OULU 2021
D 1607

ACTA UNIVERSITATIS OULUENSIS

Anna-Maiju Leinonen

TECHNOLOGY FOR PROMOTING PHYSICAL ACTIVITY IN YOUNG MEN

*UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF MEDICINE;
INFOTECH OULU;
MEDICAL RESEARCH CENTER OULU;
OULU UNIVERSITY HOSPITAL;
OULU DEACONESS INSTITUTE FOUNDATION SR*

ACTA UNIVERSITATIS OULUENSIS
D Medica 1607

ANNA-MAIJU LEINONEN

TECHNOLOGY FOR PROMOTING PHYSICAL ACTIVITY IN YOUNG MEN

Academic dissertation to be presented with the assent of the Doctoral Training Committee of Health and Biosciences of the University of Oulu for public defence in the Leena Palotie auditorium (101A) of the Faculty of Medicine (Aapistie 5 A), on 16 April 2021, at 12 noon

UNIVERSITY OF OULU, OULU 2021

Acta Univ. Oul. D 1607, 2021

Supervised by
Professor Timo Jämsä
Professor Raija Korpelainen
Doctor Riikka Ahola

Reviewed by
Docent Mika Tarvainen
Professor Corneel Vandelanotte

Opponent
Docent Katja Borodulin

ISBN 978-952-62-2886-0 (Paperback)
ISBN 978-952-62-2887-7 (PDF)

ISSN 0355-3221 (Printed)
ISSN 1796-2234 (Online)

Cover Design
Raimo Ahonen

PUNAMUSTA
TAMPERE 2021

Leinonen, Anna-Maiju, Technology for promoting physical activity in young men.
University of Oulu Graduate School; University of Oulu, Faculty of Medicine; Infotech Oulu; Medical Research Center Oulu; Oulu University Hospital; Oulu Deaconess Institute Foundation sr.
Acta Univ. Oul. D 1607, 2021
University of Oulu, P.O. Box 8000, FI-90014 University of Oulu, Finland

Abstract

Although the health benefits of physical activity (PA) are well known, the majority of adolescents are not sufficiently physically active. New innovative ways to promote active lifestyles are needed. This study aimed to evaluate the effectiveness of a wrist-worn activity monitor (Polar Active) and a gamified web-based mobile service in promoting PA in young men. The study also examined the convergent validity between three different accelerometer-based PA measurement methods.

In this study, two randomized controlled trials (RCT) were conducted in Oulu, Finland among 18-year-old men. The three-month RCT (n=276) was conducted in fall 2012 and the six-month population-based RCT (n=496) between September 2013 and March 2014. In both trials, participants were randomized to an intervention and a control group. The intervention group was given the wrist-worn Polar Active monitor with PA feedback. In the six-month trial, the intervention group also got access to a mobile service developed in this study. During both trials, PA was continuously measured in both study groups. In the control group, PA was measured with an otherwise similar monitor but which provided only the time of day and no feedback. The convergent validity was examined between the agreement in time spent at different PA levels using Polar Active, mean amplitude deviation (MAD) of raw acceleration, and Actigraph with the Freedson thresholds. In the validation study, all three activity monitors were continuously used for two weeks by 41 volunteers.

The three-month trial had a short-term positive effect on daily moderate-to-vigorous PA (MVPA) and sedentary time in the intervention group. The positive change in sedentary time was sustained for longer. During the six-month trial, a positive trend in favor of the intervention group was observed in daily MVPA. Low amount of daily vigorous PA at baseline was associated with the increase in MVPA. The functionalities of the mobile service related to PA were perceived as important and motivating, but the overall compliance with using the service and activity monitor remained low. In free-living conditions, the agreement between Polar Active, MAD, and Actigraph was dependent on the activity thresholds used and PA intensity. The information provided by this study can be utilized in future development of technology-based health services for activating young people.

