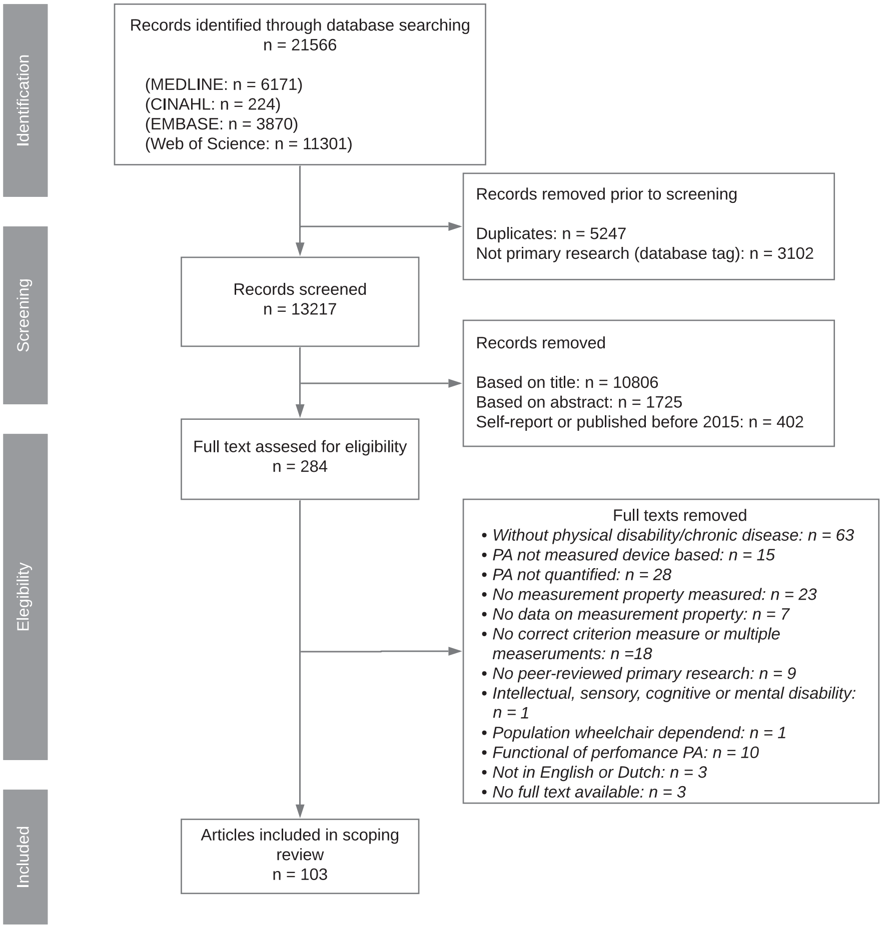

Figure 1. Flowchart of screening and review process of included studies on device-based instruments assessing physical activity. n = number of studies.

combined laboratory and free-living setting [47, 48, 69, 77, 81, 84, 85, 116, 118], and one in the home setting in which participants had to perform a set of protocolled activities [74]. Walking speed of the participants was on average slow, with speeds predominantly below 1.0 m/s. Appendix 4 provides an extended version of table 1. This table provides extra information on important in- and exclusion criteria, the tasks performed, and criterion for valid measurement days and cases (for studies performed in a free-living setting).

In total, 78 different PA devices from 43 different companies were studied on their measurement properties. In 39 studies multiple devices were used and compared [24, 43, 44, 46, 49, 51, 54, 55, 57, 58, 63, 64, 67, 70, 75, 79-81, 83, 84, 89, 92-97, 101, 103, 107, 112, 115, 116, 118, 122, 132, 133, 137, 141]. Twenty-three devices were research-grade and 55 were consumer-grade. The most frequently studied research-grade devices were from the companies ActiGraph (n=28 studies) [24, 40, 43-45, 49, 51, 55, 61, 64, 76, 79, 81, 84, 89, 93-96, 104, 105, 107, 108, 112, 114-116] and PAL technology (n=8 studies) [24, 54, 86, 91, 95, 116, 131, 138]. The most frequently studied consumer-grade devices were from the companies Fitbit (n=39 studies) [24, 41, 46, 47, 50, 52, 53, 58, 60, 64, 65, 67, 74, 75, 80, 81, 83-85, 90, 92, 94, 97-99, 101-103, 106, 109, 112, 118, 122, 127, 133, 136, 137, 140, 141] and Garmin (n=10 studies) [24, 58, 66, 80, 97, 101, 107, 130, 137, 141].

With respect to measurement properties, 97 studies determined validity [24, 40-90, 92-110, 112, 114-129, 131-134, 136-138, 140, 141], 11 studies determined reliability [46, 54, 58, 66, 91, 105, 106, 111, 113, 118, 135] and six study determined responsiveness [82, 100, 105, 106, 118, 136]. The measurement properties of 14 different PA outcomes were studied. Step count was the most frequently studied PA outcome (n=68) [24, 40, 41, 46, 47, 50, 52-54, 56-58, 63-69, 74, 75, 79-86, 89-98, 101-109, 111, 112, 116-118, 121, 123, 124, 126-133, 136, 137, 140, 141], followed by energy expenditure (n=19) [42, 43, 45, 49, 51, 55, 61, 62, 70, 71, 82, 88, 96, 114, 115, 119, 122, 125, 134] and activity time (n=15) [48, 54, 68, 80-82, 86, 91, 95, 100, 116, 120, 131, 138, 142]. In the majority of studies (n=60), PA was measured by means of only walking tasks or by using walking-related PA outcomes (e.g. steps, walked distance) [24, 40, 41, 43, 44, 46, 47, 49, 52-54, 56-58, 61, 62, 64-67, 69, 72, 74, 75, 77, 78, 83-85, 89, 90, 92, 93, 97, 98, 101, 103, 104, 107-109, 112, 113, 115, 119, 121, 123, 126-130, 132, 133, 136-139, 141].

The proprietary algorithm of the instrument was most frequently used, or the algorithm used was not reported at all. A population-specific custom algorithm was used in three research-grade and three consumer-grade devices. Devices were positioned at 15 different body positions, with the positions at the ankle, thigh, waist and wrist as most common. One device (Medtronic ICD/CRT device) was a type of pacemaker, and was surgically implanted in patients with heart failure. Validity was measured using 21 different statistical methods, reliability with three different methods, and responsiveness with five methods.

Table 2 provides an overview of the measurement properties of the research-grade devices, per PA outcome, study population, device properties (placement of the device, used algorithms) and outcome (used statistical test, result). Table 3 provides the same overview for the consumer-grade devices. Appendices 5 and 6 contain a more in-depth version of both tables, with extra information such as epoch length, sampling rate and results per condition.

Table 1. Descriptives of the 103 included studies.

Author	Year	Country	Study design	Population	N
Albaum et al. [108]	2019	Canada	Cross	iSCI	17
Alexander et al. [78]	2022	UK	Cross	MS	100
Alharbi et al. [140]	2016	Australia	Cross	Coronary heart disease	28
Alothman et al. [91]	2020	USA	Long	DM2	30
Anens et al. [79]	2023	Sweden	Cross	MS	30
Arch et al. [92]	2018	USA	Cross	Amputation[a]	50
Ata et al. [93]	2018	USA	Cross	Peripheral Aterial Disease	114
Balto et al. [83]	2016	USA	Cross	MS	45
Bianchini et al. [130]	2022	Italy	Cross	Parkinsons disease	47
Block et al. [84]	2017	USA	Cross	MS	82
Block et al. [85]	2019	USA	Cohort	MS	61
					31
Blondeel et al. [67]	2020	Belgium	Cross	COPD	30
Boeselt et al. [68]	2016	Germany	Cross	COPD	20
Campos et al. [40]	2018	Canada	Cross	Stroke	33
Caron et al. [119]	2019	France	Cross	DM2	20
Cederberg et al. [104]	2021	USA	Cross	Parkinsons disease	29
Chandrasekar et al. [112]	2018	UK	Cross	Polymyalgia rheumatica	27
Claridge et al. [120]	2019	Netherlands	Cross	Cerebral palsy	14
Clay et al. [41]	2019	New Zealand	Cross	Stroke	19
Collins et al. [94]	2019	USA	Cross	Osteoarthritis (knee)	15
Compagnat et al. [45]	2018	France	Corss	Stroke	35
Compagnat et al. [44]	2019a	France	Cross	Stroke	35
Compagnat et al. [42]	2019b	France	Cross	Stroke	38
Compagnat et al. [43]	2020	France	Cross	Stroke	26
Compagnat et al. [61]	2022	France	Cross	Stroke	26
Costa et al. [46]	2020	Brazil	Cross	Stroke	55
Coulter et al. [86]	2017	UK	Cross	MS	20
Daligadu et al. [109]	2018	Canada	Cross	Cardio-thorax surgery patients[b]	20
Daniel et al. [62]	2022	Brazil	Cross	Stroke	24
Danilack et al. [69]	2015	USA	Cross	COPD	176
de Carvalho Lana et al. [133]	2021	Brazil	Cross	Parkinsons disease	34
Dhillon et al. [70]	2018	USA	Cross	Lung disease[c]	8
Douma et al. [121]	2018	Netherlands	Cross	Cancer	72
Duclos et al. [47]	2019	Canada	Cross	Stroke	20

Study setting	% Male	Age (years)	Task	Walking speed (m/s)
FL	76.5	62.0 (41.5 - 78.5)	Physical therapy & self-directed tasks	N.R.
Lab	30.0	53.5 (47.8-58.0)	Circuit outdoors	Comfortable
FL	71.4	N.R.	Free-living 4 days	N.R.
FL	36.7	64.87 ± 5.99	Free-living 7 days (2x)	N.R.
Lab	30.0	49.2 ± 14.0	Circuit + sedentary activities	0.76 IQR 0.31 – 1.30 IQR 0.39
Lab	64-76	55.4 ± 10.1 – 58.6 ± 11.7	Circuit	0.95 ± 0.21 - 1.01 ± 0.19
Lab	77.2	69.5 ± 13.1	6MWT	N.R.
Lab	N.R.	46.7 ± 10.0	treatmill 500 steps	1.21 ± 0.27
Lab	67.0	66.3 ± 8.2	6MWT	Self-selected
Both	29.3	51.0 ± 13.7	2MWT and free-living 7 days	N.R.
Lab	28.0	50.0 ± 14.4	2 MWT	N.R.
FL	41.9	53.4 ± 11.7	Free-living 7 days	N.R.
FL	61.0	66 ± 8	Free-living 14 days	N.R.
FL	85.0	66.4 ± 7.4	Free-living 3 days	N.R.
Lab	69.7	64.9 ± 14.7	7 hours on a single day	0.82 ± 0.27
Lab	40.0	57.5 ± 8.4	Treadmill	0.50, 0.75, 1.00, 1.25 & 1.50
lab	62.0	64.2 ± 6.4	6MWT + treadmill	1.03 ± 0.18
Lab	11.0	69.2 ± 8.8	2 MWT & stairs test	1.19 (IQR 0.95-1.31)
Lab	60.0	35.4 ± 13.1	Circuit	
Lab	42.0	65.6 ± 8.2	6MWT	Self-selected (0.97 ± 0.22)
FL	33.0	68 ± 8	Free-living waking hours 28 days	N.R.
Lab	N.R.	64.6 ± 14.4	Circuit	0.6 ± 0.3
Lab	N.R.	64.6 ± 14.8	6MWT	Comfortable (0.56 ± 0.30)
Lab	52.6	65.7 ± 13.5	Circuit	0.52 ± 0.28
Lab	N.R.	64.6 (55.5-77.0)	6MWT	0.56 ± 0.3
Lab	61.5	63.5 (55.3 - 77.5)	6MWT	0.53 ± 0.30
Lab	54.5	62.5 ± 14.9	2 MWT	0.7 ± 0.3
Lab	45.0	53.7 ± 7.4	Circuit	83.9 ± 25.1 steps/min
Lab	90.0	61.3 ± 10.2	6 MWT	0.7 ± 0.2
Lab	54.0	46.2 ± 12.0	Treadmill walking	0.22 - 0.89
Both	99.0	72 ± 8	Circuit & free-living 14 days	0.97 ± 0.22
Lab	76.5	66.8 ± 7.1	2MWT	Self-selected
Lab	N.R.	42.1 ± 17.1	Circuit	N.R.
FL	63.0	63 ± 11.5	Free-living 14 days	N.R.
Both	65.0	53.9 ± 10.8	6MWT and Circuit at mall	1.02 ± 0.41 (6MWT) 0.86 ± 0.29 (Circuit)

Table 1. Continued.

Author	Year	Country	Study design	Population	N
Falter et al. [88]	2019	Belgium	Cross	Heart disease[d], DM 1&2	40
Fanchamps et al. [48]	2018	Netherlands	Cross	Stroke	25
Faria et al. [49]	2019	Brazil	Cross	Stroke	30
Farmer et al. [90]	2022	Australia	Cross	Orthopedic, neurological and other	88
Farooqi et al. [71]	2015	Swedem	Cross	COPD	19
Femiano et al.[126]	2022	Switzerland	Cross	Cardiac rehabilitation patients[e]	22
Ferreira et al. [132]	2020	Portugal	Cross	Chronic pain	50
Garcia Oliveira et al. [63]	2021	Brazil	Cross	Stroke	50
Gustafsson et al. [128]	2022	Denmark	Cross	Lumbar spinal stenosis	30
Hei Chow et al. [60]	2023	Australia	Cross	Stroke	23
Henderson et al. [64]	2021	USA	Cross	Stroke	21
					7
Herkert et al. [122]	2019	Netherlands	Cross	Coronary artery disease	19
				Heart failure	19
Holubova et al. [65]	2022	Czech Republic	Cross	Stroke	24
Huber et al. [66]	2022	Switzerland	Cross	Stroke	20
Hui et al. [50]	2018	Canada	RCT	Stroke	12
Jao et al. [95]	2017	USA	Cross	DM (half with foot amputation)	31
Jayaraman et al. [96]	2016	USA	Cross	iSCI	8
Jayaraman et al. [51]	2018	USA	Cross	Stroke	8
				iSCI	10
Jimenez-Moreno et al. [113]	2019	UK	Cross	DM1	30
Juen et al. [72]	2015	USA	Cross	pulmonary diseases[f]	28
Klassen et al. [52]	2016	Canada	Cross	Stroke	43
Klassen et al. [53]	2017	Canada	Cross	Stroke	21
Ladlow et al. [114]	2017	UK	Cross	Amputation[g]	20
Ladlow et al. [115]	2019	UK	Cross	Amputation[g]	19
Lai et al. [97]	2020	USA	Cross	Parkinsons disease	31
Lamont et al. [137]	2018	Australia	Cross	Parkinsons disease	33
Larkin et al. [131]	2016	Ireland	Cross	Rheumatoid arthritis	20

Study setting	% Male	Age (years)	Task	Walking speed (m/s)
Lab	80.0	61.9 ± 15.2	Cardiopulmonary exercise test, cycling ergometer	N.R.
Both	84.0	56 ± 12	Circuit	N.R.
Lab	70.0	62 ± 12	Circuit	Maximum speed 1.3 ± 1.0
Lab	49.0	73 ± 11	Circuit indoors and outdoors	0.81 & 0.78 (in, outdoor)
FL	0.0	69.2 ± 6.0	Free-living 14 days	N.R.
Lab	N.R.	56.6 ± 9.0	Physical therapy	N.R.
Lab	36.0	72.30 ± 6.76	Circuit	Self-selected & maximum walking speed
Lab	64.0	62 (57 - 70)	10 mWT + TUG	0.88 (0.50 - 1.13)
Lab	63.0	76.2 ± 7.8	Circuit	Comfortable
FL	65.0	74.8 ± 9.8	Free-living 7 days	N.R.
Lab	48.0	64.0 ± 13.5	Physical therapy	0.33 (0.00 - 1.21)
Lab	71.0	65.5 ± 8.3	Exercise training walking	0.49 (0.16–1.08)
Lab	74.0	61.4 ± 6.9	Circuit and treadmill	N.R.
Lab	89.0	65.1 ± 6.6	Circuit and treadmill	N.R.
Lab	62.5	58.95 ± 12.25	Circuit	N.R.
Lab	65.0	63.1 ± 12.4	Circuit, outdoor	1.34 (0.77 - 1.47)
FL	58.0	62.6 ± 9.3	Free-living 3 days (fri-sun)	0.73 ± 0.27
Lab	N.R.	56 ± 7.5	Circuit	Self-selected, 60 & 100 steps/min
Lab	87.5	48.5 ± 3.7	Circuit	N.R.
Lab	60.0	55.6 ± 9.4	Circuit	N.R.
Lab	87.5	48.5 ± 10.4	Circuit	N.R.
Lab	66.7	48 (25-72)	Circuit	N.R.
Lab	42.8	N.R.	6MWT	N.R.
Lab	70.0	65.0 ± 10.7	Circuit	Self-selected & 0.3-0.9 with increases of 0.1
Lab	N.R.	55 ± 10	Physical therapy	0.41 ± 0.27
Lab	N.R.	32 ± 5 (unilateral) 29 ± 4 (bilateral)	Treadmill	0.48, 0.67, 0.89, 1.12, 1.34
Lab	100.0	30.4 ± 4.6	Treadmill	0.48, 0.67, 0.89, 1.12, 1.34
Lab	N.R.	64.3 ± 6.3	Circuit & treadmill	1.05 ± 0.16
Lab	64.0	68.8 ± 8	Circuit	Self-selected & 60, 80, 100, 120, 140 steps/min
Lab	15.0	55 ± 14	Circuit & treadmill	Self-selected pace

5

Table 1. Continued.

Author	Year	Country	Study design	Population	N
Lavelle et al. [80]	2021	UK	Cross	MS	19
Mahendran et al. [54]	2016	Australia	Cross	Stroke	15
Mandigout et al. [55]	2017	France	Cross	Stroke	24
McGinley et al. [110]	2015	Canada	Cross	DM2	35
Miyamoto et al. [73]	2018	Japan	Cross	COPD	11
Negrini et al. [56]	2020	Italy	Cross	Stroke	43
Nishida et al. [134]	2020	Japan	Cross	DM2	51
O'Brien et al. [116]	2020	UK	Cross	Rheumatoid arthritis	22
				Rheumatoid arthritis	100
O'Neill et al. [142]	2017	UK	Cross	Bronchiectasis	55
Pham et al. [123]	2017	Germany	Long	Parkinsons disease	20
Polese et al. [57]	2019	Brazil	Cross	Stroke	37
Polhemus et al. [81]	2023	Switzerland	Cross	MS	45
Popp et al. [125]	2019	Switzerland	Cross	iSCI	30
Prieto-Centurion et al. [74]	2016	USA	Cross	COPD	4
Roberts-Lewis et al. [118]	2022	UK	Long	Progressive muscle diseases	20
					56
Rockette-Wagner et al. [105]	2021	USA	Long	Inflammatory myopathy	50
Rossi et al. [98]	2018	USA	Cross	Endometrial cancer	25
Salih et al. [138]	2016	Australia	Cross	Amputation[h]	21
Saygin et al. [106]	2022	USA	Long	Myositis	24
Schaffer et al. [58]	2017	USA	Cross	Stroke	24
Semanik et al. [99]	2020	USA	RCT	Chronic knee symptoms	35
Shimizu et al. [59]	2018	Japan	Cross	Stroke	10
Shoemaker et al. [100]	2017	USA	Cohort	Heart failure	16
Smith et al. [101]	2019	USA	Cross	Amputation[g]	32
Smith & Guerra [107]	2021	USA	Cross	Amputation[g]	35
Stuart et al. [82]	2020	UK	Long	MS	56
Takasaki [135]	2017	Japan	Cross	Lower back pain	15
Taoum et al. [139]	2020	France	Cross	Peripheral artery disease	23
Thorup et al. [127]	2017	Denmark	Cross	Heart disease[i]	24
Treacy et al. [24]	2017	Australia	Cross	Diverse motor disabilities[j]	166
Ummels et al. [75]	2018	Netherlands	Cross	CVD, cancer, COPD, osteoarthritis, chronic pain	130

Study setting	% Male	Age (years)	Task	Walking speed (m/s)
Lab	31.6	52.1 ± 11.9	Circuit	N.R.
Lab	53.3	63.4 ± 8.3	6MWT, circuit & treadmill	Slow (0.31 ± 0.11), comfortable (0.42 ± 0.17) & fast (0.54 ± 0.25)
Lab	62.5	68.2 ± 13.9	Circuit	N.R.
FL	60.0	62.8 ± 7.8	Free-living 14 days	N.R.
FL	91.6	76.6 ± 6.9	Free-living 7 days	N.R.
Lab	62.8	61.3 ± 14.95	Circuit	0.75 ± 0.32
FL	45.1	70 ± 5	Free-living 12-16 days	N.R.
Lab	14.0	53.7 ± 12.5	Circuit	N.R.
FL	29.0	58.5 ± 12.1	Free-living 7 days	N.R.
FL	40.0	60 ± 10	Free-living 7 days	N.R.
Lab	52.4	66.4 ± 9.0	Circuit	N.R.
Lab	75.7	62 ± 11	Circuit	0.9 ± 0.3 Comfartable 1.3 ± 0.6 Fast
Both	35.6	46 (IQR 40 - 51)	Circuit + Free-living 14 days	109 (61-146) steps/min
Lab	70.0	54.1 ± 11.9	Circuit	N.R.
Home	100.0	69 ± 10	6MWT	N.R.
Lab	N.R.	N.R.	Circuit	N.R.
FL	44.6	44.7 ± 15.1	Free-living 7 days	N.R.
FL	40.0	48.6 ± 15.4	Free-living 7 days	N.R.
FL	0.0	62 ± 9	Free-living 30 days	N.R.
Lab	71.4	59.4 ± 11.5	Circuit	N.R.
FL	29.2	46.2 ± 14.4	Free-living 7 days	N.R.
Lab	58.3	54 ± 13.4	Circuit	0.72 ± 0.40
FL	31.0	52 ± N.R.	Free-living 7 days	N.R.
Lab	50.0	57.5 ± 16.2	circuit	0.98 ± 0.36
FL	56.3	64.9 ± 11.3	Free-living 7 days	N.R.
Lab	66.0	49.7 ± 14.0		Self-selected
Lab	54.3	48.5 ± 14.8	2MWT	1.23 ± 0.22
FL	52.0	53.6 ± 8.0	Free-living 2-7 days	N.R.
FL	40.0	22.1 ± 4.3	Free-living 14 days	N.R.
Lab	N.R.	60.0 ± 10.0	Circuit	Self-selected
FL	91.6	67.0 ± 10.0	Day at hospital and day at home	N.R.
Lab	55.0	80 ± 11	6MWT	0.42 ± 0.22
Lab	43.6	61.5 ± 11.1	Circuit	1.3 ± 0.3

Table 1. Continued.