Keywords: activity monitor, adolescent, behavior change, gamification, health, sedentary behavior, self-monitoring

Leinonen, Anna-Maiju, Teknologian hyödyntäminen nuorten miesten fyysisen aktiivisuuden lisäämisessä.
Oulun yliopiston tutkijakoulu; Oulun yliopisto, Lääketieteellinen tiedekunta; Infotech Oulu; Medical Research Center Oulu; Oulun yliopistollinen sairaala; Oulun Diakonissalaitoksen säätiö sr.
Acta Univ. Oul. D 1607, 2021
Oulun yliopisto, PL 8000, 90014 Oulun yliopisto

Tiivistelmä

Vaikka fyysisen aktiivisuuden terveysvaikutukset ovat hyvin tiedossa, valtaosa nuorista ei liiku riittävästi. Tarvitaan uusia menetelmiä edistämään nuorten aktiivista elämäntapaa. Tämän tutkimuksen tarkoituksena oli selvittää ranteessa pidettävän aktiivisuusmittarin ja pelillistetyn mobiilipalvelun vaikutus nuorten miesten fyysiseen aktiivisuuteen. Lisäksi tutkittiin kolmen eri kiihtyvyysmittaukseen perustuvan aktiivisuusmittausmenetelmän yhtenevyyttä.

Tutkimuksessa toteutettiin kaksi satunnaistettua, kontrolloitua interventiota, oululaisilla 18-vuotiailla miehillä. Kolmen kuukauden interventio (n=276) toteutettiin syksyllä 2012 ja 6 kuukauden väestöpohjainen interventio (n=496) syyskuun 2013 ja maaliskuun 2014 välillä. Molemmissa interventioissa osallistujat satunnaistettiin interventio- ja kontrolliryhmään. Interventioryhmä sai käyttöönsä aktiivisuusmittarin, joka antoi palautetta aktiivisuudesta. Lisäksi 6 kuukauden interventiossa interventioryhmä sai käyttöönsä tutkimuksessa kehitetyn mobiilipalvelun. Molemmissa interventioissa kaikkien tutkittavien fyysistä aktiivisuutta mitattiin jatkuvasti. Kontrolliryhmä ei saanut aktiivisuuspalautetta. Aktiivisuusmittausmenetelmien yhtenevyyttä fyysisen aktiivisuuden eri tasoilla vietetyn ajan mittaamisessa tutkittiin vertaamalla Polar Active -mittaria, kiihtyvyyssignaalin perustuvaa menetelmää (mean amplitude deviation, MAD) ja Actigraph-mittaria Freedsonin raja-arvoilla. Neljäkymmentäyksi vapaaehtoista käytti kaikkia kolmea mittaria samanaikaisesti kahden viikon ajan.

Kolmen kuukauden interventiolla oli lyhytaikainen positiivinen vaikutus kohtuukuormitteisen tai raskaan fyysisen aktiivisuuden ja paikallaanolon määrään. Paikallaanolon muutos säilyi pidempään. Kuuden kuukauden interventiossa havaittiin interventioryhmässä pieni, ei-merkitsevä nousu kohtuukuormitteisessa tai raskaassa aktiivisuudessa. Aktiivisuus lisääntyi intervention aikana niillä miehillä, joilla alussa oli vähän raskasta fyysistä aktiivisuutta. Mobiilipalvelun ja aktiivisuusmittarin käyttö oli vähäistä, vaikka fyysiseen aktiivisuuteen liittyvät palvelun ominaisuudet koettiin tärkeiksi. Polar Activen, MAD:n ja Actigraphin välinen yhtenevyys oli riippuvainen käytetyistä raja-arvoista ja fyysisen aktiivisuuden intensiteetistä. Tämän tutkimuksen tietoja voidaan hyödyntää teknologiapohjaisten terveyspalveluiden kehittämisessä nuorten aktivoimiseksi.

Asiasanat: aktiivisuusmittari, itsetarkkailu, käyttäytymisen muutos, paikallaanolo, pelillistäminen, terveys

To my family and friends

Acknowledgements

This work was conducted at the Research Unit of Medical Imaging, Physics, and Technology at the University of Oulu, in close association with the Department of Sports and Exercise Medicine at the Oulu Deaconess Institute during the years 2012–2021.

I wish to express my deepest gratitude to all my supervisors, Professor Timo Jämsä, Professor Raija Korpelainen, and PhD Riikka Ahola for the guidance and advice I received along the way. Timo, from you I have received help and advice whenever I have needed them. Thank you also for your understanding and support at different turning points in my life. Raija, your positive attitude and enthusiasm is contagious. You, if anyone, see opportunities instead of obstacles. Riikka, thank you for always keeping your door open ready to help in the early years of my dissertation project, even though sometimes requests for help came at a brisk pace.