Author	Year	Country	Study design	Population	N
Van Blarigan et al. [102]	2017	USA	Cross	prostate cancer	22
Van der Weegen et al. [77]	2015	Netherlands	Cross	COPD & DM2	9
				COPD & DM2	12
Van Laerhoven et al. [124]	2022	Germany	Cross	DM	28
Vetrovsky et al[141]	2019	Australia	Cross	Heart failure	15
Wagner et al. [105]	2022	Denmark	Cross	RA	30
Webber & John [89]	2016	Canada	Cross	Geriatric rehabilitation[k]	38
Webster et al. [76]	2021	USA	Cross	COPD	59
Wendel et al. [103]	2018	USA	Cross	Parkinsons disease	33
Zbogar et al. [111]	2016	Canada	Cohort	SCI	35
Zhai et al. [87]	2020	Germany	Cross	MS	67
Yu et al. [136]	2022	Australia	Long	OA	65

[a] Lower limb, below knee, unilateral
[b] Post-coronay artery bypass graft surgery, aortic calve repair, mitral valve replacement
[c] COPD, interstitial lung disease, cystic fibrosis
[d] Ischemic heart disease, valvular heart disease
[e] coronary infarction, hypertensive cardiomyopathy, valvular cardiopathy, type-a aortic dissection
[f] COPD, congestive heart failure, other pulmonary diseases requiring pulmonary function test
[g] Lower limb, below and above knee, unilateral and bilateral
[h] Lower limb, below and above knee, unilateral
[i] Acute coronary syndrome, heart failure, coronary artery bypass grafting or valve surgery
[j] Fractured hip, pelvis, lower limb orthopedic surgery, stroke, TIA, neurological event, decreased mobility post medical or non-orthopedic surgical event, post fall with no lower limb fracture, other
[k] respiratory/infection, orthopedic, falls/decreased mobility, neurological, gastrointestinal, cancer, endocrine
Cross = cross sectional, Long = Longitudinal, RCT = randomized controlled trial
CAD = coronary artery disease, COPD = chronic obstructive pulmonary disease, CVD = cardiovascular disease, DM1 = diabetes mellitus type 1, DM2 = diabetes mellitus type 2, DM = diabetes mellitus (further details unknown), iSCI = incomplete spinal cord injury, MS = multiple sclerosis, PAD = pulmonary artery disease, SCI = spinal cord injury
Both = both free-living and laboratory with protocolled activities, FL = Free-living, Home = home situation with protocolled activities, Lab = laboratory setting with protocolled activities
MWT = minutes walking test, mWT = meter walking test, TUG = timed up and go-test
N.R. = Not reported

Study setting	% Male	Age (years)	Task	Walking speed (m/s)
FL	100.0	66 (56-83)	Free-living 7 days	N.R.
Lab	N.R.	60.9 ± 7.1 (Lab)	Treadmill	0.56 + 0.14 every 3 min
FL	N.R.	61.6 ± 9.2 (free-living)	Free-living 6-7 consecutive days	N.R.
FL	65.0	74.8 ± 9.8	Free-living 2 days	N.R.
FL	60.0	65.5 ± 12.6	Free-living 3 days	N.R.
Lab	17.0	61 (50-74)	Treadmill	0.69 – 1.39, increments of 0.14
Lab	10.5	83.2 ± 7.1	Hallway walk	0.4 ± 0.2
FL	52.5	69.4 ± 7.8	Free-living 7 days	N.R.
Lab	58.0	65.5 ± 9.4	Circuit	Comfertable and fast pace
Lab	70.0	48.9 ± 18.3	1 day of rehab	0.75 ± 0.39
FL	37.3	42.9 ± 10.9	Free-living 7 days	N.R.
FL	54.0	61.3 ± 5.99	Free-living 7 days	N.R.

Table 2. Overview of research grade devices evaluated on their measurement properties in the 52 studies.

Type	PA outcome	Population	Study	Measurement property	Criterion
ActiGraph					
GT3	EE	Amputation	Ladlow [114]	CV	IC
			Ladlow [115]	CV	IC
		iSCI	Jayaraman [96]	CV	IC
			Jayaraman [51]	CV	IC
		Stroke	Compagnat [45]	CV	IC
			Compagnat [43]	CV	IC
			Compagnat [61]	CV	IC
			Faria [49]	CV	IC
			Jayaraman [51]	CV	IC
			Mandigout [55]	CV	IC
	Steps	DM	Jao [95]	CV	DO
		Inflammatory myopathy	Rockette-Wagner [105]	Con V	F Tests & F SR
				TRT R	
				Resp	SR
		iSCI	Albaum [108]	CV	DO
			Jayaraman [96]	CV	DO

		Result	
Placement	Algorithm	Test	Outcome
Waist (SRL)	Cust	Pearson's r	r: 0.86 - 0.94
Waist (SRL)	Cust	Pearson's r	r: 0.92 – 0.96
Ankle	Prop (Freedson)	ANOVA	Sed: p<.05; low & high: p>.05
U-arm	Prop (Freedson)	ANOVA	Sed & low: p<.05; high: p>.05
Waist	Prop (Freedson)	ANOVA	Sed & low: p<.05; high: p>.05
Ankle	Prop (Freedson)	Kruskal wallis	Lying, sitting & standing: p<0.5
U-arm	Prop (Freedson)	Kruskal wallis	Lying, sitting, standing & 50SWT: p<.05
Waist	Prop (Freedson)	Kruskal wallis	All p<.05
Ankle (ua)	N.R.	Pearson's r	r = 0.41
Waist	N.R.	Pearson's r	r = 0.15
Wrist (ua)	N.R.	Pearson's r	r = 0.12
Waist	Prop	Pearson's r	r = 0.19
	Cust	Pearson's r	r = 0.44
Ankle	Cust (multiple)	LoA	-69.1 [-148.7; 10.5] -8.3 [-1.1; 17.8]
Ankle (a)	Prop (work-energy teorem)	Pearson's r	r = 0.04
	Prop (Freedson)	Pearson's r	r = 0.04
	Prop (combined)	Pearson's r	r = 0.37
Ankle (a)	Prop (Freedson)	Kruskal wallis	Lying, sitting, standing & STS: p<0.5
Ankle (ua)	Prop (Freedson)	Kruskal wallis	Lying, sitting, standing & STS: p<0.5
U-arm (a)	Prop (Freedson)	Kruskal wallis	Lying, sitting & standing: p<0.5
U-arm (ua)	Prop (Freedson)	Kruskal wallis	Lying, sitting & standing: p<0.5
Waist (a)	Prop (Freedson)	Kruskal wallis	Lying, sitting & standing: p<0.5
Waist (ua)	Prop (Freedson)	Kruskal wallis	Lying, sitting & standing: p<0.5
Ankle (ua)	N.R.	Spearman's rho	rho = 0.19
Ankle (a)	N.R.	Spearman's rho	rho = 0.21
Waist	N.R.	Spearman's rho	rho = 0.04
Wrist (ua)	N.R.	Spearman's rho	rho = 0.20
Wrist (a)	N.R.	Spearman's rho	rho = 0.08
Waist	Prop	Accuracy (%)	43.0 - 81.4%
Waist	Prop	Pearson's r	r: -0.42 - 0.66
Waist	Prop	ICC	ICC = 0.92 (CI 0.86 – 0.96)
Waist	Prop	Pearson's r	r = 0.47 (CI 0.12 - 0.71)
Ankle (la)	Prop	ICC	ICC: 0.15 – 0.99
Ankle	Prop (Freedson)	ANOVA	p>.05
U-arm	Prop (Freedson)	ANOVA	P<.05
Waist	Prop (Freedson)	ANOVA	p<.05

Table 2. Continued.

Type	PA outcome	Population	Study	Measurement property	Criterion
		MS	Block [85]	CV	DO
			Polhemus [81]	CV	DO
		Multi	Treacy [24]	CV	DO
			Webber & John [89]	CV	DO
		Osteoarthritis	Collins [94]	CV	Acc
		PD	Cederberg [104]	CV	DO
		Polymyalgia rheumatica	Chandrasekar [112]	CV	DO
		RA	O'Brien [142]	CV	DO
		Stroke	Campos [40]	CV	Acc
			Henderson [64]	CV	DO
	Intensity time	Osteoarthritis	Collins [94]	CV	Acc
	Activity time	DM	Jao [95]	CV	DO
		RA	O'Brien [142]	CV	DO
	Distance walked	Stroke	Compagnat [44]	CV	DO
		Peripheral artery disease	Taoum [139]	CV	GPS
	Counts	Amputation	Ladlow [114]	CV	IC

		Result	
Placement	Algorithm	Test	Outcome
Waist	Prop	ICC	ICC = 0.76 (CI 0.63-0.85)
Waist	Prop	CCC	CCC = 0.68 (CI 0.37 - 0.82)
	Prop (+ LFE filter)	CCC	CCC = 0.73 (0.13 - 0.84)
Waist	Prop	ICC	ICC = 0.123 (CI -0.071-0.355)
Ankle	Prop	ICC	ICC = 0.682 (CI -0.211-0.895)
	Prop (+ LFE filter)	ICC	ICC = 0.938 (CI 0.870-0.969)
Waist	Prop	ICC	ICC = -0.051 (CI -0.191-0.153)
	Prop (+ LFE filter)	ICC	ICC = 0.829 (CI 0.329-0.936)
Wrist		ICC	ICC = 0.602
Wrist (ua)	Prop	Mean difference	62 - 76 steps
Wrist (a)	Prop	Mean difference	32 - 66 steps
Waist	Prop	LoA	Walking: 141 + (0.5*mean count) [110+(0.5*mean count)]
	Prop (+ LFE filter)	LoA	Walking: 20 [-40; 81]
	Prop	LoA	Stairs: 4 [-4; 12]
	Prop (+ LFE filter)	LoA	Stairs: 0 [-5; 5]
Thigh	Prop	LoA	-30 [-116; 57]
Ankle	Prop	ICC	ICC = 0.80 (CI 0.63-0.90)
	Prop (+ LFE filter)	ICC	ICC = 0.76 (CI 0.56-0.87)
Waist	Prop	ICC	ICC = 0.70 (CI 0.47-0.84)
	Prop (+ LFE filter)	ICC	ICC = 0.82 (CI 0.66-0.90)
Ankle (a)	Prop	ICC	ICC: 0.57 - 0.81
	Prop (+ LFE filter)	ICC	ICC: 0.84 - 0.96
Ankle (ua)	Prop	ICC	ICC: 0.84 - 0.86
	Prop (+ LFE filter)	ICC	ICC : 0.77 - 0.97)
Wrist	Cut off: counts < 200	% bias	Sed: -66%
	Cut off: 1924 counts/ min, bouts of 10 min	Difference	MVPA: +281 min
Waist	Prop	Accuracy (%)	41.8 – 100%
Thigh	Prop	LoA	-0.3 [-1.2; 0.6] min - 0.2 [-0.7; 1.1] min
Ankle (ua)	Prop	Pearson's r	r = 0.95
Ankle (a)	Prop	Pearson's r	r = 0.93
Waist	Prop	Pearson's r	r = 0.86
Wrist (ua)	Prop	Pearson's r	r = 0.79
Wrist (a)	Prop	Pearson's r	r = 0.81
Hip	Cust	MAPE	11.9 - 18.8
Waist (SRL)	Prop	Pearson's r	r: 0.82-0.92
Waist (LRL)	Prop	Pearson's r	r: 0.76 – 0.80
Waist (Sp)	Prop	Pearson's r	r: 0.68 – 0.80

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Table 2. Continued.

Type	PA outcome	Population	Study	Measurement property	Criterion
	MET	Stroke	Jayaraman [51]	CV	IC
		iSCI	Jayaraman [51]	CV	IC
	Vector magnitude	Inflammatory myopathy	Rockette-Wagner [105]	Con V	F Tests & F SR
				TRT R	
				Resp	SR
GTX9	Steps	Amputation	Smith & Guerra [107]	CV	DO
		MS	Anens [79]	CV	DO
		PAD	Ata [93]	CV	DO
	Sedentary time	COPD	Webster [76]	CV	Acc
		MS	Anens [79]	CV	DO
Pal Technologies					
ActivPAL	Steps	DM	Alothman [91]	TRT R	
			Jao [95]	CV	DO
		Multi	Treacy [24]	CV	DO
		RA	Larkin [131]	CV	DO
		Stroke	Mahendran [54]	CV	DO
				TRT R	
	Activity time	Amputation	Salih [138]	CV	DO
		DM	Alothman [91]	TRT R	
			Jao [95]	CV	DO
		RA	Larkin [131]	CV	DO
		Stroke	Mahendran [54]	CV	DO
				TRT R	
	MET	Stroke	Mahendran [54]	TRT R	
ActivPAL3	Steps	MS	Coulter [86]	CV	DO
		RA	O'Brien [142]	CV	DO

		Result	
Placement	Algorithm	Test	Outcome
Ankle (a)	Prop (Freedson)	Kruskal wallis	STS: p<.05
Ankle (ua)	Prop (Freedson)	Kruskal wallis	50SWT, 6MWT & STS: p<.05
U-arm (a)	Prop (Freedson)	Kruskal wallis	All p>.05
U-arm (ua)	Prop (Freedson)	Kruskal wallis	All p>0.5
Waist (a)	Prop (Freedson)	Kruskal wallis	All p>.05
Waist (ua)	Prop (Freedson)	Kruskal wallis	All p>.05
Ankle	Prop (Freedson)	Kruskal wallis	Lying & STS p<.05
U-arm	Prop (Freedson)	Kruskal wallis	50SWT p<.05
Waist	Prop (Freedson)	Kruskal wallis	50SWT, 6MWT & STS p<.05
Waist	Prop	Pearson's r	r: -0.35 - 0.60
Waist	Prop	ICC	ICC = 0.80 (CI 0.62 – 0.89)
Waist	Prop	Pearson's r	r = 0.53 (CI 0.20 - 0.75)
Ankle	N.R.	ICC	ICC = 0.111 (CI -0.202 - 0.418)
Wrist	N.R.	ICC	ICC = 0.005 (CI -0.256 - 0.299)
Waist	Prop	Spearman's rho	rho: 0.74 - 0.79
	Prop (+ LFE filter)	Spearman's rho	rho: 0.85 - 0.93
Waist	Prop	% error	-3.1 ± 10.3%
Waist	Prop (multiple)	CCC	CCC: 0.614 -0.838
Waist	Prop	Spearman's rho	rho: 0.18 - 0.39
	Prop (+ LFE filter)	Spearman's rho	rho: 0.16 - 0.38
Thigh	Prop	ICC	ICC = 0.91
Thigh	Prop	Accuracy (%)	90.7 – 98.5%
Thigh	Prop	ICC	ICC = 0.781 [CI 0.231; 0.911]
Thigh	Prop	Pearson's r	r = 0.94 [CI 0.86; 0.98]
Thigh	Prop	ICC	ICC: 0.72 – 0.99
Thigh	Prop	ICC	ICC: 0.66 – 0.98
Thigh (a)	N.R.	LoA	Walking: 0.11 [-0.43; 0.66] sec (ue)
Thigh (ua)	N.R.	LoA	Walking: 0.004 [-0.09; 0.10] sec (ue)
Thigh	Prop	ICC	ICC: 0.74 – 0.90
Thigh	Prop	Accuracy (%)	96.6 – 100%
Thigh	Prop	Pearson's r	r: 0.74 – 0.93
Thigh	Prop	ICC	ICC = 0.99
		APE	0.3 – 3.2%
Thigh	Prop	ICC	ICC: 0.66 – 0.98
		APE	3.3 – 6.5%
Thigh	Prop	ICC	ICC: 0.65 – 0.99
Thigh	Prop	LoA	-4.7 [-22.88; 13.47] (ue)
Thigh	Prop	LoA	-30 [-116; 57] (ue)

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Table 2. Continued.

Type	PA outcome	Population	Study	Measurement property	Criterion
	Activity time	MS	Coulter [86]	CV	DO
		RA	O'Brien [142]	CV	DO
Modus Health					
StepWatch 3	Steps	Amputation	Arch [92]	CV	DO
		Multiple	Treacy [24]	CV	DO
			Webber & John [89]	CV	DO
		Stroke	Garcia Oliveira [63]	CV	DO
			Henderson [64]	CV	DO
	Distance walked	Peripheral artery disease	Taoum [139]	CV	GPS
StepWatch 4	Steps	Amputation	Smith & Guerra [107]	CV	DO
Body Media					
Sensewear armband	EE	Chronic lung disease	Dhillon [70]	CV	IC
		MS	Stuart [82]	Con V	F Tests & F SR
				Resp	F Tests & F SR
		Stroke	Compagnat [42] Mandigout [55]	CV	IC
	Steps	MS	Stuart [82]	Con V	F Tests & F SR
				Resp	F Tests & F SR
	Activity time	MS	Stuart [82]	Con V	F Tests & F SR
				Resp	F Tests & F SR
	Distance walked	Stroke	Compagnat [44]	CV	DO
	MET	MS	Stuart [82]	Con V	F Tests & F SR
				Resp	F Tests & F SR
	PA composite score	MS	Stuart [82]	Con V	F Tests & F SR

Placement	Algorithm	Result	
		Test	Outcome
Thigh	Prop	LoA	-4.6 [-26.1; 17.0] – 1.1 [-1.12; 3.34] sec
Thigh	Prop	LoA	-0.3 [-1.2; 0.6] – 0.2 [-0.7; 1.1] min
Ankle (a)	N.R.	ICC	ICC: 0.90 – 0.99
Ankle	Prop	ICC	ICC = 0.982 [CI 0.975; 0.986]
Ankle	Prop	ICC	ICC = 0.960 [CI 0.924; 0.979]
Ankle (la)	Prop	Spearman's rho	rho: 0.963 - 0.994
Ankle (a)	Prop	ICC	ICC: 0.92 - 0.96
Ankle (ua)	Prop	ICC	ICC: 0.97 - 0.97
Ankle	Cust	MAPE	16.7 $\pm$ 10.7
Ankle	N.R.	ICC	ICC = 0.967 (CI 0.929 - 0.984)
U-arm	Prop	LoA	-1.26 [-4.71; 2.19] – 0.56 [-1.68-2.80]
Arm	Prop	Spearman's rho	rho: -.0412 - 0.365
Arm	Prop	Spearman's rho	rho: -0.196 - 0.168
U-arm (ua)	Prop	Pearson's r	r: 0.48 – 0.81
U-arm (a)	N.R.	Spearman's rho	rho = 0.61
U-arm (ua)	N.R.	Spearman's rho	rho = 0.45
Arm	Prop	Spearman's rho	rho: -0.325 - 0.305
Arm	Prop	Spearman's rho	rho: -0.170 - 0.250
Arm	Prop	Spearman's rho	rho: -0.640 - 0.493
Arm	Prop	Spearman's rho	rho: -0.128 - 0.272
U-arm (a)	Prop	Pearson's r	r = 0.72
U-arm (ua)	Prop	Pearson's r	r = 0.68
Arm	Prop	Spearman's rho	rho: -0.343 - 0.316
Arm	Prop	Spearman's rho	rho: -0.191 - 0.295
Arm	Prop	Spearman's rho	rho: -0.444 - 0.376

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Table 2. Continued.