I want to thank all the people who were involved in conducting the pilot study of 46-year data collection of NFBC1966. I wish to thank my co-authors in the article related to the pilot study: Janne Kulmala, Harto Hakonen, Henri Vähä-Ypyä, Karl-Heinz Herzig, Juha Auvinen, Sirkka Keinänen-Kiukaanniemi, Harri Sievänen, and Tuija Tammelin. Special thanks to the people of LIKES and UKK institute for their help in analyzing the activity data. I would like to thank the study nurses, especially Anu Outinen-Tuuponen, for their efforts in the field work during the data collection. I warmly thank the entire MOPO study group for wonderful shared moments over the years. I want to thank my co-authors in the articles related to the MOPO project: Riitta Pyky, Maarit Kangas, Pekka Siirtola, Tim Luoto, Heidi Enwald, Tiina Ikäheimo, Juha Röning, Sirkka Keinänen-Kiukaanniemi, Matti Mäntysaari, and Paula Virtanen. Riitta, special thanks to you for your cooperation and peer support during the dissertation project. The study participants of both studies, the pilot study of NFBC1966 as well as the MOPO study, are also greatly acknowledged.

I wish to thank the members of my follow-up group Simo Saarakkala, Hannu Rintamäki, and Eero Kyllönen for their support and good discussions. I am very grateful to the pre-examiners of this thesis Corneel Vandelanotte and Mika Tarvainen for their valuable comments that further improved the manuscript. Risto Bloigu and Pentti Nieminen are acknowledged for statistical advice.

I would like to warmly thank all the members of the prior Department of Medical Technology (current MIPT) during the years, especially Riikka, Maarit, Mikko, Päivi, Jana, and Maisa. I am grateful for the help received from you, as well as conversations and laughs I have got to share with you. I want to thank my old friends for their support and company. The girls from Keminmaa - let's get together soon. Thank you especially Kakku, Sanna, Hanna, Anne, and Mirka for being listening ears in moments of both joy and worry. Hilkka, thank you for your friendship during our master's studies and afterwards. I started my occupational therapy studies during my dissertation project. Those studies brought a more people-oriented perspective to my skills and a real dose of wonderful moments with fellow students. Thank you especially Hanna, you have inspired and encouraged me in an invaluable way.

I want to thank my dear relatives. It is fortunate to be part of our great large family. I thank Riitta and Jouni, my parents-in-law, for encouragement and support. I wish to express my dearest thanks to my loving parents Liisa and Ari and my brothers and their families. Antti and Tuomas, thank you for taking care and looking after your little sister. Maria, the help you have given me during my studies has ranged from contacting books to revision of the language, thank you for your support. Mom and dad, love is deeds and you know how to do them, thank you for everything.

Finally, my loving thanks go to my own little family. Kalle, thank you for your love and support. Sometimes my not-so-good sides are also visiting at our home, thank you for letting them in. The joy of my days, Aatos and Eelis, while looking at this book you know what mom has been doing while working, or while I "titittelin" as you say it. Thank you for showing me what is really important in life. You have also taught me what true perfection is and where you can even expect to find it.

This study was financially supported by Infotech Oulu, the Health and Biosciences Doctoral Programme of the University of Oulu Graduate School, the Ministry of Education and Culture, the Finnish Cultural Foundation, the Juho Vainio Foundation, the Northern Ostrobothnia Hospital District, the Finnish Centre for Military Medicine, the European Social Fund, the European Regional Development Fund, and the Finnish Funding Agency for Technology and Innovation.

In Oulu, February 2021 Anna-Maiju Leinonen

Abbreviations and symbols

ρ	Spearman rank correlation coefficient
ANOVA	analysis of variance
AUC	area under (an ROC) curve
BMI	body mass index
ΔC	change in capacitance
c	control group
CI	confidence interval
CO_2	carbon dioxide
DLW	doubly labeled water technique
EE	energy expenditure
e.g.	exempli gratia
F	female
GEE	generalized estimation equation
GPS	global positioning system
g	gravitation unit, 1 g = 9.81 ms^{-2}
H	hydrogen
ICC	intra-class correlation coefficients
i.e.	id est
int	intervention group
LPA	light physical activity
M	male
MAD	mean amplitude deviation
MET	metabolic equivalent
MPA	moderate physical activity
MVPA	moderate-to-vigorous physical activity
N	number of subjects
NFBC1966	Northern Finland Birth Cohort 1966
O_2	dioxygen
O	oxygen
p	p value
PA	physical activity
R	Pearson's correlation coefficient
RCT	randomized controlled trial
ROC	receiver operating characteristics
SD	standard deviation

ST	sedentary time
TTM	transtheoretical model
VPA	vigorous physical activity

List of original publications

This thesis is based on the following publications, which are referred to throughout the text by their Roman numerals:

I Leinonen, A-M., Ahola, R., Kulmala, J., Hakonen, H., Vähä-Ypyä, H., Herzig, K-H., Auvinen, J., Keinänen-Kiukaanniemi, S., Sievänen, H., Tammelin, T., Korpelainen, R., & Jämsä, T. (2017). Measuring physical activity in free-living conditions – Comparison of three accelerometry-based methods. Frontiers in Physiology, 7:681. doi: 10.3389/fphys.2016.00681

II Jauho, A-M., Pyky, R., Ahola, R., Kangas, M., Virtanen, P., Korpelainen, R., & Jämsä, T. (2015). Effect of wrist-worn activity monitor feedback on physical activity behavior: A randomized controlled trial in Finnish young men. Preventive Medicine Reports, 2: 628–634. doi:10.1016/j.pmedr.2015.07.005

III Leinonen, A-M., Pyky, R., Ahola, R., Kangas, M., Siirtola, P., Luoto, T., Enwald, H., Ikäheimo, TM., Röning, J., Keinänen-Kiukaanniemi, S., Mäntysaari, M., Korpelainen, R., & Jämsä, T. (2017). Feasibility of gamified mobile service aimed at physical activation in young men: a population-based randomized controlled MOPO study. Journal of Medical Internet Research mHealth and uHealth, 5(10):e146. doi:10.2196/mhealth.6675

Contributions in the publications: For publication I, I participated in coordinating physical activity data collection and analyzing the data, and I wrote the first draft of the manuscript. For publications II and III, I participated in the planning and conducting of the trials and was responsible for the data analysis and writing the first draft of the manuscripts.

Contents

1 Introduction

Physical activity (PA) provides a large range of health benefits. It reduces the risk of developing several non-communicable diseases and improves functional ability (Lee et al., 2012). Even light-intensity PA can confer health benefits, especially among inactive people (Füzéki, Engeroff, & Banzer, 2017). In addition, sedentary behavior has been proven to have its own unfavorable effects on health (Katzmarzyk, 2010; Tremblay, Colley, Saunders, Healy, & Owen, 2010).

Despite the well-known benefits, recent evidence consistently demonstrates that the majority of young people do not meet the current PA recommendations of at least 60 minutes of moderate-to-vigorous PA each day (Husu, Vähä-Ypyä, & Vasankari, 2016; Van Hecke et al., 2016). Further, among young people in Finland, a marked decline in PA levels, especially among young males, has been identified after the age of 12. At the same time, sedentary time has been shown to have increased. (Husu et al., 2016; Liukkonen et al., 2014) In Finland, physical fitness of young male conscripts has also decreased during recent decades (Santtila, Pihlainen, Koski, Vasankari, & Kyröläinen, 2018). The transition from adolescence to adulthood is an important stage of life to intervene with PA motivation, in order to prevent negative changes in PA behavior and health in the future (Tammelin, Näyhä, Laitinen, Rintamäki, & Järvelin, 2003; Telama et al., 2005). Thus, promoting an active lifestyle among young men by increasing their PA of any intensity and decreasing sedentary time is very important from a public health point of view.

An accurate but at the same time feasible measurement method is an important part of PA studies in order to better understand the effect of PA behavior on health, as well as to examine the frequency and distribution of PA in different populations and the effects of PA interventions. The use of accelerometer-based activity monitors for measuring daily PA behavior objectively in free-living conditions has significantly increased over the last few decades (Bassett, Troiano, Mcclain, & Wolff, 2014; Corder, Ekelund, Steele, Wareham, & Brage, 2008). Despite their extensive use, accelerometers are also associated with limitations, e.g., data collection is dependent on the attachment site and wear time compliance, and standard methods for data reduction and analysis are missing (Butte, Ekelund, & Westerterp, 2012; Troiano, McClain, Brychta, & Chen, 2014).