Type	PA outcome	Population	Study	Measurement property	Criterion
				Resp	F Tests & F SR
Sensewear Pro2	Steps	Stroke	Mahendran [54]	CV TRT R	DO
	MET	Stroke	Mahendran [54]	TRT R	
Activ8					
Activ8	Activity time	CP	Claridge [120]	CV	DO
		Stroke	Fanchamps [48]	CV	DO
	Steps	Multi	Ummels [75]	CV	DO
Philips					
Actical	EE	Chronic lung disease	Dhillon [70]	CV	IC
		Stroke	Mandigout [55]	CV	IC
	Activity kilocounts	SCI	Zbogar [111]	TRT R	
	Steps	SCI	Zbogar [111]	TRT R	
Axivity					
AX3/AX6	Steps	Cardiac rehab	Femiano [126]	CV	DO
		Lumbar spinal stenosis	Gustafsson [128]	CV	DO
McRoberts					
Dynaport	EE	Stroke	Daniel [62]	CV	IC
Dynaport Hybrid	Steps	PD	Pham [123]	CV	DO
Vandrico Inc.					
Metria-IH1	EE	iSCI	Jayaraman [96]	CV	IC
			Jayaraman [51]	CV	IC
		Stroke	Jayaraman [51]	CV	IC
	Steps	iSCI	Jayaraman [96]	CV	DO

		Result	
Placement	Algorithm	Test	Outcome
Arm	Prop	Spearman's rho	rho: -0.110 - 0.356
U-arm (a)	N.R.	APE	21.9 – 66.8%
U-arm (a)	N.R.	APE	2.2 – 38.5%
U-arm (a)	N.R.	APE	17.8 – 26.8%
Thigh (frontal) (la)	N.R.	Spearman's rho	rho: -0.04 – 0.86
Thigh (lateral 2cm) (la)	N.R.	Spearman's rho	rho: 0.49 – 0.99
Pocket	N.R.	Spearman's rho	rho: 0.14 – 0.79
Thigh (frontal)	N.R.	% time difference	-3.8 – 6.5%
Pocket	N.R.	Pearson's r	r = 0.24
Wrist	Prop	LoA	-3.4 [-6.4; -0.4] - -0.8 [-1.6; 0.0]
Ankle (a)	N.R.	Spearman's rho	rho = 0.30
Ankle (ua)	N.R.	Spearman's rho	rho = 0.20
Waist	N.R.	Spearman's rho	rho = -0.01
Wrist (a)	N.R.	Spearman's rho	rho = -0.19
Wrist (ua)	N.R.	Spearman's rho	rho = -0.27
Wrist	N.R.	Pearson's r	r = 0.74 [CI 0.54; 0.86]
Waist	N.R.	Pearson's r	r = 0.84 [CI 0.70; 0.92]
Wrist	Cust	MAPE	4.1 - 143.0%
Lower back	Prop	ICC	ICC: -0.04 - 1.00
Thigh	Prop	ICC	ICC: -0.16 - 1.00
Waist	Prop	ICC	ICC: -0.10 - 1.00
Wrist	Prop	ICC	ICC: -0.10 - 0.99
Lower back	Prop	ICC	ICC: 0.77 - 0.94
Lower back	Cust.	Kappa	k: 0.70 – 0.71
U-arm	Prop	ANOVA	All p>.05
U-arm	Prop	Kruskal wallis	All p>.05
U-arm (a)	Prop	Kruskal wallis	All p>.05
U-arm (ua)	Prop	Kruskal wallis	STS: p<.05
U-arm	Prop	ANOVA	p < 0.05

Table 2. Continued.

Type	PA outcome	Population	Study	Measurement property	Criterion
	MET	iSCI	Jayaraman [51]	CV	IC
		Stroke	Jayaraman [51]	CV	IC
Activinsight					
GENEactive	Raw acceleration (ENMO - mg)	Myotonic dystrophy type 1	Jimenez-Moreno [113]	TRT R	
CamNtech					
Actiheart	EE	Amputation	Ladlow [115]	CV	IC
Espruino					
Bangle.js	Steps	DM	Van Laerhoven [124]	CV	Acc
Garcia Oliveira et al.					
AMoR	Steps	Stroke	Garcia Oliveira [63]	CV	DO Acc
	Sedentary time	Stroke	Garcia Oliveira [63]	CV	DO
Maastricht Instruments BV					
MOX (1.01)	Counts	Multi	Van der Weegen [77]	CV	Acc
	Intensity time	Multi	Van der Weegen [77]	CV	Acc
Medtronic					
ICD/CRT device	Activity time	Heart failure	Shoemaker [100]	CV	Acc
				Resp	Acc
StepsCounts					
PiezoRX	Steps	MS	Anens [79]	CV	DO
Xsens					
MTw	EE	DM	Caron [119]	CV	IC
ZurichMOVE					
JUMP	EE	iSCI	Popp [125]	CV	IC

Placement	Algorithm	Result	
		Test	Outcome
U-arm	Prop	Kruskal wallis	All p>.05
U-arm (a)	Prop	Kruskal wallis	50SWT & STS: p<.05
U-arm (ua)	Prop	Kruskal wallis	STS: p<.05
Wrist & Ankle	N.A.	ICC	0.86 [95% CI 0.74; 0.93] to 0.97 [95% CI 0.95; 0.99]
Chest	Branched-Model equation	Pearson's r	r 0.81 – 0.86
Wrist	Custom (open source)	LoA	-566.7 [-4111.5 - 2978.0] - 17.48 [-211.5 - 246.5]
Thigh	N.R.	ICC	ICC: 0.999 - 0.999
Thigh	N.R.	ICC	ICC: 0.981 - 0.985
Thigh	N.R.	ICC	ICC = 0.960 (CI 0.929 - 0.977)
Lower back		Pearson's r	r = 0.98 (range 0.95 - 1.00)
Lower back		Spearman's rho	rho = 0.82 (range 0.60 - 0.94)
Lower back		LoA	-2.3 - -0.5
Chest (internal)	Prop	LoA	-0.77 [-2.71; 1.17] hours/day (ue)
Chest (internal)	Prop	LoA	0.19 [-0.79; 1.17] hours/day (oe)
N.R.	N.R.	Spearman's rho	rho: 0.82 - 0.99
Lower back	Bouten's equation	LoA	-1.17 [-6.45; 4.14] W/kg (oe)
Multiple	Cust	Pearson's r	r = 0.92

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Table 3. Overview of consumer grade devices evaluated on their measurement properties in the 67 studies.

Type	PA outcome	Population	Study	Measurement property
Fitbit				
Alta	Steps	Cancer	Rossi [98]	Con V
		COPD	Blondeel [67]	CV
		MS	Lavelle [80]	CV
		Stroke	Holubova [65]	CV
	Activity time	MS	Lavelle [80]	CV
Charge	Steps	Amputation	Smith [101]	CV
		Multi	Treacy [24]	CV
		PDs	Lamont [137]	CV
Charge 2	EE	CAD	Herkert [122]	CV
		Heart failure	Herkert [122]	CV
	Steps	Heart failure	Vetrovsky [141]	CV
		Osteoarthritis	Collins [94]	CV
		PD	Lai [97]	CV
		Progressive muscle diseases	Roberts-Lewis [118]	CV
	Intensity time	Osteoarthritis	Collins [94]	CV
Flex	Steps	Amputation	Smith [101]	CV
		CAD	Alharbi [140]	CV
		Post heart operation	Daligadu [109]	CV
		MS	Balto [83]	CV
			Block [84]	CV
			Block [84]	CV
			Block [85]	CV
			Block [85]	CV
		Multi	Ummels [75]	CV
	Intensity time	Chronic knee symptoms	Semanik [99]	CV
		CAD	Alharbi [140]	CV
		Stroke	Hei Chow [60]	CV
	Distance walked	Post heart operation	Daligadu [109]	CV
Flex 2	Steps	MS	Block [85]	CV
		Osteoarthritis	Yu [136]	CV
				Resp

			Result	
Criterion	Placement	Algorithm	Test	Outcome
SR	N.R.	N.R.	CCC	CCC = 0.00005 [CI -0.22 - 0.22]
Acc	Wrist	Prop	LoA	306 [-2068; 2680] (oe)
DO	Wrist	N.R.	LoA	-302.8 [-1036.8; 431.1] (oe)
DO	Upper limb (b)	Prop	MARD	3.05 - 85.67%
	Lower limb (b)	Prop	MARD	1.33 - 11.08%
	Waist	Prop	MARD	0.47 - 3.66%
Acc	Wrist	N.R.	% error	100% [range -38.7 - 100]
DO	Wrist	N.R.	ICC	ICC = 0.86
DO	Wrist	N.R.	ICC	ICC = 0.399 [CI -0.026- 0.654]
Acc	Wrist	N.R.	ICC	ICC: 0.18 – 0.94
IC	Wrist	Prop	ICC	ICC = 0.10
IC	Wrist	Prop	ICC	ICC = 0.42
Acc	Wrist	N.R.	CCC	CCC = 0.48 [CI 0.20 - 0.69]
Acc	Wrist	Prop	ICC	ICC = 0.602
DO	Wrist	N.R.	ICC	ICC: 0.27 – 0.47
DO	Wrist	N.R.	Spearman's rho	rho = 0.97 [CI 0.96 - 0.98]
Acc	Wrist	Cust	% bias	-5 – 37%
DO	Wrist	N.R.	ICC	ICC = 0.843
Acc	N.R.	Prop	Pearson's r	r = 0.947
DO	Wrist	N.R.	CCC	CCC = 0.43
DO	Wrist	N.R.	MPE	12.4 – 13.8%
DO + ACC	Wrist	N.R.	ICC	2MWT DO: ICC = 0.69
				2MWT ACC: ICC = 0.59
ACC	Wrist	N.R.	ICC	ICC = 0.74
DO	Wrist	N.R.	ICC	ICC = 0.69 [CI 0.53 - 0.80]
ACC	Wrist	N.R.	ICC	ICC = 0.98 [CI 0.97 - 0.98]
DO	Wrist	N.R.	Pearson's r	r = 0.31
Acc	Wrist	Prop	Spearman's rho	rho: 0.25 – 0.73
Acc	N.R.	Prop	Pearson's r	r: 0.04 – 0.72
Acc	Wrist	Prop	ICC	ICC: -0.236 - 0.884
DO	Wrist	N.R.	CCC	CCC = 0.37
Acc	Wrist	N.R.	ICC	ICC = 0.98 [CI 0.97 - 0.99]
SR	Wrist	N.R.	Correlation	0.20 - 0.28
SR & tests	Wrist	N.R.	Correlation	-0.28 - 0.28

Table 3. Continued.

Type	PA outcome	Population	Study	Measurement property
Inc.	Steps	PD	de Carvalho Lana [133]	CV
Inspire HR	Steps	MS	Polhemus [81]	CV
				CV
		Progressive muscle diseases	Roberts-Lewis [118]	CV
				TRT R
				Resp
	Activity time	MS	Polhemus [81]	CV
	Intensity time	MS	Polhemus [81]	CV
		Progressive muscle diseases	Roberts-Lewis [118]	CV
				TRT R
				Resp
	MET	Progressive muscle diseases	Roberts-Lewis [118]	CV
				TRT R
				Resp
One	Steps	Amputation	Arch [92]	CV
		Cancer	Van Blarigan [102]	CV
		MS	Balto [83]	CV
		Multi	Ummels [75]	CV
			Treacy [24]	CV
		Myositis	Saygin [106]	CV
				TRT R
				Resp
		PDs	Lai [97]	CV
		Stroke	Duclos [47]	CV
			Henderson [64]	CV
			Hui [50]	CV
			Klassen [52]	CV
			Klassen [53]	CV
	Intensity time	Cancer	Van Blarigan [102]	CV
		Myositis	Saygin [106]	CV
		Stroke	Hui [50]	CV
Surge	Steps	PD	Wendel [103]	CV

			Result	
Criterion	Placement	Algorithm	Test	Outcome
DO	Waist	N.R.	Pearson's r	r = 0.82
DO	Wrist	N.R.	CCC	CCC = 0.66 (CI 0.14 - 0.80)
Acc	Wrist	N.R.	CCC	CCC: 0.33 - 0.65
Acc	Wrist	N.R.	Spearman's rho	rho = 0.76 (CI 0.60 - 0.87)
Acc	Wrist	N.R.	ICC	ICC = 0.96 (CI 0.92 - 0.98)
Acc	Wrist	N.R.	AUC	AUC = 0.86 (CI 0.75 - 0.97)
Acc	Wrist	N.R.	CCC	CCC: 0.18 - 0.52
Acc	Wrist	N.R.	CCC	CCC: 0.41 - 0.80
Acc	Wrist	N.R.	Spearman's rho	rho = 0.51 (CI 0.29 - 0.69)
	Wrist	N.R.	ICC	ICC = 0.78 (CI 0.63 - 0.87)
Acc	Wrist	N.R.	AUC	AUC = 0.72 (CI 0.56 - 0.88)
Acc	Wrist	N.R.	Spearman's rho	rho = 0.63 (CI 0.47 - 0.74)
	Wrist	N.R.	ICC	ICC = 0.94 (CI 0.89 - 0.97)
Acc	Wrist	N.R.	AUC	AUC = 0.90 (CI 0.81 - 0.98)
DO	Ankle (a)	N.R.	ICC	ICC: 0.88 – 0.97
Acc	Waist	N.R.	Pearson's r	r = 0.94
Acc	Waist	N.R.	Pearson's r	r = 0.67
DO	Waist	N.R.	MPE	1.9% - 1.9%
DO	Waist	N.R.	Pearson's r	r = -0.15
DO	Ankle	N.R.	ICC	ICC = 0.919 [CI 0.772 - 0.961]
	Waist	N.R.	ICC	ICC = 0.397 [CI -0.087 - 0.689]
Acc	Waist	Prop	ICC	ICC = 0.96 (CI 0.92 - 0.98)
	Waist	Prop	ICC	ICC = 0.89 (CI 0.72 - 0.96)
SR	Waist	Prop	Spearman's rho	rho = 0.63
DO	Waist	N.R.	ICC	ICC: 0.98 – 0.98
DO	Ankle	Prop	% error	0.50 – 2.67%
DO	Ankle (a)	Prop	ICC	ICC: 0.71 - 0.92
	Ankle (ua)	Prop	ICC	ICC: 0.78 - 0.92
Acc	Ankle (ua)	Prop	Regression r	r: 0.97 – 0.99
DO	Ankle (ua)	Prop	MPE	4.0 – 15.8%
	Waist	Prop	MPE	7.7 – 84.6%
Acc	Ankle (ua)	Prop	LoA	156.1 [-239.6; 551.9] (u)
Acc	Waist	Prop	Pearson's r	r: 0.65 – 0.85
Acc	Waist	Prop	ICC	ICC: 0.59 - 0.96
Acc	Ankle (ua)	Prop	Regression r	r: 0.41 – 0.97
DO	Wrist (la)	Prop	ICC	ICC: -0.003 – 0.41

Table 3. Continued.

Type	PA outcome	Population	Study	Measurement property
Ultra	Steps	Stroke	Costa [46]	CV
Zip	Steps	COPD	Blondeel [67]	CV
			Pietro-Centurion [76]	CV
		Cardiac diseases	Thorup [127]	CV
		MS	Lavelle [80]	CV
		Multi	Farmer [90]	CV
		PD	Wendel [103]	CV
		Polymyalgia rheumatica	Chandrasekar [112]	CV
		Stroke	Clay [41]	
			Schaffer [58]	CV
				TRT R
Garmin				
Forerunner 35	Steps	Stroke	Huber [66]	CV
				TRT R
Vivofit	Steps	Amputation	Smith [101]	CV
		Heart failure	Vetrovsky [141]	CV
		Multi	Treacy [24]	CV
		PD	Lamont [137]	CV
		Stroke	Schaffer [58]	CV
				TRT R
Vivofit 3	Steps	Amputation	Smith & Guerra [107]	CV
		Heart failure	Vetrovsky [141]	CV
Vivifit 4	Steps	MS	Lavelle [80]	CV
	Activity time	MS	Lavelle [80]	CV
Vivosmart 3	Steps	PD	Lai [97]	CV
Vivosmart 4	Steps	PD	Bianchini [130]	CV
Omron				
Active Style Pro HJA-350	MET	Stroke	Shimizu [59]	CV
Active Style Pro HJA-750c	EE	DM	Nishida [56]	CV

Criterion	Placement	Algorithm	Result	
			Test	Outcome
DO	Wrist (b)	N.R.	Pearson's r	r = 0.67
Acc	Waist	Prop	LoA	-1055 [-2820; 589] (ue)
DO	Waist	N.R.	LoA	6 [-14; 25] (ue)
Acc	Waist	Prop	ICC	ICC: 0.60 – 0.96
DO	Waist	N.R.	LoA	-6.2 [-717.4; 705.0] (oe)
DO	Foot	Prop	ICC	ICC: 0.60 - 0.85
DO	Waist	Prop	ICC	ICC: -0.03 – 0.98
DO	Waist	N.R.	LoA	1 [-8;10] – 10 [-55; 74]
	Shirt, midline	N.R.	LoA	-6 [-81; 68] – 12 [-58; 83]
	Waist	N.R.	Kendall Tau-b	τ = 0.80
DO	Waist	N.R.	MAPE	-88.2 – 4.2%
	Waist	N.R.	ICC	ICC = 0.974
Acc	Wrist (ua)	N.R.	LoA	-1.6 [-86.9; 83.5] - 5.0 [-63.7; 2689.5]
	Wrist (ua)	N.R.	ICC	ICC: 0.989 - 0.996
DO	Wrist (b)	N.R.	ICC	ICC = 0.86
Acc	Wrist	N.R.	CCC	CCC = 0.89 [CI 0.75; 0.96]
DO	Wrist	N.R.	ICC	ICC = 0.259 [CI -0.071; 0.556]
Acc	Wrist	N.R.	ICC	ICC: 0.36 – 0.97
	Wrist (ua)	N.R.	MAPE	-90.1 – -16.0%
	Wrist (a)	N.R.	MAPE	-68.2 – -4.0%
	Wrist (ua)	N.R.	ICC	ICC = 0.964 [CI 0.916; 0.984]
	Wrist (a)	N.R.	ICC	ICC = 0.858 [CI 0.672; 0.939]
DO	Ankle	N.R.	ICC	ICC = 0.122 (CI -0.141 - 0.398)
	Wrist	N.R.	ICC	ICC = 0.895 (CI 0.802 - 0.945)
Acc	Wrist	N.R.	CCC	CCC = 0.92 [CI 0.78; 0.97]
DO	Wrist	N.R.	LoA	-251.05 [-717.4; 253.6] (oe)
DO	Wrist	N.R.	% error	100% [range 100 - 100]
DO	Wrist (la)	N.R.	ICC	ICC: 0.67 – 0.97
DO	Wrist (b)	Prop	ICC	ICC = 0.66 (CI 0.31 - 0.83)
MET com	Waist	Prop	T-test (1-sample)	P<.05
DLW	Waist	TEE = BMR (Ganpule's equation) * PAL	Pearson's r	TEE: r = 0.87

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Table 3. Continued.

Type	PA outcome	Population	Study	Measurement property
	PAL	DM	Nishida [56]	CV
	Intensity time	COPD	Miyamoto [73]	
HJ-113	Steps	Amputation	Smith [101]	CV
HJ-322U-E	Steps	Heart failure	Vetrovsky [141]	CV
HJ-720ITC	Steps	COPD	Danilack [69]	CV
Walking Style x	Steps	Multi	Ummels [75]	CV
Yamax				
Digiwalker CW-700	Steps	Bronchiectasis	O'Neill [142]	CV
		Multi	Ummels [75]	CV
	Activity time	Bronchiectasis	O'Neill [142]	CV
Digiwalker SW-200	Steps	MS	Anens [79]	CV
			Balto [83]	CV
			Lavelle [80]	CV
	EE	COPD	Farooqi [71]	CV
	PAL	COPD	Farooqi [71]	CV
Google				
Fit	Steps	PD	de Carvalho Lana [133]	CV
		Stroke	Costa [46]	CV
				TRT R
			Polese [57]	CV
	EE	Stroke	Faria [49]	CV
Android stepcounter	Steps	RA	Wagner [105]	CV
Apple				
Watch Sport	EE	Multi	Falter [88]	CV
Health	Steps	MS	Balto [83]	CV

			Result	
Criterion	Placement	Algorithm	Test	Outcome
DLW	Waist	PAL = ([BMR (Ganpule's equation) + AEE (prop)]*10/9)*BMR	Pearson's r	r = 0.71
Acc	Waist	Cust	Pearson's r	r: 0.38 – 0.81
Acc	Waist	Cust	Pearson's r	r: -0.05 – 0.83
DO	Waist	N.R.	ICC	ICC = 0.928
Acc	Waist	N.R.	CCC	CCC = 0.82 [CI 0.56; 0.93]
DO	Waist	N.R.	LoA	34 [-186; 253]
DO	Waist	N.R.	Pearson's r	r = 0.25
Acc	Waist	N.R.	LoA	-167 [-3078; 2745] (oe)
DO	Wrist	N.R.	Pearson's r	r = -0.33
Acc	Waist	N.R.	LoA	Daily activity time: 165 [62; 269] min
DO	N.R.	N.R.	Spearman's rho	rho: 0.64 - 0.97
DO	Waist	N.R.	MPE	8.5 – 9.7%
DO	Waist	N.R.	LoA	119.4 [-498.0; 736.8] (ue)
DLW	Waist	Harris-Benedict	ICC	ICC = 0.70 [CI 0.23; 0.89]
		Schofield	ICC	ICC = 0.71 [CI 0.21; 0.89]
		WHO	ICC	ICC = 0.74 [CI 0.33; 0.90]
		Moore	ICC	ICC = 0.69 [CI 0.21; 0.88]
		Nordic Nutrtion Recommendation	ICC	ICC = 0.70 [CI 0.17; 0.89]
		Nordenson	ICC	ICC = 0.40 [CI -0.16; 0.77]
DLW + IC	Waist	Cust	ICC	ICC = 0.34
DO	Waist	N.R.	Pearson's r	r = 0.92
DO	Waist	N.R.	Pearson's r	r = 0.66
	Waist	N.R.	ICC	ICC = 0.76
DO	Front pocket (a)	N.R.	ICC	ICC = 0.93 [CI 0.86; 0.96]
IC	Front pocket (a)	N.R.	Pearson's r	r = 0.30
DO	Waist	Prop	MAPE	1.0 - 19.3%
IC	Wrist	Prop	ICC	ICC = 0.797
DO	Front pocket	N.R.	MPE	2.7 – 2.9%

Table 3. Continued.