Among young people, technology plays a significant role in different areas of life such as in education, leisure activities, and socialization. Thus, utilizing technology to promote an active lifestyle is a natural choice as a method in this population. Self-monitoring of PA using an activity tracker has been found to be an effective behavior change strategy for increasing PA (Bravata et al., 2007; Conroy et al., 2011; Lubans, Morgan, & Tudor-Locke, 2009). Studies concerning the independent role of continuous feedback provided by accelerometers as a mean to promote PA or reduce sedentary time among adults are available (Godino et al., 2013; Van Hoye, Boen, & Lefevre, 2015), but the number of studies conducted among young people is still low.

In previous studies, web-based services and mobile apps have been utilized for promoting PA behavior. The general challenges with these intervention methods have been the poor engagement and retention of participants, especially among young people, and relatively small and short-lived intervention effects (Flores-Mateo, Granado-Font, Ferré-Grau, & Montaña-Carreras, 2015; Hamel, Robbins, & Wilbur, 2011). In many previous studies, control group design and objective measurement of PA have not been used, leading to limited quality (Bort-Roig, Gilson, Puig-Ribera, Contreras, & Trost, 2014; Lau, Lau, Wong, & Ransdell, 2011). In addition, the lack of interventions targeted at young people, especially at young boys, has been highlighted (Ashton, Hutchesson, Rollo, Morgan, & Collins, 2014; Hamel et al., 2011; Schoeppe et al., 2016). Gamification, referring to the use of game design techniques, game principles, and mechanics in non-game contexts, is one of the latest strategies used for fitness and health-related services to improve user experience and engagement (King, Greaves, Exeter, & Darzi, 2013).

The first part of this thesis aimed to examine the convergent validity between three different accelerometer-based PA measurement methods (study I). Study I was conducted as part of the pilot study of the 46-year data collection of the Northern Finland Birth Cohort 1966. The second part aimed to evaluate the feasibility and effectiveness of a wrist-worn activity monitor with activity feedback (study II) and an automated gamified web-based mobile service (study III) in promoting PA behavior among young men. The second part of this thesis is related to the population-based MOPO project, the goal of which was to prevent marginalization and promote PA and health in young Finnish men (Ahola et al., 2013).

2 Review of the literature

2.1 Physical activity and sedentary behavior

2.1.1 Definition of physical activity

Traditionally, physical activity (PA) is defined as any bodily movement produced by the contraction of skeletal muscles and resulting in energy expenditure (EE) (Caspersen, Powell, & Christenson, 1985). Depending on whether PA is planned or not, it can be classified as structured or incidental activity. Structured PA is a planned event such as an exercise session, while incidental PA is usually the consequence of daily activities (e.g., housework or transport). (Caspersen et al., 1985) An important part of PA is the domain where PA occurs. The most common PA domains are leisure time, occupational, domestic, and transport (Strath et al., 2013).

PA is multidimensional construct and it consists of the different dimensions which are type, duration, frequency, and intensity of activity (Strath et al., 2013). The type of PA can refer to specific mode of activity such as walking or cycling or, on the other hand, to the context of physiological and biomechanical demands of activity (e.g., aerobic, strength, and flexibility). Duration is the time spent participating a PA session and it is usually expressed in minutes, while frequency of PA describes how often a PA session occurs during a specific time period, and intensity refers to the rate of EE when being physically active (Strath et al., 2013; World Health Organization, 2010).

By using duration, frequency, and intensity of PA, a total volume of PA per specific time period, typically one day or a week, can be estimated (Bassett et al., 2014). The total volume of PA can simply be counted by multiplying these three PA dimensions over a given time period (Strath et al., 2013). This single metric may enhance comparisons between results of different research studies. However, the separate activity variables are also needed in addition to the total volume, in order to better understand the various characteristics of PA and its relation to health. (Bassett et al., 2014)

2.1.2 Intensity of physical activity

Based on EE, the intensity of PA can be expressed either in estimates of kilocalories burnt or by using the unit of metabolic equivalent of task (MET). One MET reflects the resting metabolic rate obtained while sitting quietly. For an adult the amount of oxygen consumption at rest is approximately 3.5 ml O_2/kg/min, i.e., 1 MET. (Ainsworth et al., 2011)