Type	PA outcome	Population	Study	Measurement property
Iphone CMPedometer	Steps	PAD	Ata [93]	CV
Iphone SE	Steps	Cancer	Douma [121]	CV
	Distance walked	Cancer	Douma [121]	CV
Geonaute				
Onstep 400	EE	Stroke	Compagnat [43]	CV
			Mandigout [55]	CV
	Distance walked	Stroke	Compagnat [44]	CV
JawBone				
Up2	Steps	MS	Balto [83]	CV
		PD	Wendel [103]	CV
Up24	Steps	Multi	Ummels [75]	CV
Up Move	Steps	MS	Balto [83]	CV
		PD	Wendel [103]	CV
Polar				
A300	Steps	COPD	Boeselt [68]	CV
	Activity time	COPD	Boeselt [68]	CV
	MET	COPD	Boeselt [68]	CV
	Calories	COPD	Boeselt [68]	CV
Loop	Steps	Amputation	Smith [101]	CV
T131	EE	Chronic lung disease	Dhillon [70]	CV
Samsung				
Galaxy S4 mini	Mean vector magnitude	MS	Zhai [87]	CV
	Variance vector magnitude	MS	Zhai [87]	CV
Health	Steps	PD	de Carvalho Lana [133]	CV
		Stroke	Costa [46]	CV TRT R
Lumo				
Lumoback	Steps	Multi	Ummels [75]	CV
	Intensity time	Lower back pain	Takasaki [135]	TRT R

Criterion	Placement	Algorithm	Result	
			Test	Outcome
DO	Hand/front pocket	N.R.	% error	-7.2 ± 13.8%
Acc	Waist	N.R.	ICC	ICC = 0.97 [CI 0.95; 0.98]
Acc	Waist	N.R.	ICC	ICC = 0.47 [CI 0.21; 0.67]
IC	Waist	Prop	Pearson's r	TEE: r = 0.66
		Cust	Pearson's r	TEE: r = 0.87
IC	Neck	N.R.	Spearman's rho	rho = -0.16
	Waist	N.R.	Spearman's rho	rho = -0.07
DO	Neck	Prop	Pearson's r	r = 0.91
	Waist	Prop	Pearson's r	r = 0.98
DO	Wrist	N.R.	MPE	1.9 – 3.9%
DO	Wrist	Prop	ICC	ICC: -0.02 – 0.17
DO	Wrist	N.R.	Pearson's r	r = 0.09
DO	Waist	N.R.	MPE	8.4 – 8.9%
DO	Waist	Prop	ICC	ICC: -0.03 – 0.85
Acc	Wrist	Prop	ICC	ICC = 0.986
Acc	Wrist	Prop	ICC	Daily activity: ICC = 0.335
Acc	Wrist	Prop	ICC	ICC = 0.066
Acc	Wrist	Prop	ICC	ICC = 0.829
DO	Wrist	N.R.	ICC	ICC = 0.723
IC	N.R.	Flex Heart Rate Method	LoA	-0.5 [-1.6; 0.7] – 0.4 [-0.3; 1.1]
Acc	Habitual phone pos.	N.R.	Spearman's rho	rho: 0.06 – 0.33
Acc	Habitual phone pos.	N.R.	Spearman's rho	rho: -0.13 – 0.29
DO	Waist	N.R.	Pearson's r	r = 0.54
DO	Waist	N.R.	Pearson's r	r: 0.18 – 0.19
	Waist	N.R.	ICC	ICC: -0.70 – 0.10
DO	Lower back	N.R.	Pearson's r	r = 0.19
	Lower back	Prop	ICC	Sed.: ICC = 0.75 [CI 0.26; 0.91]

5

Table 3. Continued.

Type	PA outcome	Population	Study	Measurement property
Pacer Health				
Pacer Pedometer	Steps	PD	de Carvalho Lana [133]	CV
		Stroke	Costa [46]	CV
				TRT R
Withings				
Go	Steps	Heart failure	Vetrovsky [141]	CV
Health Mate	Steps	MS	Balto [83]	CV
Alexander et al.				
mSteps	Distance walked	MS	Alexander [78]	CV
Corussen LLC				
Accupedo	Steps	Multi	Ummels [75]	CV
DHS group				
MOVEBAND	Steps	Amputation	Smith [101]	CV
Juen				
MoveSense	Distance walked	Pulmonary disease	Juen [72]	CV
Leap Fitness Group				
Pedometro	Steps	Chronic pain	Ferreira [132]	CV
Letscom				
Letscom smartwatch	Steps	MS	Lavelle [80]	CV
	Activity time	MS	Lavelle [80]	CV
Mario Herzberg				
EasyFit pedometer	Steps	Chronic pain	Ferreira [132]	CV
Mio				
Slice	EE	CAD	Herkert [122]	CV
		Heart failure	Herkert [122]	CV
Nakosite				
3D walking	Steps	Stroke	Negrini [56]	CV
Pedometer Australia				
G-Sensor 2026	Steps	Multi	Treacy [24]	CV

			Result	
Criterion	Placement	Algorithm	Test	Outcome
DO	Waist	N.R.	Pearson's r	r = 0.77
DO	Waist	N.R.	Pearson's r	r: 0.68 – 0.80
	Waist	N.R.	ICC	r: 0.68 – 0.80
Acc	Wrist	N.R.	CCC	CCC = 0.90 [CI 0.77-0.96]
DO	Front pocket	N.R.	MPE	1.5 – 3.5%
DO	Arm	N.R.	LoA	0.262 [-1.496; 2.020] m (oe)
DO	Waist	N.R.	Pearson's r	r = 0.32
DO	Wrist (b)	N.R.	ICC	ICC = 0.897
DO	Lower back	Cust	LoA	-7.7 [CI -33.0; 17.6] meter (oe)
DO	Arm & waist	N.R.	Pearson's r	For all tasks and placements: p ≥ 0.99
DO	Wrist	N.R.	LoA	-390.0 [-1006.7; 226.7] (oe)
Acc	Wrist	N.R.	% error	52.9% [range 5.6 - 65.1]
DO	Arm & waist	N.R.	Pearson's r	For all tasks and placements: p between -0.32 and 0.24
IC	Wrist	Prop	ICC	ICC = 0.12
IC	Wrist	Prop	ICC	ICC = 0.11
DO	Ankle (a)	Prop	ICC	ICC: -0.20 – 0.70
	Ankle (ua)	Prop	ICC	ICC: -0.28 – 0.69
	Waist	Prop	ICC	ICC: -0.42 – 0.57
	Wrist (a)	Prop	ICC	ICC: -0.50 – 0.45
	Wrist (ua)	Prop	ICC	ICC: -0.41 – 0.45
DO	Waist	N.R.	ICC	ICC = 0.308 [CI -0.094; 0.604]

5

Table 3. Continued.

Type	PA outcome	Population	Study	Measurement property
ProtoGeo Oy				
Moves	Steps	MS	Balto [83]	CV
Technogym				
MyWellnes Key	Intensity time	DM	McGinley [110]	CV

Ordering on number of studies evaluating manufacturer. This is a condensed version of the more detailed table in appendix 6.

EE = energy expenditure, MET = metabolic equivalent, PAL = physical activity level
CAD = coronay artery disease, COPD = chronic obstructive pulmonary disease, DM = diabetes mellitus, iSCI = incomplete spinal cord injury, MS = multiple sclerosis, PAD = pulmonary artery disease, PD = Parkinson's disease, RA = rheumatoid arthritis, SCI = spinal cord injury
CV = Criterion validity, Con V = construct validity, Resp = responsiveness, TRT R = test-retest reliability
Acc = accelerometer, DLW = doubly labelled water, DO = direct observation, IC = indirect calorimetry, SR = self-report
(a) = affected side, (b) = both affected and unaffected side, (la) = less affected side, (LRL) = longest residual limb, (SRL) = shortest residual limb, (ua) = unaffected side
Cust = custom algorithm, LFE = low frequency effect, N.R. = not reported, Prop = proprietary algorithm, TEE = total energy expenditure
APE = absolute percentage error, CCC = concordance correlation coefficients, ICC = intraclass correlation coefficient, LoA = limits of agreement, MAPE = mean absolute percentage error, MARD = mean absolute relative difference, MPE = mean percentage error
[CI] = 95% confidence intervals, (oe) = over estimation, (ue) = under estimation, MVPA = moderate to vigorous physical activity, MWT = minutes walking test, Sed = sedentary, STS = sit-to-stand test, SWT = steps walk test

Research-grade devices

ActiGraph

Measurement properties of a type of ActiGraph were determined in 28 studies, with 24 studies evaluating type GT3 [24, 40, 43-45, 49, 51, 55, 61, 64, 81, 84, 89, 94-96, 104, 105, 108, 112, 114-116, 139] and four studies evaluating type GT9 [76, 79, 93, 107] (table 2). Only validity was measured in these 28 studies, with 27 determining criterion validity, and 1 construct validity [105]. For the GT3, the criterion validity of energy expenditure, steps, time spent in intensity zones, time in activities, distance walked, metabolic equivalent (MET) and activity counts and construct validity for steps and vector magnitude was measured in 12 unique diagnosis groups and one mixed group with variable diagnoses. Four studies applied custom-created algorithms [61, 114, 115, 139], two studies applied both a custom and a proprietary algorithm [43, 61], two studies did not report on used algorithms [45, 55] and the other studies used proprietary algorithms (n=21), with Freedson [143] the most commonly reported. The GT3 was placed at five different body regions (ankle, upper arm, thigh, waist and wrist), at both the affected and unaffected side (for diagnosis groups that may suffer from unilateral impairment, e.g. stroke, unilateral

			Result	
Criterion	Placement	Algorithm	Test	Outcome
DO	Front pocket	N.R.	MPE	12.5 – 14.2%
SR	Waist	Prop	Spearman's rho	rho = 0.81 [CI 0.76; 0.85]

amputation). The GT9 was studied on criterion validity of steps and sedentary time in 5 different diagnosis groups, placed on the ankle, waist or wrist. Three studies used one or more proprietary algorithms [76, 79, 93], and one study did not report on the used algorithm [107].The used epoch length of the instruments ranged from 0.033 sec to 60 sec, or it was not reported. Sampling rate was set at 10 Hz (1 study [45]), 30 Hz (14 studies [40, 44, 49, 51, 61, 64, 76, 81, 84, 113, 115, 116, 140, 142]), 50 Hz (1 study [107]), 90 Hz (1 study [79], 100 Hz (2 studies [93, 104]), or it was not reported (9 studies [24, 43, 55, 89, 94-96, 105, 108]). The criterion validity was measured with 13 different statistical tests (among others: Pearson's r, Spearman's rho, intraclass correlation coefficient (ICC), Bland-Altman level of agreement, % accuracy). The results had a wide range of variation, with correlations between 0.004 to 0.97 and accuracy between 43.0% to 81.4%. This large variability was found among different PA outcomes, but also within PA outcomes.

PAL technologies

The devices of PAL technologies were evaluated in eight studies, six studies evaluating the ActivPAL [24, 54, 91, 95, 131, 138] and two studies evaluating the

ActivPAL3 [86, 116] (table 2). Criterion validity for steps, time spent in different activities or MET were measured in seven studies [24, 54, 86, 95, 116, 131, 138] in five unique diagnosis groups and one mixed group with variable diagnoses. Test-retest reliability was measured for steps, time spent in different activities and MET in two studies [54, 91] in two unique diagnosis groups. One study did not report the used algorithm [138], the other seven used proprietary algorithms. All studies placed the device on the thigh. The used epoch lengths were 0.1 sec [91], 1 sec [95] and 15 sec [54, 131, 138]. Three studies did not report the epoch length [24, 86, 116]. Sampling rate was set at 10 [54, 91] or 20 Hz [86], or was not reported [24, 95, 116, 131, 138]. Test-retest reliability was measured as ICC, ranging from 0.654 to 0.997 and as absolute percentage error, ranging from 3.3% to 6.5%, depending on the PA outcome, diagnosis group and task. Criterion validity was measured as Pearson's r, ICC, Bland-Altman level of agreement, percentage accuracy and percentage error, and varied with correlations between 0.65 and 0.99, accuracy between 90.7-100% and error between 0.3-3.1%, all depending on the PA outcome, diagnosis group and task.

Consumer-grade devices

Fitbit

Eleven different types of Fitbits were evaluated: Alta (n=4 studies) [65, 67, 80, 98], Charge (n=3 studies) [24, 101, 137], Charge 2 (n=5 studies) [94, 97, 118, 122, 141], Flex (n=9 studies) [60, 75, 83-85, 99, 101, 109, 140], Flex 2 (n=2 studies) [84, 136], Inc (n=1 study) [133], One (n=12 studies) [24, 47, 50, 52, 53, 64, 75, 83, 92, 97, 102, 106], Surge (n=1 study) [103], Ultra (n=1 study) [46] and Zip (n=9 studies) [41, 58, 67, 74, 80, 90, 103, 112, 127] (table 3). Criterion validity was measured for steps, energy expenditure, MET, time spent in different intensity zones, time spent in different activities and distance walked by 38 studies in 15 unique diagnosis groups, and three mixed groups with variable diagnoses. Convergence validity of the Alta was measured in one study for steps in cancer patients [98]. Test-retest reliability of the Inspire (n=1 study) [118], One (n=1 study) [106] and the Zip (n=1 study) [58], for steps, MET and time spent in different intensity zones in patients with stroke, myositis or progressive muscle diseases. Responsiveness was measured for the Flex 2 (n= 1 study), Inspire (n=1 study) and One (n=1 study) for steps, MET and time spent in different intensity zones in patients with osteoarthritis, myositis or progressive muscle diseases. The Charge, Charge 2, Flex, Flex 2, Surge and Ultra were positioned at the wrist or it was not reported, the Alta at the lower limb, waist or wrist, the One at the ankle or waist, and the Zip at the foot, the waist or the midline of a shirt. Devices were placed at both the affected and unaffected side (for diagnosis groups that may suffer from unilateral impairment). One study used a custom algorithm [94], the other studies either used proprietary algorithms or did not report the used algorithm. Criterion validity of the Fitbits was measured with 13 different statistical tests, with correlations ranging from -0.236 to 0.99 and mean percentage errors ranging from 1.9 to 84.9%. Convergence validity, measured with concordance correlation coefficient, was smaller than 0.001 compared with a questionnaire. Test-retest reliability, measured with ICC, was 0.78 - 0.97. Responsiveness was measured with area under the curve (0.72 – 0.90) or correlation (-0.28 – 0.63).

Garmin

Six different types of Garmin devices were evaluated: Forerunner 35 (n=1 study) [66], Vivofit (n=5 studies) [24, 58, 101, 137, 141], Vivotfit 3 (n=2 studies) [107, 141], Vivofit 4 (n=1 study) [80], Vivosmart 3 (n=1 study) [97] and Vivosmart 4 (n=1 study) [130] (table 3). Studies measured criterion validity for steps and time spent in different activities in five unique diagnosis groups and one mixed group with variable diagnoses. Test-retest reliability of the Forerunner 35 and Vivofit was measured for steps in a stroke population. All devices were worn on the wrist, with the Vivofit 3 also worn on the ankle in one study [107]. One study used the proprietary algorithm [130], the other studies did not report on the used algorithm. Sampling rate and epoch length were not reported for the devices. Criterion validity was measured using 5 different statistical tests (ICC, concordance correlation coefficient, Bland-Altman level of agreement, percentage error and mean absolute percentage error). Correlations ranged from 0.12 to 0.97, depending on the device, PA outcome and task. Test-retest reliability was measured using ICC, ranging from 0.86 to 0.99.

Discussion

This scoping review provides a critical mapping of the research on measurement properties (validity, reliability and responsiveness) of device-based instruments assessing PA in ambulatory adults with disabilities and/or chronic diseases. The results show a large variability in research on the measurement properties of device-based instruments assessing PA in adults with physical disabilities and/or chronic diseases. Predominantly, different forms of validity are assessed in a total of 78 different research- and consumer-grade devices using 14 different PA outcomes in 23 different diagnosis groups. There is large variability in measurement properties within and between instruments and studies. The ActiGraph devices are the most frequently studied research-grade devices, and the Fitbit devices are the most frequently studied consumer-grade devices.

PA outcomes

PA behavior is assessed with a variety of different PA outcomes. The most commonly used PA outcome is step count, comparable to previous reviews on the use of device-based PA instruments [144-146]. However, step count informs only about walking and walking-related tasks and does not give information on the intensity and duration of PA behavior from a broader perspective. Even when step count is not used as the PA outcome, we have found that studies mostly use walking-related tasks to study the measurement properties. This results in device-based PA instruments only applicable for valid and reliable measurement of walking, and thereby excluding valid and reliable measurement of other modes of PA behavior such as cycling and swimming.

The importance of frequency, intensity and duration of PA is stressed by the guidelines for PA, which typically include statements on the frequency and duration in certain intensities needed for achieving optimal health benefits [147, 148]. Energy expenditure and intensity time are PA outcomes that take two of these dimensions into account (i.e. intensity and duration). However, the trend visible in this scoping review is that incorporating intensity in the PA outcome results in lower validity outcomes. As intensity depends on the used cut-off points and algorithms [149], given the fact that these are mostly developed for a general population [9], this finding is not surprising. Custom-made disease-specific algorithms could be a solution to increase validity outcomes. In the eight studies using custom algorithms in five different instruments, generally moderate to good values of validity are found [43, 61, 73, 94, 114, 115, 125, 134]. However, just two of these studies compare a custom disease-specific algorithm with a proprietary algorithm, reporting increased validity for the custom algorithm [43, 61]. More research needs to compare custom disease-specific algorithms with proprietary algorithms.

When using intensity time and energy expenditure as PA outcomes only, information on how and where PA is being performed is not acquired. This information can be of importance for rehabilitation specialists and policymakers to identify possibilities to improve PA behavior in people with physical disabilities and/or chronic diseases. The how (or mode) of PA can be measured using activity time. This outcome is used by 15 studies, with a variety of outcomes on measurement properties [48, 54, 68, 80-82, 86, 91, 95, 100, 116, 120, 131, 138, 142]. As device-based PA instruments only capture movement or acceleration of the body, the where (or context) of PA cannot be measured with these instruments [15]. Self-report instruments can fill this gap, hence the consensus that both self-report and device-based PA instruments should be used in complement to each other [12, 14]. In conclusion, we can say that different PA outcomes have different advantages and disadvantages, but none of the device-based PA outcomes is able to capture the complete construct of PA (i.e. setting, mode, intensity, duration, frequency). This requires future research consideration.

Population

Most of the studies on measurement properties of device-based PA instruments are conducted in diagnosis-specific populations, and only six studies concerned a mixed population including people with different physical disabilities and/or chronic diseases [24, 75, 77, 88-90]. People with different diagnoses may suffer from different walking-related complications [19-22], which could have an effect on measurement properties of device-based PA instruments (e.g. frequency spectrum of accelerations, energetic cost and efficiency of movement/activities). Thus, a diagnosis-specific approach in these studies seems logical. However, this diagnosis-specific focus does have the drawback that it lacks generalizability to other types of physical disabilities and/or chronic diseases. It might be of interest to conduct studies using a functioning-specific focus, in line with the ICF model [35]. Functional limitations may differ between individuals within diagnosis groups, and different diagnoses might share problems with functioning, such as slower and asymmetrical gait [16-18], which can influence the measurement properties of PA devices [23]. Studies using this functioning-specific approach can give insight in PA devices with good measurement properties for multiple physical disabilities and/or chronic diseases. This is of relevance as monitoring and measuring PA is important for all physical disabilities and/or chronic diseases. As self-monitoring is an important behavior change technique [8], a PA device that is valid and reliable for a variety of people with physical disabilities and/or chronic diseases might increase feasibility of PA promoting interventions for people with physical disabilities and/or chronic diseases. The same can be suggested for the rehabilitation setting, in which a variety of patient groups are treated. Correct measurement and monitoring of PA in the rehabilitation setting can lead to a more tailored approach to improve PA behavior, which ultimately may improve health and functioning [150].

Measurement properties and statistics

The criterion validity of the device-based PA instruments is the most common studied measurement property. Besides criterion validity, only 11 studies on (test-retest) reliability [46, 54, 58, 66, 91, 105, 106, 111, 113, 118, 135] and six studies on responsiveness are included [82, 100, 105, 106, 118, 136]. Good reliability of a device-based PA instrument is needed for suitable clinical application to ensure that a change in PA behavior over time is related to an actual change instead of measurement error. Good responsiveness is needed as a prerequisite for measuring effectiveness of PA promotion in clinical care. During our search, we found studies that investigated the number of days needed for reliable measurement of PA using devices in free-living settings [151-154]. Although this is important information, it is not considered a measurement property since it does not provide information on the measurement error and the extent to which repeated measurement outcomes are the same for people who have not changed [37].

There is a large variety of statistical methods used to study the measurement properties of the different devices, which makes it difficult to compare the different studies. Most studies included in this review assessed criterion validity and test-retest reliability, for which methods of correlational nature are recommended [155]. The use of techniques comparing means (e.g. t-test and analysis of variance) is irrelevant in studies on measurement properties, since these pretend to measure a difference (from a criterion measure or between two measurements), instead of an agreement [37]. Still, a number of included studies did not use the appropriate statistical methods according to the international standards of the COSMIN group.

Technical decisions

Using device-based PA instruments in research or clinical practice, numerous choices about data collection and data processing need to be made. All these choices could influence the measurement properties. First, one needs to think about the placement of the device on the body. Multiple studies showed the influence of placement of the device on measurement properties [24, 40, 44, 45, 51, 53, 55, 56, 58, 65, 89, 96, 107, 112, 114, 120, 128], with no clear advantage to a single location. Algorithms and cut-off points are developed with a certain placement in mind, and are not interchangeable between placements [150, 156], explaining at least part of the influence of placement on measurement properties. Secondly, epoch length and sampling rate should be considered when using PA measurement devices. Previous studies have shown that different epoch lengths result in differences in PA outcomes [15, 157]. However, none of the reviewed studies have looked at the influence of epoch length on measurement properties. Furthermore, in a large number of studies (n=25 in research-grade devices, n=59 in consumer-grade devices) the used epoch length is not reported. The same is found for sampling rate, which is also not always reported. Therefore, we cannot make recommendations on the optimal epoch length and sampling rate. However, for the use of device-based instruments in practice, one needs to critically assess considerations such as accuracy versus storage capacity. Thirdly, another important choice is the algorithm used to convert the measured accelerations of movement into interpretable PA outcomes. Applying different general algorithms could lead to differences in measurement properties, which is shown by the three studies that compared multiple algorithms [49, 71, 76]. And as mentioned previously, custom-made disease-specific algorithms could influence the measurement properties when using intensity-based PA outcomes [43]. For research and clinical use, we suggest applying an algorithm that is evaluated for the specific population and activity level. However, based on our findings we cannot recommend certain algorithms, as this is beyond the scope of this review. Considering the effect of these technical choices on PA outcomes and the measurement properties of the device-based instruments, Burchartz et al. already stated in their state of science paper on device-based PA instruments that all important technical decisions (such as placement on the body, the used epoch length, sampling rate and algorithm) should be reported in studies on measurement properties [15]. As it is apparent from this review that reporting the technical decisions is not common practice in studies on measurement properties, we wholeheartedly support this recommendation.

Strengths and limitations

The main strength of this scoping review is the detailed and extensive mapping of studies using a broad range of methodological approaches and in a diverse group of ambulatory people with physical disabilities and/or chronic diseases. Furthermore, we used a systematic process in this scoping review, with the screening and selection process for the majority done in duplicate using information from four major databases. Another strength is the transparency and openness of the current scoping review. We provided additional information on the screening and analysis processes in the supplements and on Open Science Framework, which greatly improves the reproducibility of our scoping review. Lastly, we provided detailed information on decisions made in the included studies, which has not been reported in such detail in previous reviews on this topic. The appendices add an extra layer of information for the interested reader, and provide extra emphasis on the large variability of the studies (e.g. the variety in what is considered a valid day/case among the studies).

However, some limitations of this scoping review should be acknowledged. One of the limitations is related to the search strategy. Although we carefully developed our search strategy, together with an information specialist, it is possible that we missed important search terms (e.g. specific wearables, specific disease groups), which could have resulted in missed relevant studies. Also, the inclusion of some search terms could have led to a relative overrepresentation of certain studies or devices used in the studies. As an example, 'ActiGraph' was included as a search term in our search strategy, which we found as the most used research-grade device in the literature. However, a previous review of device-based PA instruments in cardiovascular patients also found the ActiGraph as most frequently used instrument [146]. We did not apply the search filter for measurement properties developed by the COSMIN group [158], as this increased our search results exponentially.

Another limitation is our Dutch view on the rehabilitation setting. One of our inclusion criteria was that the physical disability or chronic disease of the participants must be a primary reason for rehabilitation. However, rehabilitation might not be organized the same across countries. This may have resulted in us excluding certain diagnosis groups that would be included by researchers of other countries, and vice versa, using the same in- and exclusion criteria.

In the current scoping review, we did not differentiate the overview of the measurement properties to the used setting (i.e. laboratory setting vs free-living setting) of the studies, which can be considered a limitation. The difference in setting might influence the measurement properties, and thus entail different concepts. We reported the used setting of the studies in the description table (table 1) so that readers who are interested in these concepts can find this information in the current scoping review. However, future reviews could put more in-depth focus on the differences in setting and their effect on measurement properties.

A limitation inherent to research on device-based PA instruments is the rapidly changing field with regard to the technology. The technology of these devices develops rapidly, leading to newer models to hit the market before previous models have been properly studied. This is especially true for the consumer-grade instruments, which illustrates a commercialky-driven approach to the development of new technology, not necessarily leading to a quality-driven market. For research purposes, there is more need for valid and reliable instruments.

Future directions

Considering the importance of PA in people with physical disabilities and/or chronic diseases, and the need to measure and quantify PA in this population as stated by different research agenda's [9-11], instruments with good measurement properties are vital. Due to the large variability in measurement devices and the methods used to evaluate these, we were unfortunately unable to make concrete recommendations for specific devices and settings based on this review. However, this review provides an overview of detailed information per measurement device, which we use to provide directions for research on measurement properties of device-based instruments assessing PA in people with physical disabilities and/or chronic diseases.

- The focus of research on measurement properties of device-based PA instruments in people with physical disabilities and/or chronic diseases needs to be less on step count as a PA outcome, as it provides a very narrow view of PA behavior. Energy expenditure and intensity time seem important, but the validity of these outcomes needs to be improved. More research is needed on the measurement properties when using activity time since this can be important information for rehabilitation purposes. To better measure the multidimensionality of PA, the use of device-based PA instruments can be supplemented by the simultaneous application of self-report instruments.
- Studies on measurement properties of device-based instruments should inform readers of important technical decisions made for data collection and data processing. Especially the placement of the device on the body, the epoch length, sampling rate, and the used algorithm in full detail should be reported, as these are known to influence PA measurement. This information will help with

data comparison between studies, but will also inform in detail in which situation a device-based instrument should or could be used.

- Future research should investigate the influence of disease-specific versus general algorithms on the measurement properties (in this case mainly validity) of device-based PA instruments. Intensity is an important aspect of PA, as evidenced by the focus of PA guidelines on moderate to vigorous PA [147, 148]. The use of custom disease-specific algorithms could improve the ability of device-based instruments to capture intensity.
- More research on the measurement properties of device-based PA instruments should be conducted in populations consisting of people with different physical disabilities and/or chronic diseases, for example by using a functioning-specific approach. It would be beneficial to have a single device-based PA instrument with good measurement properties available for different diagnosis groups. This will improve the ease of use in a rehabilitation setting where different diagnosis groups are treated.
- Raw data from device-based instruments should be used, instead of using PA outcomes processed by proprietary algorithms. In this way, the measurement properties of the device-based instruments when using raw data can be studied in a diverse population, and this raw data can subsequently be processed into PA outcomes using disease-specific or even individualized algorithms. Important to note, is that these algorithms should also be validated. The use of raw data has also been recommended by previous studies [15, 150].
- Reliability and responsiveness of device-based instruments should be studied more often. These measurement properties are especially important when device-based PA instruments are used to study changes in PA behavior over time. And although there has been an increase in studies on these measurement properties (especially responsiveness) in the last two to three years, they are still underrepresented in the literature of this scoping review.
- The methodologically correct statistical methods should be used while studying measurement properties of device-based instruments. This will help with comparing different studies and will result in better informed researchers and health professionals when selecting device-based instruments.

Conclusion

There is a large variability in research on the measurement properties of device-based instruments assessing PA in ambulatory adults with physical disabilities and/or chronic diseases. This variability shows a need for more standardization of and consensus on research in this field. Based on this scoping review, the results could provide researchers and health professionals with some directions for selecting a device-based PA instrument that suits their need. Finally, to improve research and bridge knowledge gaps, we provide future directions for researchers interested in studying the measurement properties of device-based instruments assessing PA in ambulatory adults with physical disabilities and/or chronic diseases.

List of abbreviations

PA = physical activity
MET = metabolic equivalent
ICC = intraclass correlation coefficient

Declarations

Ethics approval and consent to participate
Not applicable

Consent for publication
Not applicable

Availability of data and materials
Additional information can be found on Open Science Framework (https://osf.io/c27xv/). This includes information on the original protocol, the complete list of search results, an overview of the screening process (number of search results, duplications removed per deduplication step according to the method of Bramer et al., included and excluded per phase), the used checklists for the screening, the filled-in checklists by the screeners with results, and the data extracting tool (both the filled in version and a clean version).

Competing interests
We have no conflict of interest to declare that have relevance to the contents of this article.

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Authors' contributions

PB, FH, LHVvdW, RD and LAK conceptualized the scoping review. PB, LAK and IB performed selection of the eligible studies. PB extracted data, synthesized the data, prepared tables and figures, and drafted the manuscript. All authors contributed significantly in interpretation of results. All authors critically reviewed the manuscript. All authors read and approved the final manuscript.

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Appendices

Appendix 1 – Protocol deviations
A file containing details of the deviations we made to the protocol

Appendix 2 – Full search strategy for each database
A file containing the search strategy used for each database

Appendix 3 –PICO, Selection criteria and Checklists
A file containing the PICO and the selection criteria used for the scoping review. Als contains the checklist that were used during the screening process.

Appendix 4 – Expanded description of the 103 studies included in the scoping review
A file containing the description of the included studies in more detail. Extra information on in- and exclusion criteria, the used task in the study and criteria for valid days and cases.

Appendix 5 – Expanded overview of research-grade devices evaluated on their measurement properties in 52 studies
An expanded overview of the research-grade devices evaluated on their measurement properties. Extra information on epoch length, sampling rate and results per condition.

Appendix 6 - Expanded overview of consumer-grade devices evaluated on their measurement properties in 74 studies
An expanded overview of the consumer-grade devices evaluated on their measurement properties. Extra information on epoch length, sampling rate and results per condition.

6

General discussion and conclusion

The aim of this thesis was to provide a comprehensive exploration of the construct physical activity behavior among people with physical disabilities and/or chronic diseases, utilizing data from the Rehabilitation, Sports, and Active lifestyle (ReSpAct) prospective cohort study, as well as exploring international literature on device-based physical activity monitoring. The exploration focused on 1) the characteristics of physical activity behavior; 2) the determinants of physical activity behavior; and 3) measurement of physical activity behavior; all in relation to the above described population.

Summary of the main findings

Characteristics of physical activity behavior

The main finding of this thesis is that participants of the Rehabilitation, Sports, and Exercise program (RSE, in Dutch: "Revalidatie, Sport en Bewegen"), were able to increase and maintain their physical activity behavior, on the short to mid-term (**Chapter 2**) and long-term (**Chapter 4**). Additionally, this thesis showed that physical activity behavior is highly heterogeneous among people with physical disabilities and/or chronic diseases. In **Chapter 2**, which explored the dose characteristics of physical activity among this population up to 1 year after rehabilitation, a considerable degree of variation in the setting, mode, frequency, duration and intensity of physical activity behavior among participants of the ReSpAct study was found. **Chapter 4** described that the development of physical activity after participation in a physical activity promoting rehabilitation program up to 6-8 years later is heterogeneous and best described by multiple sub-populations (moderately active, highly active and increasingly active), rather than one unified average trend. Focusing on the dose characteristics, **chapter 2** described that the majority of total physical activity behavior is performed during household activities, and two-thirds of the total physical activity being of light intensity. Moderate to vigorous intensity activity, on the other hand, is most often performed during leisure time, including sports.

Determinants of physical activity behavior

This thesis described different types of determinants and their effect on physical activity behavior and the development of physical activity behavior over time, guided by the Physical Activity for people with a Disability (PAD) model [1]. **Chapter 2** focused on how personal characteristics such as diagnosis, age, sex and BMI influence physical activity levels in the ReSpAct population. Participants who are younger, are female, and have lower BMI were more physically active. In addition, higher educated participants increased their physical activity level more up to one

6

year after rehabilitation compared to lower educated participants. **Chapter 3** described that intrinsic motivation and self-efficacy appear to be important psychosocial determinants for physical activity behavior, with higher scores on these determinants leading to higher levels of physical activity. Furthermore, participants who successfully increased their intrinsic motivation over time showed a more positive development in physical activity behavior over time. Contrary to expectations, (change in) social support does not consistently show a significant association with (change in) physical activity behavior among participants of the ReSpAct study. When looking at long-term physical activity adherence, **chapter 4** showed that perceived fatigue and perceived barriers regarding physical activity, such as lack of energy or physical complaints, increase the odds of belonging to a more favorable trajectory of physical activity behavior development. Perceived fatigue and perceived barriers regarding physical activity are therefore important modifiable determinants to target early on in rehabilitation. Taken together, these findings offer valuable guidance for clinical practice in rehabilitation: identifying who might need more intensive support and which psychosocial or contextual aspects should be addressed to effectively initiate and maintain a physically active lifestyle among people with physical disabilities and/or chronic diseases.

Measurement of physical activity behavior

The third main topic explored in this thesis concerns the measurement of physical activity behavior in people with physical disabilities and/or chronic diseases. In general, two distinct types of instruments for the measurement of physical activity behavior can be used, namely self-report and device-based instruments. **Chapters 2-4** are based on self-reported measures of physical activity behavior, using the Adapted SQUASH recall questionnaire. In **chapter 5** device-based instruments for physical activity are studied with respect to their measurement properties when used in populations of adults with physical disabilities and/or chronic diseases. A scoping review of the literature revealed a large variability, both in applied research methodologies used on and outcomes of the measurement properties of device-based instruments in ambulatory adults with physical disabilities and/or chronic diseases, showing a need for more standardization of research in this field. Additionally, **chapter 5** showed the plethora of available instruments, technical decisions, and even available outcomes of physical activity, each of which have an influence on how physical activity behavior is presented. Of the available physical activity outcomes, measurement properties of device-based instruments are most often studied for the outcome of step counts. However, step count only captures a specific aspect of the construct of physical activity. Outcome measures taking a broader perspective by incorporating intensity, mode, frequency and duration of PA, such as energy expenditure, tend to lead to less favorable measurement properties of a device, such as a lower validity in people with physical disabilities and/or chronic diseases (**chapter 5)**. Together, these findings confirm the complexity and difficulty of using device-based measurement of physical activity behavior in people with physical disability and/or chronic diseases. The wide variation in instruments, methodologies and outcome measures hinder clear conclusions about their validity and reliability. Additionally, the apparent poorer performance of the instruments for more comprehensive physical activity measures, such as intensity, may limit their usability. This thesis highlight these limitations and underscores the need for more standardization of research on measurement properties of device-based physical activity measurement instruments used in people with physical disabilities and/or chronic diseases.

Discussion

Construct of physical activity behavior

This thesis shows that physical activity behavior among people with physical disabilities and/or chronic diseases is a complex, multidimensional construct, shown by the large heterogeneity of the behavior and the issues on the measurement of the construct (**this thesis**). It is important to understand that the construct physical activity behavior consists of physiological and behavioral aspects. The common definition, also used in this thesis, is 'any bodily movement produced by skeletal muscles that results in energy expenditure' [2], which clearly reflects the physiological aspects. Additionally, the intensity of physical activity is typically expressed using percentage of maximum heart rate**,** oxygen consumption**,** or metabolic equivalents (METs) [ACSM]. And physical activity is an inte**r**play between physical function, physical capacity, energy supply and energy cost [3, 4]. But as the name implies, physical activity behavior is also inherently a behavior, and thus influenced by behavioral, experiential and contextual elements [1, 5]. In people with physical disabilities and/or chronic diseases, physical activity behavior is often embedded in the challenges of daily functioning, and shaped by personal capabilities, psychosocial determinants (such as motivation and self-efficacy), often the use of assistive technology, all in the context of environmental barriers [6-8].

This duality becomes particularly evident when examining how the construct of physical activity is measured in people with physical disabilities and/or chronic diseases. Self-report instruments rely on the individual perception and interpretation of physical activity behavior. In contrast, device-based instruments register continuous body acceleration (in 1, 2 or 3-orthogonal directions) above a certain threshold and apply processing algorithms to derive specific physical activity outcomes. In the cohort studies of this thesis (**chapters 2-4**), physical activity was assessed using a self-report instrument (the Adapted-SQUASH) that combined perceived intensity with standardized MET values to classify reported activities by intensity level [9]. Perceived physical activity behavior is an individual notion of physical activity, among others driven by perceptions, memory, experience, fatigue and dependent on physical mental fitness. Perceived intensity among individuals will vary in the context of these variables. The underlying MET values (derived from a given factor times resting metabolism) for certain activities are assumed to be identical among people [10], but at least seem different among people with physical disabilities and/or chronic diseases [11, 12]. Thus, our finding of high amounts of physical activity behavior of light intensity and during household activities in **chapter 2** underlines the prominent role of these activities in the daily lives of people with physical disabilities and/or chronic diseases. Notably, these activities might go undetected when using device-based instruments, as the movement pattern may not exceed the required acceleration threshold. Moreover, emerging evidence now supports the health benefits of light-intensity activity. Provided that it is accumulated in approximately three to four times greater volume as moderate to vigorous physical activity, light-intensity physical activity was found to result in comparable health benefits [13, 14]. Taken together, this shows the need of incorporating light intensity activities in physical activity promotion.

Throughout this thesis (**chapters 2-4**) self-report instruments have further demonstrated value in capturing behavioral context and perceived effort, offering rich insights into the experience and setting of activity. However, self-report instruments clearly focus on the behavioral side of the construct physical activity behavior in people with physical disabilities and/or chronic diseases, and might therefore underexpose the physiological aspect. Because of the strong focus on the behavioral aspect, self-report instruments are also prone to biases such as overreporting, recall error, or social desirability [15-19]. **Chapter 5** shows that device-based instruments highlight more the physiological aspect of the construct physical activity behavior, offering detailed data on accelerations, energy expenditure and intensity, among others. These instruments are considered to provide a more objective measurement of physical activity behavior. However, **chapter 5** also shows that the use of these instruments in people with physical disabilities and/or chronic diseases are not without methodological limitations. First of all, whether a device is valid and reliable for measuring physical activity in people with physical disabilities and/or chronic diseases greatly depends on a number of different aspects, such as in which population of people with physical disabilities and/or chronic diseases the instruments is used, the device that is used (e.g. consumer vs research grade, which brand) and the physical activity outcome that is being measured (e.g. number of steps, energy expenditure). Furthermore, the device-based instruments use algorithms to derive physical activity behavior outcomes. Similar to the use of standardized MET-values in self-report instruments, these algorithms are typically developed and calibrated using data from young, healthy individuals [20, 21], which limits their applicability to (older) people with physical disabilities and/or chronic diseases. Especially when the intensity component or energy expenditure is incorporated, these algorithms tend to behave more poorly in people with physical disabilities and/or chronic diseases (**Chapter 5**). Given the heterogeneity in physical functioning and movement patterns among individuals with physical disabilities and/or chronic diseases, even algorithms specifically developed for this population may not perform equally well across different subgroups. This shows a need for more individualized or adaptive algorithms, for example by using artificial intelligence or machine learning techniques to tailor measurement to the individual [22, 23].

Concluding, the above discussed points reinforce the notion that self-report and device-based instruments capture different, but complementary, aspects of the physical activity behavior construct [21]. This also explains the often-found low correlations between self-report and device-based instruments [9, 18, 24]. This further suggests that both instruments should be viewed as additive, instead of identical to each other. Each method has its own strengths and limitations [15], but together they provide a more complete and comprehensive assessment of the construct physical activity behavior. Future studies should therefore consider a combined measurement strategy [25-27], especially when studying physical activity behavior among people with physical disabilities and/or chronic diseases, where behavioral, contextual and perceptual aspects of physical activity might differ from physiological signal outputs.

Sustained physical activity behavior

In **chapter 2** we have seen that participants were able to increase their physical activity behavior following and up to one year after participating in a physical activity promoting rehabilitation program. Considering the health benefits, and secondary and tertiary healthcare related prevention mechanisms of a physically active lifestyle, this is of course an encouraging finding. However, a key aim of today's rehabilitation practice and health care extends beyond short- to mid-term (up to one year after rehabilitation) increases in physical activity, focusing instead on a sustained physically active lifestyle. This makes the results of **chapter 4**, in which we found that most participants had maintained the increased physical activity behavior 6-8 years after discharge from rehabilitation, very promising. Especially as it is typically seen that physical activity behavior declines after rehabilitation, and/or after physical activity promotion programs are ended [28, 29].

However, we have also seen in **chapter 2** that there was large heterogeneity in physical activity behavior among participants and in **chapter 4** that the development of physical activity over time up to 8 years after rehabilitation is best described by multiple sub-populations as compared to one single population. Informed by behavior change theories and models, most prominently the PAD model [1], we sought to provide insight in this heterogeneity of the development of physical activity behavior over time by studying determinants thought to influence physical activity behavior. The heterogeneity in physical activity behavior between participants of ReSpAct can in part be explained by the personal determinants age, sex, BMI and diagnosis (**chapter 2)**, and by the psychosocial determinants self-efficacy, motivation and attitude (**chapter 3**). These effects were time independent, meaning that, for example, people with higher self-efficacy scores were also more physically active at each measurement moment up to one year after rehabilitation (as **chapters 2 and 3** use only data from ReSpAct 1.0). These results are comparable to previous studies on determinants of physical activity behavior, both in the general population as in people with physical disabilities and/or chronic diseases [30-34]. The heterogeneity in development of sustained physical activity up to 8 years after rehabilitation was in part explained by perceived fatigue and perceived barriers regarding physical activity at baseline (**chapter 4**). The important role of perceived fatigue in physical activity behavior among people with physical disabilities and/or chronic diseases was also shown in the other research project of ReSpAct 2.0 [35]. Moreover, perceived barriers have consistently been associated with physical activity behavior in previous studies [36-38]. Importantly, a separate study based on ReSpAct data demonstrated that participants were able to decrease their perceived barriers following the physical activity promoting rehabilitation program [39], further supporting their relevance in physical activity promoting and counseling programs.

And although the results from **chapters 2-4** provide evidence that these determinants are important for physical activity behavior, as theorized by behavior change theories [1, 40-43], it does not really provide insight in how behavior is changed within a person. Interestingly, when we examined the within-person changes over time, only increases in intrinsic motivation were significantly associated with increased physical activity levels. This finding aligns with the Self-Determination Theory, which places importance on intrinsic motivation for sustained behavior change, particularly when individuals experience autonomy, competence, and relatedness [42, 44]. The role of self-efficacy, as emphasized by theories such as the Social Cognitive Theory [40] and the Health Action Process Approach [43], was confirmed as a between-person factor, but the dynamic influence of self-efficacy over time appeared limited in our data. Similarly, stage-based models of behavior change propose that different determinants play a role depending on an individual's stage in the behavior change process [41, 43, 45], whereas our results showed limited stage-specific variation. Only 'attitude towards physical activity' was more strongly associated with physical activity behavior in people initiating as opposed to those maintaining physical activity behavior. In **chapter 3**, we discussed several potential explanations for lack of effects related to changes in other determinants and behavioral stages, such as the high baseline scores of psychosocial variables, the used physical activity measurement instrument, and the specificity of the measured determinants. Nevertheless, these findings raise questions about the predictive values of behavior change theories in people with physical disabilities and/or chronic diseases. Do we really need to focus on changing multiple different determinants, or is motivation the key component for sustainable behavior change among people with physical disabilities and/or chronic diseases in rehabilitation practice? Although I do not believe that to be the case, nor does more than 70 years of scientific literature [46], our results nonetheless underscore the need for further longitudinal research in physical activity behavior change in people with physical disabilities and/or chronic diseases. Ideally, such research should combine self-report and device-based measures at a regular interval to best be able to capture changes in relevant determinants and their effect on physical activity behavior.