PA can be classified into different intensity categories by produced MET values. The typically used categories are sedentary behaviors and light, moderate, and vigorous PA (Garber et al., 2011). Some variation exists between the used MET based thresholds for different PA categories, but usually sedentary behavior refers to the PA in which the consumption of energy is ≤1.5 METs. Sedentary behavior includes activities such as sitting, lying down, and watching television. The difference between the terms sedentary behavior and physical inactivity is important to notice. While sedentary behavior refers to any waking behavior with a low amount of EE in a sitting or reclining position, physical inactivity refers to an insufficient amount of PA. (Tremblay et al., 2017) The second lowest activity category, i.e., light PA (LPA) is usually defined as 1.5–3 METs including activities such as standing still, slow walking, and household activities. Moderate PA (MPA) involves EE at the level of 3–6 METs and vigorous PA (VPA) at the level of 6 METs or more. (Norton, Norton, & Sadgrove, 2010) The sum of MPA and VPA, i.e., moderate-to-vigorous PA (MVPA) is specified in the PA recommendations and is therefore a common variable to describe activity.

2.1.3 Physical activity and health in young people

Nowadays it is well known that PA associates with an overall healthier lifestyle (Lee et al., 2012; World Health Organization, 2010). Regular PA has been shown to prevent many diseases, such as cardiovascular diseases, diabetes, certain cancers, and depression (Ekelund et al., 2012; Lee et al., 2012; Warburton, Nicol, & Bredin, 2006; Sieverdes et al., 2012). PA also has other positive effects, such as increased physical fitness as well as improved bone health and cognitive function (Jämsä, Vainionpää, Korpelainen, Vihriälä, & Leppäluoto, 2006; Ross & McGuire, 2011; Esteban-Cornejo, Tejero-Gonzalez, Sallis, & Veiga, 2015). In addition to MVPA, LPA can also confer health benefits (Füzéki et al., 2017). Among young people, LPA is most clearly associated with cardiometabolic biomarkers (Poitras et al., 2016). Even a small increase in overall daily PA and an increase in LPA have been shown to have positive effects on health (Ekelund et al., 2015; Katzmarzyk, 2014; Wen et al., 2011). PA level has been found to be affected by various social-environmental (e.g., built and natural environment as well as peer/parent support) (Deliens, Deforche, De Bourdeaudhuij, & Clarys, 2015; Kantomaa, Tammelin, Näyhä, & Taanila, 2007; Schoeppe et al., 2017) and biological (e.g., sex hormones and genes) (Lightfoot et al., 2018) factors. Adolescence is an important stage of life because during that period many long-term behavior patterns, including PA behavior, are adopted. In addition, PA in adolescence has both direct and indirect effects on health status as an adult. (Hallal, Victora, Azevedo, & Wells, 2006; Tammelin et al., 2003; Telama et al., 2005)

To maintain health through regular PA, children and young people aged 5–17 years should accumulate 60 minutes or more of MVPA a day. For adults (18–64 years old) it is recommended to accumulate 30 or more minutes of MPA at least five days per week (i.e., 150 minutes in total) or at least 75 minutes of VPA throughout the week. (World Health Organization, 2010) PA recommendations have recently been updated in many countries and the requirement for 10-minute activity bouts has been removed (Piercy et al., 2018). In most European countries, less than 50% of young people meet the PA recommendation, younger children being more active than adolescents (Husu et al., 2016; Van Hecke et al., 2016). According to the review article of Hallal et al. (2012), 80% of adolescents aged 13–15 years do not meet the global PA recommendation based on self-reports. The corresponding result was 60–70% in another review in which the age range varied from 11 to 18 years (Ekelund, Tomkinson, & Armstrong, 2011).

In Finland, a significant decrease in PA has been observed after the age of 12, while 50% of all primary school children (7–12 years) meet the PA recommendations, but among students at lower secondary level (13–16 years) the proportion is only 17% (Ministry of Social Affairs and Health, 2013; Telama & Yang, 2000). Furthermore, among students aged 16–19 years only 9% reach the global recommendations (Ministry of Social Affairs and Health, 2013). A secular decrease in time spent in MVPA in recent decades among adolescents has been reported by several research groups (Knuth & Hallal, 2009; Sigmundová, El Ansari, Sigmund, & Frömel, 2011; Thompson et al., 2009). However, Ekelund et al. (2011), for example, did not confirm this notion in their review. Providing an overview and defining secular changes concerning population levels of PA is challenged by variation in assessment methods and outcome variables used in different studies (Van Hecke et al., 2016).