Methodological considerations

Strengths

The main strength of the current thesis is the use of the large-scale, long-term, diagnosis-overarching prospective cohort study ReSpAct and the focus on the multidimensional construct of physical activity behavior. First, by using a prospective cohort study design, we were able to examine physical activity behavior among people with physical disabilities and/or chronic diseases in a natural, real-world context, rather than under controlled or artificial conditions. Second, by using a diagnosis-overarching approach, our results more closely relate to a general rehabilitation population. And third, since ReSpAct was set up as a multicenter study, the cohort consists of people with physical disabilities and/or chronic diseases from across the Netherlands. These three points enhance generalizability and thereby the relevance of this thesis for rehabilitation practice and policy. Additionally, we included a large sample size of 1719 participants. A large sample size is important for high statistical power, which is necessary when studying associations between a construct and its determinants, cross-sectionally and longitudinally [47]. And lastly, following participants over a long time period of 6-8 years, enables the possibility of uncovering (lasting) patterns and associations of the development of physical activity behavior, both between individuals as well as within individuals over time [48, 49]. These patterns and associations can in turn inform the development or refinement of theoretical models [50].

Another strength of this thesis is its multidimensional approach to the construct of physical activity behavior. It helps in understanding physical activity behavior in people with physical disabilities and/or chronic diseases, and how it differs among subgroups in a rehabilitation setting. Also, it provides information for more tailored physical activity counseling, by helping identify dimensions that offer the most opportunity for improvement. And lastly, incorporating all dose characteristics is important to fully capture the construct of physical activity among people with physical disabilities and/or chronic diseases.

Limitations

One limitation of the research described in this thesis is the potential for selection bias in the ReSpAct cohort. Since one of the aims of the ReSpAct cohort was to evaluate the Rehabilitation, Sports and Exercise (RSE) program (**chapter 1**), all participants were required to participate in this physical activity promoting rehabilitation program. Additionally, participants were asked to fill in up to four comprehensive questionnaires in a time period of 1 year, with an additional comprehensive questionnaire 5-7 years later, all lasting up to 60 minutes each to fill in. Thus, it is plausible that only people who were the most motivated and most interested in physical activity and sports participated. Indeed, **chapter 2** shows the ReSpAct cohort to be on average more physically active compared to other populations with physical disabilities and/or chronic diseases, whereas **chapter 3** shows the ReSpAct cohort to have high motivation and positive attitude towards physical activity. This might influence the generalizability of the findings in the current theses. However, there was still a large variability in levels of physical activity behavior, as well as variation in personal characteristics (e.g. age, diagnosis group, education level), expressing that we were able to include a large heterogeneous cohort. Additionally, since the baseline measure was performed just before discharge from rehabilitation, the participant was already participating in the program RSE. And although the research of Van der Ploeg showed that sports participation during rehabilitation alone was not enough to increase physical activity behavior after rehabilitation [51-53], it could have led to a more motivated population with a better attitude towards physical activity and motivational intervention program.

A second limitation is the exclusive use of self-report instruments, especially concerning physical activity behavior. Self-report instruments measuring physical activity behavior have a tendency to overestimate actual time spent being physically active when compared to device-based instruments [16, 19]. Furthermore, as previously mentioned, self-report and device-based instrument are two distinct and complementary aspects of physical activity behavior [25, 26], and thus should be ideally used in addition to each other. However, due to practical, financial and time constraints, collecting physical activity behavior data using device-based instruments was not possible in this large-scale prospective cohort.

A third limitation is also related to the measurement of physical activity behavior. We aimed to provide insight in the full multidimensional construct of physical activity behavior among people with physical disabilities and/or chronic diseases. In **chapter 2**, we indeed explored physical activity behavior in its full dimensional scope, providing information on all dose characteristics (i.e. intensity, frequency, duration, mode and setting). However, in **chapters 2 and 3**, we operationalized physical activity behavior as a single summary score (the SQUASH score), which combines duration and perceived intensity. While this operationalization was necessary for statistical analysis, and allows for better comparability, it may have resulted in a loss of detailed behavioral information, particularly regarding variation in modes of activity or setting.

COVID-19

An important caveat to note about the ReSpAct 2.0 study is that the data collection (T4) took place between March 2021 and August 2021, which was during the COVID-19 pandemic. The COVID-19 pandemic had a significant influence on the lives of people due to the implementation of public health and social distancing measures. In the Netherlands, measures such as keeping 1.5 meter distance from others, closing public places, advice to stay at home as much as possible and prohibiting large gatherings were implemented on a national level during various periods of the first and second year of the pandemic (2020-2022) [54]. Although important for limiting the spread of the COVID-19 virus, these measures did have a negative effect on physical activity behavior and quality of life of people with physical disabilities and/or chronic diseases [55, 56]. The findings of **chapter 3** that most participants appeared to maintain a similar level of physical activity behavior 6-8 years after participating in the RSE program, even during a period with additional barriers and adverse effects to be physically active such as COVID, make these results even more promising. Especially when we consider the result of **Appendix 1**, which showed that 37% of the participants even report to be less physically active during the COVID-19 pandemic then before the COVID-19 pandemic. We therefore can consider the hypothesis that the outcomes of the ReSpAct 2.0, especially physical activity and psychosocial outcomes, could have been more positive in a situation without the COVID-19 pandemic.

Implications for rehabilitation practice

The findings of the current thesis shows that adults with physical disabilities and/or chronic diseases who participated in the RSE rehabilitation program were able to improve and maintain a physically active lifestyle. This highlights the importance of the broad implementation of physical activity promotion during and briefly after rehabilitation as a standard component of rehabilitation care. Previous research, complemented by the current thesis, identifies tailored counseling and motivational interviewing as key strategies for promoting physical activity for people with physical disabilities and/or chronic diseases [28, 53, 57]. To optimize these strategies, rehabilitation professionals should consider how personal characteristics, (changes in) psychosocial determinants and the stage of behavioral change (i.e. initiating or maintaining) influence the patients' physical activity behavior. In particular, this thesis concludes that motivation, self-efficacy, perceived barriers and perceived fatigue are critical factors to address as part of physical activity coaching during and after rehabilitation. By targeting these elements, rehabilitation professionals may enhance the effectiveness of physical activity promotion and support long-term adherence to physical activity behavior beyond the rehabilitation phase. Considering the health benefits, and secondary and tertiary health prevention of sustained physical activity behavior, plus the growing strain on health care, this is critical for the continued accessibility of health care.

Implications for future research

As mentioned previously, future research on the construct of physical activity behavior in people with physical disabilities and/or chronic diseases should focus on the measurement of the different construct characteristics (setting, mode, frequency, duration and intensity). It is important to optimize physical activity measurement in this population, for example by combining both self-report and device-based measurement instruments, and potentially apply artificial intelligence to individualize algorithms and calculations underlying these instruments. Furthermore, future research should focus on longitudinal research in physical activity behavior change with measurement at a regular interval to best be able to capture changes in determinants and their effect on physical activity behavior.

Moreover, when examining physical activity behavior in people with physical disabilities and/or chronic diseases, future research should consider not only the quantity but also the quality of physical activity behavior. Recent research shows that positive experiences (i.e. the quality) of physical activity is positively associated with self-reported well-being in people with physical disabilities and/or chronic diseases, more than the quantity of physical activity [58]. Given that both positive experiences and motivation are important for behavior change [42] (**this thesis**), incorporating the quality of physical activity behavior during physical activity promotion and counseling strategies may further enhance their effectiveness for sustained physical activity behavior.

However, it is also time to take the next step. Even though this thesis provides insight and recommendations for optimization of individually tailored counseling to promote physical activity behavior, we recommend to look beyond only physical activity behavior, and to a healthy lifestyle in general. A healthy lifestyle, comprised of sufficient physical activity behavior, healthy nutrition, adequate and qualitative good sleep, a healthy weight, avoiding distress, smoking and alcohol consumption, helps to improve health related quality of life, participation and overall well-being [59-61]. Already in the Netherlands, multiple efforts are made in this area, such as the Healthy Habits program, a lifestyle program for health care institutions working with people with a physical or cognitive disability [62]; GLI (combined lifestyle intervention, in Dutch: Gecombineerde Leefstijl Intervention), a lifestyle intervention that is typically offered in primary healthcare, for people with obesity covered by the Dutch basic health insurance [63]; and LOFIT, a research project that aims to gain insight into the (cost-)effectiveness of a dedicated lifestyle front office in secondary/tertiary care [64]. Especially research programs such as LOFIT and its follow-up programs COHORT (aiming to set up a national data register for future research on lifestyle care) and LILLo (a learning network for lifestyle front offices in the Netherlands) are promising [64, 65], and should be performed globally for optimal healthy lifestyle promotion for people with physical disabilities and/or chronic diseases.

General conclusion

This thesis confirms that physical activity behavior among people with physical disabilities and/or chronic diseases is a complex, multidimensional construct that encompasses both physiological and behavioral components. While physical activity behavior and its development over time were highly heterogeneous among participants of the ReSpAct study, participants were (on average) able to increase and maintain physical activity behavior up to eight years following an individually tailored physical activity promoting rehabilitation program. These results also confirm the importance of individually tailored counseling using motivational interviewing during the transition period from rehabilitation to daily life. By providing a comprehensive exploration of the construct, this thesis potentially contributes to improving physical activity promoting and counseling programs, for example by showing the role of activities of light intensity and activities performed in the household setting among people with physical disabilities and/or chronic diseases.

Furthermore, focusing on determinants such as increasing self-efficacy and motivation, and decreasing perceived barriers and perceived fatigue during counseling might enhance the effectiveness to achieve a sustained active healthy lifestyle. We also suggest that future research should now focus on measuring the construct of physical activity behavior in people with physical disabilities and/or chronic diseases using the additive values of both self-report and device-based instruments, and look at the qualitative aspects of physical activity behavior. Furthermore, we need to expand from promoting physical activity behavior towards promoting a healthy lifestyle behavior integrating physical activity, nutrition, sleep and psychosocial well-being, which are essential for sustainable health and participation among people with physical disabilities and/or chronic diseases.

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Appendix

The Impact of the COVID-19 Pandemic on Physical Activity and Social Isolation among Adults with Physical Disabilities Living in Canada and The Netherlands

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Abstract

Background: The impact of the COVID-19 pandemic among people with physical disabilities might differ between countries due to differences in implemented measures and infection rates. This study aimed to understand the impact of the pandemic on physical activity (PA) and social isolation among adults with physical disabilities in Canada and the Netherlands, and examine associations between PA and social isolation.

Methods: Secondary data from two studies were used: the Canadian COVID-19 Disability Survey (n = 353) and the Dutch Rehabilitation, Sports and Active lifestyle (ReSpAct) 2.0 study (n = 445). Self-reported PA was measured using IPAQ-SF and Adapted-SQUASH. Social isolation was measured using the PROMIS Social Isolation. Descriptive and regression analyses were performed.

Results: Canadian participants spent on average 163 min (Median = 0; IQR = 120) on moderate-to-vigorous PA per week and Dutch participants 934 min (Median = 600; IQR = 1125). In Canada, 64% reported to have become less physically active since the pandemic compared to 37% of Dutch participants. In both samples, no clinically relevant associations were found between PA and social isolation.

Conclusions: The findings emphasize the negative impact of the pandemic on PA and social isolation in adults with physical disabilities in Canada and the Netherlands. Future research is needed to better understand if and how PA can be used to reduce social isolation in people with disabilities. This study illustrates how cross-country collaborations and exchange provide opportunities to inspire and learn from initiatives and programs in other countries and may help to improve PA support among people with disabilities during and after the pandemic.

Keywords: physical activity; social isolation; COVID-19 pandemic; physical disability; rehabilitation; mental health

Introduction

In response to the COVID-19 pandemic, countries all over the world implemented public health and social distancing measures, aiming to slow down the transmission of the virus [1]. For example, in Canada, recreation facilities, national parks, and non-essential businesses were closed for various periods in the first and second year of the pandemic. Citizens were encouraged to maintain a distance of 2 m to others, were asked to avoid social gatherings and crowded places, and were asked to stay at home as much as possible [2]. As many health and social distancing measures were determined by provincial governments, COVID-19 strategies differed within the country [3]. In contrast, the Netherlands implemented such as keeping 1.5 m distance to others, closing public places (schools, restaurants and non-essential businesses), and prohibiting large gatherings for various periods in the first and second year of the pandemic [4]. Citizens were asked to stay at home as much as possible [4]. Furthermore, many sports events were canceled [5].

Although these measures were important in limiting the spread of the coronavirus, they have shown to have had negative side effects on physical activity (PA), social isolation, general health, mental health, and lifestyle of people with and without disabilities [6–10]. For example, the closure of many recreation and fitness facilities limited people to engage in PA [11–13]. Results from a rapid systematic review showed that decreased PA during the pandemic was associated with increased levels of depression and anxiety [14]. Similar results were found in another systematic review on relationships between various components of mental health distress (e.g., social isolation, anxiety, stress) and PA in the general population [8]. Furthermore, PA has been suggested as a promising strategy to reduce feelings of social isolation and mental health distress [8]. For example, the Broaden-and-Build Theory of Positive Emotions suggests that individuals' positive emotions and feelings resulting from PA participation may help them to think more creatively and build personal resources, which may then reduce feelings of social isolation [15,16]. Another theory, called the Social Control Theory, suggests that someone's behavior is partly influenced by their social environment. According to this theory, social control is an important factor in promoting healthy behavior, such as engaging in PA [17]. In other words, individuals with lower social control as a result of poor social connections (e.g., not being married) tend to engage in less PA compared to individuals with better social control (e.g., married, being socially connected to friends). Taking together, this may suggest a potential negative impact of the pandemic on PA and social isolation. While previous studies have focused on understanding the impact of the pandemic on PA and social isolation [14,18–20], and examined the relationships between these two constructs [21,22], these studies mainly derived from studies conducted in general population or older adults [21,22].

Still, limited studies reported on the impact of the pandemic on PA and social isolation in a diverse group of adults with physical disabilities. Indeed, people with disabilities (PWD) have been considered as an under-research population in PA research [23].

This is concerning, as the pandemic has, in particular, had a negative impact on PA in people with disabilities (PWD) [24]. PWD have been overly affected by the pandemic, as their unique barriers and needs have not always been considered in the response strategies to the COVID-19 outbreak [1,25]. Before the pandemic, studies consistently reported that PWD are less physically active compared to people without disabilities [23,26]. The low levels of PA in PWD can be explained by the many barriers they experience to engage in PA [23]. For example, barriers can exist on community level (e.g., lack of accessible equipment), institutional level (e.g., lack of disability-specific knowledge on PA among healthcare professionals), interpersonal level (e.g., lack of social support), and intrapersonal level (e.g., perceived fatigue or pain) [23]. The pandemic might have worsened already existing barriers as the COVID-19 measures lead to a diminished access to sport and recreation services and limited opportunities to take part in (group-based) PA.

Besides the impact of the pandemic on PA, a scoping review showed that as a result of COVID-19 measures, there are health and social participation differences experienced by PWD compared to people without disabilities during the first wave of the COVID- 19 pandemic [27]. For example, PWD experienced limited access to health, education, and essential community services, as well as psychological consequences resulting from disrupted routines and activities [27]. A study in Canada among people working with a disability showed that people with a physical disability reported more health concerns during the pandemic than people without disabilities [28].

While the impact of the COVID-19 pandemic on PA and health in PWD has been described in the literature [9], limited studies have focused on understanding the impact on PA and social isolation in PWD living in different countries. An example of a Canadian cohort study of PWD is the COVID-19 Disability Survey. This study was initiated to record the experiences, needs and concerns of PWD living in Canada during the pandemic. The survey included questions on PA and social isolation during the pandemic. Another example of a cohort of PWD is the Dutch Rehabilitation, Sports and Active Lifestyle (ReSpAct) cohort study, which started in the year 2012. This cohort included >1700 adults with physical disabilities and/or chronic disease who received support to become and stay physically active during and after rehabilitation, as part of the Rehabilitation, Sports and Exercise (RSE) program [29]. The ReSpAct cohort is known as a relatively active cohort of PWD. During the pandemic, ReSpAct participants were invited to complete a survey on PA and social isolation [30]. We do not know whether ReSpAct participants are able to sustain their high levels of PA during pandemic. While both cohort studies are conducted in different countries with different purposes and historical backgrounds, they have collected similar information on the impact of the pandemic on PA and social isolation in different groups of PWD, making them in particular suitable and interesting for a multi-country study on the impact of the pandemic.

Understanding the impact of the pandemic on PWD living in different countries is of additional value as it provides opportunities to study influence of the pandemic in different contexts and enhances international collaborations and exchange. Furthermore, studying the impact of the pandemic on PWD living in Canada (COVID-19 Disability Survey) and the Netherlands (ReSpAct) is of particular interest, as both countries are high-income countries that play leading roles in expanding our knowledge on rehabilitation, PA and disabilities sports [31,32]. A previous policy comparison study showed that federal governments of both countries provide funding to local governments to promote PA in PWD, but the way they promote PA differs between governments [33]. For example, in Canada national PA promotion programs are organized by provinces and territories via long-term agreements. In the Netherlands, PA promotion in PWD is being done by municipalities via time-limited programs (e.g., PA promotion programs in rehabilitation) [33]. Furthermore, the Netherlands is a small, densely populated country with 17 million people (population density: 512 per km2), while Canada is a large, thinly populated country with more than 33 million people (population density: 3 per km2). Countries also differed in implemented COVID-19 measures and infection rates. On 23 June 2021, the Netherlands counted a total of 1.7 million infections, while Canada, with almost twice the population, counted 1.4 million infections [34]. These differences in PA promotion strategies, infrastructure, and the COVID-19 measures and infection rates might have resulted in differences in perceived impact of the pandemic between people with physical disabilities living in Canada and the Netherlands.

The primary aim of this study was to understand the impact of the COVID-19 pandemic on PA and social isolation among adults with physical disabilities living in Canada and the Netherlands. The secondary aims were to understand the impact of the pandemic on general health, mental health and lifestyle among adults with physical disabilities, and to examine relationships between PA and social isolation. Our hypotheses were that the pandemic has a negative impact on PA, social isolation, general health, mental health and lifestyle in PWD in Canada and the Netherlands; and that the negative impacts are greater in the Canadian sample compared to Dutch sample due to the different historical back- ground of both samples. We also hypothesized that PA and social isolation are significantly associated, in which adults with higher PA levels perceive lower levels of social isolation. This study provides new insights into the impact of the pandemic on this vulnerable group in two different countries. The findings can be used to inform future research and program development to improve PA support to PWD during and after the pandemic.

Materials and Methods

This secondary data analysis study used a quantitative cross-sectional study design using data from two studies: the COVID-19 Disability Survey in Canada (www. disabili tysurvey.ca, accessed on 7 December 2022) and the ReSpAct (Rehabilitation, Sports and Active Lifestyle) 2.0 study in the Netherlands [30,35]. The Research Ethics Board of the University of British Columbia gave approval for the COVID-19 Disability Survey (Open Science Framework: https://osf.io/z4gr2, accessed on 7 December 2022). The Central Ethics Committee of the University Medical Center Groningen (UMCG) gave approval for the ReSpAct 2.0 study.

Canadian Study Design and Study Population

The Canadian COVID-19 Disability Survey (www.disabilitysurvey.ca, accessed on 7 December 2022) is an ongoing study consisting of an online 20-min initial survey and four 15-min follow-up surveys. The survey included questions about the experiences, concerns, and needs of people living with a disability during the COVID-19 pandemic in Canada. The COVID-19 Disability Survey was an initiative led by the Abilities Centre in partnership with Canadian Disability Participation Project (CDPP) researchers. Partner organizations from across Canada were involved in the development of the survey. Participants of the COVID- 19 Disability Survey were recruited via social media and via the partner organizations.

Adults who identified as having any form of disability, parents of a child with a disability and family members of someone with a disability living in their household were eligible to participate. The term 'disability' refers here to a broad definition of disability, including impairment to see, impairment to hear, impaired ability to walk, impaired flexibility, impaired hand function, impaired memory, chronic pain, learning disability, autism spectrum disorder, intellectual disability, and a psychological, psychiatric or mental health condition. Additional inclusion criteria were being able to either understand written English or French, or American Sign Language (ASL) and being a Canadian resident.

For this study, data from adults with a physical disability who completed the English version of the COVID-19 Disability Survey were used. This included people with an impaired ability to walk, impaired flexibility, impaired hand function and chronic pain. In total, 353 people met the inclusion criteria.

Dutch Study Design and Study Population

ReSpAct is a prospective cohort study. ReSpAct 2.0 is a 6–8 year follow-up study of the ReSpAct 1.0 study [35]. The ReSpAct study was designed to evaluate the RSE program, which is an evidence-based tailored counseling program to promote PA among people with physical disabilities and/or chronic diseases during and after rehabilitation [29]. Participants of the ReSpAct 1.0 were enrolled 3–6 weeks before discharge from rehabilita- tion. Participants who took part in the ReSpAct 1.0 study were recruited for the ReSpAct 2.0 follow-up study via a newsletter. Further details on recruitment methods are described in Supplementary File S1.

The study population of ReSpAct 2.0 included adults with physical disabilities and/or chronic diseases that participated in the ReSpAct 1.0 study 6–8 years ago. Inclusion criteria of ReSpAct 2.0 were: (1) previous participation in ReSpAct 1.0; (2) being 18 years or older; and (3) having a physical disability and/or chronic disease. Exclusion criteria were: (1) not being able to complete the questionnaires even with help; (2) having withdrawn consent to participate in follow-up research; and (3) being deceased between ReSpAct 1.0 and ReSpAct 2.0.

All participants of ReSpAct 2.0 were included in current study if they were diagnosed with one or more of the following conditions: (1) impairment in musculoskeletal system; (2) amputation; (3) brain impairment; (4) neurological impairment; (5) spinal cord injury; (6) impairment in organs; (7) chronic pain; and (8) other impairments. People with visual or auditive impairments were excluded. People of whom the type of disability/chronic disease was not registered were also excluded. In total, 445 people met the inclusion criteria.

Data Collection in Canada and The Netherlands

Canadian data were collected between 18 December 2020 and 23 August 2021. Dutch data were collected between 29 March 2021 and 26 August 2021. Both studies included questions about demographics (gender, marital status, age), PA, social isolation, general health, and changes in PA, lifestyle and mental health since the start of the pandemic.

Physical Activity

Two validated questionnaires were used to measure self-reported PA levels. In the Canadian dataset, the International Physical Activity Questionnaire Short-Form (IPAQ-SF) was used [36]. The IPAQ-SF is a 7-item survey that assesses moderate and vigorous PA, walking, and sitting time of individuals during the past 7 days. For the Canadian study, the IPAQ-SF was adjusted for people with physical disabilities by including examples of PA specific for people with disabilities, such as wheelchair racing and arm cranking. In the Dutch dataset, the Adapted-SQUASH (Adapted Short Questionnaire to ASsess Health enhancing PA) was used [37]. The original

SQUASH is a self-reported recall questionnaire to assess daily PA of adults without a disability based on an average week in the past month [38]. It measures the frequency, duration, and intensity in 4 different settings of PA, namely 'PA during commuting', 'PA at work or at school', 'PA during leisure-time', and 'carrying out household activities'. The Adapted-SQUASH was developed to create a questionnaire that better aligns with the perceived intensity of activities among adults with disabilities by using appropriate metabolic equivalent of task (MET) values [39,40]. The total minutes of moderate and vigorous PA per week was used as the PA outcome measure. For both datasets, three PA outcome measures were reported: the total minutes moderate PA per week, total minutes vigorous PA per week and total minutes on moderate and vigorous PA per week.

In both studies, the impact of the pandemic on PA was measured by asking participants whether or not their PA had changed since the start of the COVID-19 pandemic, using 3 answer options: (1) no change in PA (2) becoming more physically active or (3) becoming less physically active. In Canada, change in PA was asked with 1 general question asking about the change in participation in exercise, sports, and recreational PA. In the Netherlands, this was asked with 4 questions on change in different settings/domains of PA to align with the format of the Adapted-SQUASH (commuting; work/school; leisure time; household activities). For the purpose of this study, we only present the data on change in leisure time PA, as change in leisure time PA is most comparable with the Canadian question on change in participation in exercise, sports, and recreational PA.

Social Isolation

In both studies, social isolation was measured using the validated PROMIS Social Isolation 8a questionnaire. The PROMIS Social Isolation assesses perceptions of being avoided, excluded, detached, disconnected from, or unknown by others in the adult population [41]. The questionnaire consists of 8 questions with 5-point answer scale (never; rarely; sometimes; often; and always). Each answer corresponds to a score of 1–5, producing the continuous social isolation raw-score (sum of response scores). A conversion table was used to translate the raw-score into the standardized social isolation T-score. The PROMIS Social Isolation can be used to compare the data of the survey to that of the general population, where a T-score of 50 represents the mean score in a sample of individuals from the general population in the United States (reference population). A higher score indicates greater social isolation [41].

General Health, Mental Health and Lifestyle

In Canada, general health was measured using the validated PROMIS Global Health questionnaire [42]. This questionnaire can be used to measure the health of adults and children in the general population and of those living with a chronic condition, and aims to globally reflect someone's assessment of their health. The PROMIS Global Health consists of 10 questions. We used the first item on self-reported general health (the first question). In the Netherlands, general health was measured with one question on their general health, based on the RAND-12 Health Status Inventory, which is an abbreviated version of the RAND-36 Health Status Inventory (RAND-36) [43,44]. In both studies, the question on self-reported general health used a 5-point answer scale (excellent; very good; good; fair; and poor).

In both studies, the extent to which the pandemic impacted participants' mental health was measured using a 5-point answer scale (not at all; very little; to some extent; to a great extent; and completely). To measure the effect of the pandemic on lifestyle, both studies asked participants whether their eating habits, smoking habits, and alcohol consumption had changed since the start of the pandemic, using a 3-point answer scale (no change; positive change (eating healthier/smoking less/drinking less alcohol); and negative change (eating less healthy/smoking more/drinking more alcohol). These lifestyle factors were chosen as in addition to physical inactivity, poor eating habits, smoking, and excessive alcohol consumption are important risk factors for the development of chronic conditions [26]. The questions on changes in mental health and lifestyle were developed by the Canadian research team and translated into Dutch for the ReSpAct 2.0 survey.

Data Analyses

All analyses were performed in IBM SPSS Statistics for Windows, Version 25.0. IBM Corp, Armonk, NY, USA. Descriptive analyses were used to describe demographic factors and the impact of the pandemic and associated measures on PA, social isolation, general health, mental health and lifestyle.

Physical Activity

For both the Canadian and Dutch samples, the results on PA levels were presented as 'moderate PA in minutes per week', 'vigorous PA in minutes per week', and 'total minutes of moderate and vigorous PA per week', giving the mean, standard deviation, minimum, and maximum. Since this variable was not normally distributed, the median, 25th percentile, and 75th percentile were presented as well. For both studies, participants that state to have spent 6720 min or more on PA per week (or 16 h per day) were excluded [37,38].

For the Canadian sample, change in PA was presented by describing the percentage of either no change in PA, becoming more physically active or becoming less physically active regarding participation in exercise, sports, and other recreational PA. In the Netherlands, change in PA was presented by describing the percentage of either no change in PA, becoming more physically active or becoming less physically active during leisure time.

Social Isolation

Results of the social isolation raw-score were presented by giving the mean, standard deviation, minimum and maximum of the social isolation raw-score. Since this variable was not normally distributed in the Netherlands, the median, 25th percentile and 75th percentile were also presented. The social isolation T-score was divided in groups of a T-score below 40, between 40 and 50, between 50 and 60, and 60 and higher, to compare this score to that of the reference population.

General Health, Mental Health, and Lifestyle Changes

Results were presented by giving percentages on how many people rated their general health as 'excellent, 'very good', 'good', 'fair', or 'poor'. Results for the extent to which COVID-19 negatively impacted one's mental health were also presented by giving per- centages on how many people indicated the negative impact on mental health as either 'not at all', 'very little', 'to some extent', 'to a great extent' or 'completely'. Change in lifestyle results were presented by giving percentages on how many people experienced no change, a positive change, or a negative change since the start of the pandemic for each lifestyle aspect.

Associations between Physical Activity and Social Isolation

The associations between PA and social isolation were analyzed using linear regression analyses, conducted separately for both samples. Since the score of the Dutch sample was not normally distributed, bootstrapped analyses were conducted (bias corrected and accelerated; 1000 samples) for that sample. The results of the (bootstrapped) analyses are presented using a table showing the regression coefficient (B), p-value, and 95% confidence interval of both the crude and adjusted analysis (confounders included age, gender, marital status). See Supplementary File S2 for a detailed substantiation of these confounders.

Results

Characteristics of the Study Population

Table 1 presents participants' descriptive information of the Canadian sample (n = 353) and Dutch sample (n = 445). Of the Dutch participants, 49.7% identified as man, compared to 34.1% of the Canadian participants. In both studies, most of the participants were aged between 51 and 70 years old. In the Dutch study, the majority was married or living as if married (69.6%), while most of the Canadian participants was divorced, separated, never married, or single (59.2%).

Table 1. Participants' demographics per country (short version).

Descriptive Variables	Canada (n = 353)	The Netherlands (n = 445)
Gender [n (%)]	Missing n = 7	Missing n = 99
Man	n = 101 (29.2%)	n = 172 (49.7%)
Woman	n = 228 (65.9%)	n = 170 (49.1%)
Not listed/prefer not to answer	n = 17 (4.9%)	n = 4 (1.2%)
Age in categories [n (%)]	Missing n = 5	Missing n = 0
18–30 (young adults)	n = 40 (11.5%)	n = 14 (3.1%)
31–50 (middle-aged adults)	n = 141 (40.5%)	n = 119 (26.7%)
51–70 (senior adults)	n = 146 (42.0%)	n = 266 (59.8%)
≥71 (elderly persons)	n = 21 (6.0%)	n = 46 (10.3%)
Marital status [n (%)]	Missing n = 0	Missing n = 100
Married or living as if married	n = 122 (34.6%)	n = 240 (69.6%)
Widowed	n = 17 (4.8%)	n = 8 (2.3%)
Divorced, separated, never married, or single	n = 209 (59.2%)	n = 86 (24.9%)
Other	n = 5 (1.4%)	n = 11 (3.2%)
Type of disability * [n (%)]		
(Possible to have more than 1 disability)	Missing n = 0	
Impaired ability to walk	n = 266 (75.4%)	-
Impaired flexibility	n = 161 (45.6%)	-
Impaired ability to use hands	n = 125 (35.4%)	-
Chronic or long-term pain	n = 240 (68.0%)	-
Other	n = 53 (15.0%)	-
Diagnosis/disability main category ** [n (%)]		Missing n = 0
Impairment musculoskeletal system	-	n = 76 (17.1%)
Amputation	-	n = 17 (3.8%)
Brain	-	n = 120 (27.0%)
Neurology	-	n = 71 (16.0%)
Spinal cord injury	-	n = 10 (2.2%)
Organs	-	n = 49 (11.0%)
Chronic pain	-	n = 77 (17.3%)
Other impairments	-	n = 25 (5.6%)
Paid work	Missing n = 0	Missing n = 95
Yes	n = 101 (28.6%)	n = 121 (34.6%)
No	n = 252 (71.4%)	n = 229 (65.4%)
Social isolation raw-score		
Mean (std. error)	24.3 (0.5)	13.9 (0.3)
Std. deviation	8.4	6.1
Median	24	12
Minimum–maximum	8–40	8–40
25th percentile	18	8
75th percentile	31	17

Table 1. Participants' demographics per country (short version).

Descriptive Variables	Canada (n = 353)	The Netherlands (n = 445)
Social isolation T-score * (%)**		
T-scores lower than 40	n = 17 (5%)	n = 111 (32%)
T-scores 40–50	n = 44 (13%)	n = 134 (39%)
T-scores 50–60	n = 147 (43%)	n = 91 (26%)
T-scores higher than 60	n = 131 (39%)	n = 12 (3%)
Self-reported general health (%)		
Excellent	n = 8 (2%)	n = 10 (3%)
Very good	n = 42 (12%)	n = 26 (7%)
Good	n = 125 (36%)	n = 144 (40%)
Fair	n = 112 (32%)	n = 146 (41%)
Poor	n = 59 (17%)	n = 30 (8%)
Negative impact of COVID-19 on mental health (%)		
Not at all	n = 18 (5%)	n = 121 (34%)
Very little	n = 49 (14%)	n = 132 (37%)
To some extent	n = 134 (40%)	n = 65 (18%)
To a great extent	n = 86 (25%)	n = 23 (7%)
Completely	n = 51 (15%)	n = 12 (3%)
Changes in lifestyle since COVID-19 (%)		
No changes in eating habits	n = 99 (30%)	n = 243 (69%)
Less healthy eating habits	n = 181 (54%)	n = 56 (16%)
Healthier eating habits	n = 54 (16%)	n = 54 (15%)
No changes in smoking habits	n = 15 (36%)	18 (53%)
Less healthy smoking habits	n = 16 (38%)	n = 8 (24%)
Healthier smoking habits	n = 26 (21%)	n = 8 (24%)
No changes in alcohol consumption	n = 58 (46%)	n = 119 (80%)
Less healthy alcohol consumption	n = 41 (33%)	n = 13 (9%)
Healthier alcohol consumption	n = 26 (21%)	n = 16 (11%)

Notes: * In the Canadian survey, type of disability was assessed by asking how participants would describe their disability, in which participants could select more than 1 option. ** Diagnosis/disability of Dutch participants was registered by rehabilitation professionals at baseline. *** A T-score of 50 on social isolation represents the mean score in a sample of individuals from the general population in the United States (reference population). A higher score indicates greater social isolation [41]. Supplementary File S3 includes figures illustrating the findings on general health, mental health and lifestyle changes

Physical Activity

Canadian participants spent on average 100 min (SD 269.2, median 0.0) on moderate PA in the previous week, and 64 min (SD 240.6, median 0.0) on vigorous PA (see Table 2). Dutch participants spent on average 706 min (SD 867.5, median 355.0) on moderate PA per week, and 227 min (SD 328.4, median 120.00) on vigorous PA (see Table 2).

Of the Canadian participants that participated in PA (N = 242), 64.5% reported that they became less physically active since the start of the pandemic, 13.2% reported to have become more physically active, while 22.3% reported no change in their PA.

Of the Dutch participants that participated in PA (N = 335), 37.0% reported that they became less physically active during leisure time, while 18.5% became more active, and 44.5% reported no change in leisure time PA. Supplementary File S4 provides additional details on changes in PA since the start of the pandemic.

Social Isolation

Table 1 shows the social isolation score (raw scores and T-scores) among Canadian and Dutch participants. 82.0% of Canadian participants experienced greater social isolation than the reference population in the US, compared to 29.0% of the Dutch participants.

General Health, Mental Health and Lifestyle

17.1% of Canadian participants reported having poor general health, compared to 8.4% of Dutch participants. 2.3% Canadians indicated having excellent general health, compared to 2.8% of Dutch participants.

94.7% of Canadian participants reported experiencing some negative impact of COVID- 19 on their mental health (ranging from very little to completely impacted), compared to 65.7% of Dutch participants.

As for change in lifestyle, the eating habits of more than half of Canadian participants (54.2%) became less healthy, compared to 15.9% of Dutch participants. About the same amount of Canadian and Dutch participants started eating healthier (16.2% and 15.3%, respectively). By far the largest part of Dutch participants experienced no change in eating habits (68.8%), compared to 29.6% of Canadians. 38.1% of Canadian participants that smoked, started smoking more since the start of the pandemic, compared to 23.5% of Dutch participants that smoked. 32.8% of Canadian participants started drinking more alcohol, compared to 8.8% of Dutch participants. In both countries, many participants experienced no change in alcohol consumption (Canada: 46.4%; Netherlands: 80.4%).

Table 2. Physical activity levels in Canada and the Netherlands.

	Moderate Physical Activities in Minutes in Past Week (n = 325)	Vigorous Physical Activities in Minutes in Past Week (n = 330)	Total Minutes of Moderate and Vigorous Physical Activities in Past Week (n = 330)
Canada			
Mean (std. error)	99.9 (14.9)	64.2 (13.2)	162.6 (23.0)
Std. deviation	269.2	240.56	417.5
Median	0.0	0.0	0.0
Minimum	0.0	0.0	0.0
Maximum	3360.0	2880.0	3540.0
25th percentile	0.0	0.0	0.0
75th percentile	90.0	15.0	120.0
The Netherlands			
Mean (std. error)	706.2 (42.9)	227.3 (16.2)	933.5 (49.3)
Std. deviation	867.5	328.4	996.6
Median	355.0	120.0	600.0
Minimum	0.0	0.0	0.0
Maximum	4920.0	2580.0	4980.0
25th percentile	60.0	0.0	180.0
75th percentile	1080.0	325.0	1305.0

Notes: In Canadian survey, self-reported physical activity was measured using IPAQ-SF [36]. In the Dutch survey self-reported physical activity was measured using the Adapted-SQUASH [37].

Associations between Physical Activity and Social Isolation

Table 3 reports on the crude and adjusted associations between PA and social isolation for the Canadian and Dutch samples separately. Results indicate no clinically relevant associations between PA and social isolation. To illustrate, in the Canadian sample, a 1 h increase in PA was associated with a non-significant decrease of −0.090 (−0.257–0.050) points in social isolation.

Table 3. Associations between physical activity and social isolation for the Dutch and Canadian samples separately

	The Netherlands		Canada	
	B, 95% Confidence Interval	p-Value	B, 95% Confidence Interval	p-Value
Physical activity #, crude	-0.020 (-0.059-0.190)	0.310	-0.068 (-0.245-0.069)	0.328
Physical activity, adjusted *	0.001 (-0.040-0.042)	0.975	-0.090* (-0.257-0.050)	0.199

Notes: # Physical activity is presented per hour. * Adjusted for age, gender and marital status.

Discussion

This study provides new insights into the negative impact of the COVID-19 pandemic on PA, social isolation, general health, mental health and lifestyle among adults with physical disabilities living in Canada and the Netherlands. Overall, Dutch participants reported higher levels of PA, lower levels of social isolation, and better general health during the second year of the pandemic, compared to Canadian participants. In both samples, no clinically relevant associations were found between PA and social isolation.

Physical Activity

The percentage of the participants that reported to be less physically active since the start of the pandemic was high among both Canadian participants and Dutch participants (64% vs. 37%, respectively). This negative impact of the pandemic on PA levels was reported in other studies among people with and without disabilities across the world [6,8]. We found large differences in PA levels between Canadian and Dutch participants (163 min vs. 934 min of PA). PA levels of the Canadian participants were generally low, but comparable to findings from other studies on measured self-reported PA among people with physical disabilities [9,10,13,45]. In contrast, PA levels of Dutch participants were high compared to other Dutch studies on self-reported PA among people with physical disabilities and/or chronic diseases [46–48]. The Dutch Adapted-SQUASH may overestimate participants' PA levels more than the IPAQ-SF because the Adapted-SQUASH includes items on various PA settings. The differences between countries may therefore be explained by differences in questionnaires. To consider these differences in questionnaires, we specifically focused the analyses on the most robust PA-measures: moderate and vigorous PA. Dutch participants were still consistently more active compared to the Canadian population, but comparisons should be made with caution.

A possible explanation for these high PA levels and relatively lower negative impact of the pandemic reported by Dutch participants is that the Dutch survey was conducted as part of the ongoing ReSpAct study. ReSpAct participants took part in the RSE program in which they received PA counseling during and after their rehabilitation treatment 6–8 years ago [30]. They were supported to maintain a physically active lifestyle after discharge from rehabilitation [30]. While the Dutch cohort may be a selective, non-representative sample in terms of their PA interests and motivation towards an active lifestyle [30], it is encouraging that many of the Dutch participants reported high levels of PA during the pandemic. Our findings from the 6–8 years follow-up study are promising in terms of the potential long-term outcomes of integrating PA promising strategies during and after rehabilitation. Indeed, the Netherlands has a history of programs focusing on integrating and promoting PA in rehabilitation and hospital settings. These findings and previous studies may inspire other groups in other countries to integrate PA promotion strategies in rehabilitation and hospital settings in order to improve PA levels in PWD [29,49,50].

The Canadian participants were recruited as part of the COVID-19 Disability Study, a unique research partnership initiative to record the experiences, needs and concerns of PWD living in Canada during the pandemic. While this study did not have a specific focus on PA, the findings of the COVID-19 Disability Study have been used to inform policy changes in Ontario regarding access to PA programs specific for PWD. Recreation facilities could re-open for PWD who needed physical therapy. This is an example of how research findings could inform policy changes and immediately have a positive influence on lives of many Canadians with disabilities. This impactful initiative may be explained by the fact that the COVID-19 Disability Survey has been designed, conducted and disseminated in partnership between researchers and relevant research users (i.e., community organiza- tions). Furthermore, the findings were shared via accessible, open-access reports available on www.disabilitysurvey.ca (accessed on 7 December 2022). Together, the COVID-19 Dis- ability Survey provides an example of how a research partnership approach may contribute to improving the translation of research findings to practice and policy, and may inspire other groups to apply a similar research partnership approach to their (future) projects [51].

Social Isolation

Canadian participants reported higher levels of social isolation than Dutch participants (82% vs. 29%) during the second year of the pandemic. In a study conducted in the UK, 49% of the PWD reported to feel lonely during the pandemic [24]. An increase in feelings of loneliness and social isolation during the pandemic has been reported in previous studies among older adults and PWD [10,45,52]. The generally high levels of social isolation among Canadian participants in comparison with the Dutch participants may be explained by differences in implemented COVID-19 and lockdown measures. The data collection for the Canadian study started in December 2020 when COVID-19 restrictions were still in place in many provinces. The data collection for the Dutch study took place between March–August 2021, a period where many COVID-19 restrictions were lifted. As such, it is possible that Dutch participants were less negatively impacted by the pandemic compared to Canadians due to the differences in policies and lockdown measures. Another explanation for the difference in social isolation may be the higher percentage of Dutch participants (69.6%) reporting to be married compared to the Canadian participants (34.6%). Marital status has been linked to social isolation [53]. Similarly, Dutch participants reported higher levels of PA, which may contribute to lower levels of social isolation, as supported by various theoretical frameworks (e.g., Broaden-and-Build Theory of Positive Emotions, Social Support Theory). However, this explanation is not supported by our findings on the associations between PA and social isolation.

The lack of clinically relevant associations between PA and social isolation was in contrast to our hypothesis. This may be due to the multidimensional aspect of both PA and social isolation. For example, we only looked at PA on moderate and vigorous intensity, while PA on mild intensity (e.g., walking/wheeling) may also be associated with social isolation. However, findings of previous studies examining relationships between PA and social isolation were also mixed [21,22]. Future (longitudinal) research is needed to understand if and how PA can be used as an effective strategy to reduce social isolation and other mental health distress in PWD, both during and after the pandemic.

General Health, Mental Health and Lifestyle

More than half of Canadian participants (53%) and 44% of the Dutch participants reported their current health as fair or poor. Previous studies conducted before and during the COVID-19 pandemic showed that PWD reported lower levels of health and well-being compared to those without disabilities [26,45,52]. Various studies from across the world reported the negative impact of the pandemic on health and well-being in PWD [7–9,45,52]. Indeed, our results showed that almost all Canadian participants (95%) reported to some negative impact of COVID-19 on their mental health, compared to 72% of Dutch participants. The higher percentages of the Canadians reporting a negative impact on their mental health compared to the Dutch participants may be related to the differences in PA levels. A systematic rapid review on the association of PA with depression and anxiety found that engaging in PA during the pandemic was associated with lower levels of depression and anxiety [14]. Differences in COVID-19 measures between countries could also explain differences in perceived (negative) impact between countries. As countries differ in pandemic response strategies and infection waves do not happen simultaneously across countries [54], differences in reported negative impact on mental health could be partly attributed to that. Future research is needed to longitudinally monitor mental health of PWD during, but also after the pandemic and its relationships with PA, and other lifestyle behaviors.

Regarding changes in other lifestyles, we found that Canadians reported less healthy eating and more alcohol and tobacco consumption since the pandemic more often com- pared to the Dutch participants. A systematic review among people aged 16 and older on snacking behavior, fast-food consumption, and alcohol consumption during the pan- demic showed that increased snacking was found for a significant portion of the popula- tion (18.9–45.1%), whereas fast-food consumption showed a tendency towards decrease (15.0–41.3%) [55]. In 17 out of 23 studies, alcohol consumption did not change during the lockdown for most participants [55]. Grossman, Benjamin-Neelon and Sonnenschein [56] reported that 60% of US adults over 21 years reported increased drinking compared to before the pandemic. Reasons for increased drinking included increased stress (45.7%), increased alcohol availability (34.4%), and boredom (30.1%). Although the prevalence of increased alcohol consumption during the pandemic was lower in our samples, the percentage of participants reporting to have increased their alcohol consumption during the pandemic is still worrisome. They do partly overlap with findings from the UK [45] and emphasize the need to develop multiple lifestyle programs and interventions to support PWD, but also people without disabilities in starting and maintaining a healthy lifestyle during and after the pandemic.

Limitations and Future Directions

Some limitations need be acknowledged. First, both studies used different criteria to include participants with physical disabilities and/or chronic diseases. As such, study pop- ulations in the Canadian and Dutch study were not fully identical due to these differences in recruitment and promotion strategies between countries. We were also unable to do any sub-analyses focusing of specific groups of disabilities as type of disability/diagnosis was measured in different ways. Another limitation is that we did not collect detailed information on different mental health components, such as anxiety, depression, or stress. Furthermore, we only reported on changes in PA, eating, smoking and alcohol consump- tion, and did not collect data on other lifestyle factors, such sleep or stress management activities. Moreover, PA was not assessed by the same questionnaire in both samples, making direct and valid cross-country comparisons of PA difficult or even impossible. Another limitation of this study is the cross-sectional design of the study. We examined the associations between PA and social isolation cross-sectionally. As such, we cannot determine any cause-and-effect relationships between PA and social isolation related to the pandemic. Finally, this study provides a snapshot of the impact of the pandemic on PA, social isolation, general health, mental health and lifestyle among people with physical disabilities in Canada and the Netherlands. The pandemic is, unfortunately, not over. As reduced PA could lead to progression of disablement in older or diseased populations, further research on the aftermath of the pandemic for people with physical disabilities is recommended. It is important to identify what long-term or sustained consequences the pandemic has on the lifestyle, general- or mental health and social isolation of people with physical disabilities, as well as the consequences of the decrease in PA for this group on the longer term.

Implications

This multi-country study is the first that systematically identified and compared the impact of the pandemic on PA, social isolation, general health, mental health and lifestyle changes in a vulnerable population of adults with physical disabilities living in Canada and The Netherlands. Although many studies have been conducted on the impact of the COVID-19 pandemic, still a limited amount studied the impact of the pandemic on diverse group of adults with physical disabilities. This study adds to the existing literature by understanding how the pandemic impacted a diverse, active and less active group of adults with physical disabilities in different settings (Canada and the Netherlands), with different PA promotion backgrounds. We also add to the existing literature by examining associations between PA and social isolation in these two unique groups of PWD. As described in the previous section, both the Canadian and Dutch studies are unique, nationwide initiatives that may inspire other groups from across the world to initiative activities to improve PA levels in PWD (e.g., PA promotion in rehabilitation/hospital, conducting and disseminating research in partnership, publishing open-access, accessible reports). In addition to the new insights into differences between countries, cross-country comparative studies provide opportunities to inspire and learn from initiatives, and programs implemented in other countries. Cross-country comparative studies can promote and improve international collaborations between research groups.

A practical example of how international collaborations can enhance the impact of research findings and improve support to PWD is the implementation of the Canadian PA Coaching Service, called Get in Motion, in the Netherlands. Get in Motion is an evidence- based phone-based PA coaching service that was developed in 2008 to support people with spinal cord injury to engage in a PA [57]. At the start of the COVID-19 pandemic, the Get in Motion PA coaching service was re-launched to support Canadians with physical disabilities during the pandemic [58]. The service offers unique opportunities for people with physical disabilities to connect with volunteer coaches, and may also have positive impact on clients' general health and social isolation via these social connections. In the second year of the pandemic, the Dutch Ministry of Health, Welfare and Sports provided financial support to transfer the Get in Motion program to the Netherlands. Indeed, the service has now been adapted to the Dutch context and will be ready for official launch in the fall of 2022. In sum, the Dutch implementation of the Canadian Get in Motion service is a clear example of how international collaborations has the potential to improve research impact and enhance many lives of PWD. We encourage other groups to start and continue similar initiatives to enhance collaborations between countries across the world, including collaborations between low-, middle- and high-income countries.

Conclusions

This study provides a first insight into the negative impact of the COVID-19 pandemic on PA, social isolation, general health, mental health, and lifestyle changes among a diverse group of adults with physical disabilities living in Canada and the Netherlands. In both studies, a large part of participants reported a decrease in their PA since the start of the pandemic. In line with our hypotheses, our findings suggest that Canadian participants reported a greater negative impact than Dutch participants. These findings should be interpreted with caution, as the Dutch ReSpAct cohort is known as an active and motivated cohort and the Adapted SQUASH and the IPAQ PA questionnaires cannot be directly compared. Future research is needed to better understand if and how PA can be used to reduce social isolation in PWD. This study illustrates how cross-country collaborations and exchange provide opportunities to inspire and learn from initiatives and programs in other countries and may help to improve PA support among people with disabilities during and after the pandemic.

Supplementary Materials

The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/disabilities2040054/s1, File S1: Details on recruitment methods of ReSpAct 2.0 study; File S2: Selection of confounders; File S3: Figures of results, and File S4: Change in physical activity. References [59–65] are cited in the supplementary materials.

Author Contributions

Conceptualization, T.H., F.H., COVID-19 Disability Survey Group and the ReSpAct 2.0 Group; methodology, K.M., T.H. and F.H.; software, K.M., T.H. and F.H.; validation, all authors; formal analysis, K.M., T.H. and F.H.; investigation, K.M., P.B. and F.H.;

resources, COVID-19 Disability Survey Group and the ReSpAct 2.0 Group; data curation, K.M. and P.B., COVID-19 Disability Survey Group and the ReSpAct 2.0 Group; writing—original draft preparation, K.M.; writing—review and editing, all authors; visualization, K.M. and F.H.; supervision, T.H. and F.H.; project administration, COVID-19 Disability Survey Group and the ReSpAct 2.0 Group; funding acquisition, COVID-19 Disability Survey Group and the ReSpAct 2.0 Group. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement
The data that support the findings of this study are available on request from the corresponding author.

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Conflicts of Interest
The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Nederlandse samenvatting
Dankwoord
About the author
List of publications

Nederlandse samenvatting

Ongeveer 1,5 miljard mensen wereldwijd leven met enige vorm van beperking, met een hogere prevalentie bij ouderen. Door de vergrijzing zal het aantal mensen met een lichamelijke beperking en/of chronische ziekte blijven stijgen, terwijl tegelijkertijd de zorgcapaciteit, o.a. het aantal beschikbare zorgprofessionals, afneemt. Dit zorgt voor een toenemende druk op de zorg in het algemeen, en de revalidatiegeneeskunde in het bijzonder. Daardoor is gezondheidspreventie in elke vorm (van primaire tot tertiaire, en universele tot zorggerelateerde preventie) essentieel voor de toekomst van duurzame gezondheidszorg.

Het stimuleren van beweeggedrag kan een belangrijke rol spelen in alle vormen van preventie. Een actief beweeggedrag heeft namelijk voordelen voor cognitieve, mentale en fysieke gezondheid en voor de kwaliteit van leven van mensen met lichamelijke beperkingen en/of chronische ziekten. Ook vermindert of voorkomt een actief beweeggedrag lange termijn effecten en impact van een al bestaand gezondheidsprobleem. Helaas blijken mensen met een lichamelijke beperking en/of chronische ziekte vaak onvoldoende actief te zijn.

Revalidatie biedt een belangrijke kans op het initiëren en stimuleren van duurzaam beweeggedrag bij deze populatie. Revalidatieprogramma's gericht op het geven van persoonlijke counseling tijdens en vlak na revalidatie hebben de potentie om duurzaam beweeggedrag teweeg te brengen. Het Revalidatie, Sport en Bewegen (RSB) programma is zo'n revalidatieprogramma. Om dit landelijk geïmplementeerde RSB programma te evalueren is de multicenter longitudinale cohortstudie Revalidatie, Sport en Actieve leefstijl (ReSpAct) geïnitieerd. De oorspronkelijke vragenlijststudie (ReSpAct 1.0; 2013 - 2015) is uitgebreid met een aanvullend onderdeel (ReSpAct 2.0; 2021), waarbij dezelfde populatie van mensen met lichamelijke beperkingen en/of chronische ziekten tot 6-8 jaar na revalidatie is gevolgd in dit cohort. Deze ReSpAct (1.0 & 2.0) studie vormt de basis van dit proefschrift.

Ondanks de veelbelovende rol die revalidatieprogramma's zoals RSB hierbij kunnen spelen, is het ontwikkelen van duurzaam beweeggedrag nog steeds een grote uitdaging. Meer inzicht in het construct beweeggedrag bij mensen met een lichamelijke beperking en/of chronische ziekte, hoe dit gedrag zich ontwikkelt na revalidatie en welke determinanten hierin een rol spelen, is hiervoor noodzakelijk. Dit proefschrift heeft als doel om het construct beweeggedrag bij mensen met lichamelijke beperkingen en/of chronische ziekten uitgebreider te verkennen. Deze verkenning richt zich op drie specifieke thema's beschreven in de verschillende hoofdstukken, namelijk 1) de karakteristieken van het beweeggedrag; 2) de determinanten van het beweeggedrag; en 3) het meten van het beweeggedrag.

Beweeggedrag tot 1 jaar na revalidatie

Hoofdstuk 2 beschrijft het beweeggedrag van mensen met een lichamelijke beperking en/of chronische ziekte vanaf ontslag van revalidatie tot 1 jaar na revalidatie. De verschillende dosis-kenmerken (intensiteit, frequentie, duur, vorm en setting), de ontwikkeling van beweeggedrag over de tijd en de invloed van persoonlijke kenmerken op het beweeggedrag worden beschreven. De studie laat zien dat deelnemers aan het RSB programma in staat zijn hun beweeggedrag te versterken en dat grotendeels vast te houden in het eerste jaar na ontslag. Ook toont de studie aan dat het grootste deel van het beweeggedrag wordt verricht met een lichte intensiteit en in de huishoudelijke setting. De persoonlijke kenmerken leeftijd, sekse, BMI en opleidingsniveau hadden invloed op (de ontwikkeling van) het beweeggedrag. Jongere deelnemers, deelnemers van het vrouwelijk geslacht, en deelnemers met een lager BMI waren actiever. Verder nam het beweeggedrag meer toe over de tijd bij deelnemers met een hoger opleidingsniveau. Dit alles toont de grote diversiteit in het beweeggedrag van mensen met een lichamelijke beperking en/of chronische ziekte tot een jaar na ontslag van revalidatie, en geeft aanknopingspunten voor het verder ontwikkelen van beweeginterventies.

Om mensen met lichamelijke beperkingen en/of chronische ziekten beter te ondersteunen bij het ontwikkelen van actief beweeggedrag tijdens en na revalidatie, is het van belang om te weten welke determinanten van invloed zijn op het initiëren en onderhouden van een actief beweeggedrag. Gebaseerd op het theoretische *Physical Activity for people with a Disability (PAD) model*, richt **hoofdstuk 3** zich op psychosociale factoren die samenhangen met het beweeggedrag van deelnemers aan ReSpAct. Door gebruik te maken van hybride multilevel regressie modellen, zijn de effecten van zelfeffectiviteit, motivatie, sociale steun en houding (allen in relatie tot beweeggedrag) zowel tussen personen als binnen een persoon over de tijd geanalyseerd. Tussen personen bleken zelfeffectiviteit en intrinsieke motivatie voorspellers voor een actiever beweeggedrag; hoe sterker deze overtuigingen, hoe actiever de mensen (gemiddeld over tijd) zijn. Met betrekking tot effecten binnen een persoon: deelnemers die intrinsiek gemotiveerder raakten, vertoonden een sterkere toename in beweeggedrag. De relatie tussen de attitude ten opzichte van beweeggedrag en de mate van beweeggedrag bleek sterker bij deelnemers die hun beweeggedrag initiëren dan bij deelnemers die hun beweeggedrag onderhouden, waarbij mensen met een positievere attitude gemiddeld actiever zijn. Sociale steun had, in tegenstelling tot verwachtingen vanuit theorie en literatuur, geen associatie met beweeggedrag. Deze bevindingen tonen dat motivatie en zelfeffectiviteit belangrijke aangrijpingspunten kunnen zijn binnen de revalidatie om gedragsverandering te stimuleren.

Beweeggedrag 6 tot 8 jaar na revalidatie

Bij duurzaam actief beweeggedrag spreken we van gedrag dat op de lange termijn wordt onderhouden. Echter bij veel onderzoek worden deelnemers maar maximaal 1 jaar gevolgd. Om duurzaam beweeggedrag teweeg te brengen, is het ook van belang te begrijpen hoe het beweeggedrag verloopt en samenhangt met persoonskenmerken op de lange termijn. Daarom is in **hoofdstuk 4** gekeken naar het beweeggedrag van deelnemers van ReSpAct 6-8 jaar na ontslag uit de revalidatie. Deze studie laat zien dat de ontwikkeling van het beweeggedrag na revalidatie heterogeen is, en het beste kan worden beschreven door drie verschillende trajecten: 1) een stabiel matig actief traject (N=297); 2) een stabiel hoogactief traject (N=71); en 3) een toenemend actief traject (N=22). De studie laat ook zien dat de deelnemers van ReSpAct in alle drie trajecten in staat zijn een duurzaam beweeggedrag te ontwikkelen en te onderhouden 6 tot 8 jaar na revalidatie. De mate van ervaren vermoeidheid en ervaren barrières om actief te zijn ten tijde van ontslag van revalidatie waren belangrijke voorspellers tot welk traject iemand behoorde. Minder ervaren vermoeidheid en minder ervaren barrières verhoogden de kans om tot het hoogactieve traject te behoren. De bevindingen van deze unieke lange termijn studie wijzen op het belang van het integreren van adviezen over vermoeidheid en het bespreken van barrières tijdens de revalidatie voor het ontwikkelen van een duurzaam beweeggedrag.

Het meten van het beweeggedrag

Het meten van het beweeggedrag bij mensen met een lichamelijke beperking en/of chronische ziekte kan op twee verschillende manieren gedaan worden. Het kan gemeten worden met zelf gerapporteerde instrumenten zoals vragenlijsten en dagboeken, en met *device-based instrumenten* zoals accelerometers, smartwatches en stappentellers. Elk van deze instrumenten heeft zijn eigen voor- en nadelen. Bij zelf-gerapporteerde instrumenten speelt de individuele perceptie en interpretatie van beweeggedrag een belangrijke rol. Bij device-based instrumenten hebben met name de gebruikte instelling een bepalende rol. Om naast de zelf gerapporteerde manier van meten van beweeggedrag zoals gebruikt in **hoofdstuk 2-4** ook de device-based manier te belichten, wordt in **hoofdstuk 5** middels een scoping review de beschikbare literatuur omtrent de klinimetrische eigenschappen (validiteit, betrouwbaarheid en responsiviteit) van device-based instrumenten bij mensen met een lichamelijke beperking en/of chronische ziekte beschreven. Deze scoping review laat zien dat er grote variatie is in gebruikte instrumenten, analysemethoden en gerapporteerde uitkomsten in de beschikbare literatuur, wat vergelijking tussen studies moeilijk maakt. Verder blijkt uit de review dat het aantal gezette stappen de meest onderzochte uitkomstmaat van beweeggedrag is. Het aantal gezette stappen geeft echter maar een beperkt inzicht in het construct beweeggedrag. Als een meer multidimensionale uitkomstmaat wordt gebruikt, zoals energieverbruik of het aantal minuten per intensiteitsniveau, dan zijn de klinimetrische eigenschappen vaak minder goed. Dit is te verklaren doordat de algoritmes onderliggend aan deze uitkomstmaten voornamelijk ontwikkeld en gekalibreerd zijn met data van een gezonde populatie, waardoor ze minder geschikt zijn voor gebruik bij mensen met lichamelijke beperkingen en/of chronische ziekten. De bevindingen in deze scoping review benadrukken dat standaardisatie in onderzoeksopzet en analysemethoden nodig zijn in dit veld. Daarnaast laat het zien dat geen enkel instrument het volledige construct van beweeggedrag bij mensen met lichamelijke beperkingen en/of chronische ziekten adequaat weet te meten. Ook geeft de studie een aantal aanbevelingen voor toekomstig onderzoek naar de klinimetrische eigenschappen van device-based instrumenten bij mensen met lichamelijke beperkingen en/of chronische ziekten.

Discussie en conclusie

In **hoofdstuk 6** worden de resultaten van het proefschrift bediscussieerd en wordt er een algemene conclusie gegeven. Het proefschrift onderschrijft de complexiteit en multidimensionaliteit van het construct beweeggedrag bij mensen met een lichamelijke beperking en/of chronische ziekte, wat zowel fysiologische als gedragsmatige componenten omvat. Het proefschrift draagt bij aan het beter begrijpen van deze complexiteit. Het laat zien dat het beweeggedrag zeer heterogeen is tussen individuen, maar ook binnen individuen over tijd. Het toont aan dat persoonlijke en psychosociale factoren van invloed zijn op (de ontwikkeling van) het beweeggedrag. Daarnaast beschrijft en bediscussieert het proefschrift de verschillende manieren van het meten van het beweeggedrag, en hoe dit effect kan hebben op de interpretatie ervan.

Verder laten resultaten van dit proefschrift zien dat het grootste deel van de deelnemers van het RSB programma in staat zijn om duurzaam beweeggedrag op de lange termijn te ontwikkelen. Een veelbelovend resultaat, zeker omdat de dataverzameling van ReSpAct 2.0 plaatsvond tijden de COVID-19 pandemie, een periode waarvan deelnemers aangaven dat hun beweeggedrag negatief had beïnvloed. Dit onderstreept de belangrijke rol van revalidatie en persoonlijke counseling bij het ontwikkelen van een duurzaam beweeggedrag tijdens en na revalidatie. Daarnaast kunnen de bevindingen van dit proefschrift helpen bij het verder ontwikkelen van revalidatieprogramma's en interventies gericht op het stimuleren en ontwikkelingen van duurzaam beweeggedrag. We bevelen aan om in toekomstig onderzoek bij mensen met een lichamelijke beperking en/of chronische ziekte het beweeggedrag te onderzoeken door gebruik te maken van een combinatie van zelf-gerapporteerde en device-based instrumenten, en om meer aandacht te hebben voor de ervaringsaspecten (ofwel kwaliteit) van het beweeggedrag. Als vervolgstap, voor onderzoek in het algemeen en het RSB programma in het bijzonder, is het belangrijk om programma's uit te breiden van het bevorderen van duurzaam beweeggedrag naar het bevorderen een duurzame gezonde leefstijl, waarbij ook voeding, roken, alcoholgebruik, ontspanning en slaap worden meegenomen.

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About the author

Pim Brandenbarg was born on Oktober 18th, 1990 in Hengelo (o), the Netherlands. In 2009 he graduated from secondary school at Twickel College in Hengelo. From 2009 to 2015 Pim studied Human Movement Sciences at the University of Groningen. He obtained his Master of Science in Human Movement Sciences with a specialization in rehabilitation and functional recovery. His master thesis focused on walking adaptations during an obstacle avoidance task and the influence of spatiotemporal information.

In 2017, Pim briefly worked at the department of Primary and Long-term Care of the University Medical Center Groningen. He worked as a junior researcher on a pilot research-project focused on the development of a self-management tool for male patients with lower urinary tract symptoms. He combined this with a research assistant function for the OPTion-study, a project on shared-decision making in palliative oncology care, at the same department.

In 2018, Pim started his PhD in the research project ReSpAct, a collaboration between the department of Human Movement Science and department of Rehabilitation Medicine - Center for Rehabilitation of the University Medical Center Groningen. During his PhD, Pim explored the construct of physical activity behavior among people with physical disabilities and/or chronic diseases, with a focus on the characteristics, determinants and measurement of the construct. This resulted in the current thesis, and 4 internationally published scientific papers.

Since 2023, Pim works as a Health Controller at the department of finance and healthcare administration of the Martini Ziekenhuis.

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