2.1.4 Sedentary behavior and health in young people

Sedentary behavior has been proven to have its own unfavorable effects on health (e.g., through metabolism and vascular health), and thus, in addition to the amount of daily PA, attention should be paid to sedentary time (Katzmarzyk, 2010; Matthews et al., 2015; Tremblay et al., 2010). Many studies have stated that the association between sedentary time and health is independent of the amount of daily PA (Koster et al., 2012; Santos et al., 2013; Van Der Ploeg, Chey, Korda, Banks, & Bauman, 2012), however, MVPA time has been shown to have some level of protective effect (Chau et al., 2013; Ekelund et al., 2015; Ekelund et al., 2016; Matthews et al., 2012).

One of the most prevalent subcategories of sitting time is time spent watching television. According to a systematic review (Tremblay et al., 2011) watching television for over two hours a day leads to adverse health effects among children and adolescents. The association between television viewing and mortality have been found to be even stronger than the association for overall sitting time (Matthews et al., 2012). However, different definitions of sedentary behavior used in research and a lack of longitudinal studies with objective assessment challenge studies related to the health effects of sitting (Gibbs, Hergenroeder, Katzmarzyk, Lee, & Jakicic, 2015; Stamatakis et al., 2019). There is no global recommendation for daily sedentary behavior time because the risk related to sedentary behavior may be dependent on the amount of daily PA. However, the general view is that prolonged sitting should be avoided. (Kahlmeier et al., 2015).

Sedentary behavior has been shown to increase with age among children and young people. In addition to age, factors affecting higher sedentary behavior in youth are lower socioeconomic status and higher number of consumer electronics at home. (Pate, Mitchell, Byun, & Dowda, 2011) According to the study conducted in Finland, children aged 7-14 years spent over half of their waking hours (7.3 hours as total) sedentary (Husu et al., 2016). In the United States older adolescents aged 16–19 years (together with older adults) are sitting on average more than the rest of the population, spending approximately 8 hours a day in sedentary behavior (Matthews et al., 2008).

2.2 Measurement of physical activity behavior

PA and sedentary behavior can be measured using either subjective or objective methods. Accurate measurement methods are important in order to better understand the frequency and distribution of PA in different populations and the effect or even the dose-response of PA behavior on health. Also, the intra- and inter-individual changes in PA and sedentary behavior over time are important variables e.g., to examine the effects of PA interventions. (Atkin et al., 2012; Corder et al., 2008; Trost, Pate, Freedson, Sallis, & Taylor, 2000)

2.2.1 Subjective methods

Subjective methods have traditionally been used for estimating PA. Those refer to self-reporting methods such as questionnaires, diaries, and behavioral logs as well as to interviews. While using subjective methods participants are usually asked to either recall their PA behavior during a certain time period in the past or to report their usual activity behavior. (Kohl III, Fulton, & Caspersen, 2000)

Subjective methods are inexpensive, easy to use, and have relatively low participant burden. In addition, subjective methods provide valuable information concerning the type and context of behavior. Therefore, those methods are still widely used, especially in large epidemiological studies. (Atkin et al., 2012; Kohl III et al., 2000) However, subjective methods have been shown to overestimate the amount of daily PA and underestimate the amount of LPA and sedentary time (Cerin et al., 2016; Shephard, 2003). In addition, recall bias, misinterpretation, and social desirability can affect the results of self-administered methods (Adams et al., 2005; Prince et al., 2008).

2.2.2 Objective methods

Objective methods use the measurement of at least one physiological or biomechanical parameter for estimating PA metrics. Objective methods include wearable monitors, such as pedometers, accelerometers, heart rate monitors, foot-contact monitors, and combined sensors, as well as indirect calorimetry and the doubly labeled water (DLW) method. Also direct observation, which means witnessing PA behavior either in real time or on a videotape, can be seen as an objective measurement method as it relies on information giving by another person. (Butte et al., 2012; Corder et al., 2008; Kohl III et al., 2000) By using objective methods it is possible to get more comprehensive information about the PA behavior of a person compared to subjective methods. The common indicators of PA which can be measured by objective methods with varying accuracy include the following (Butte et al., 2012; Matthews et al., 2012):

1. Total PA
2. Duration, frequency, and intensity of PA
3. Time spent at different intensity levels (sedentary, light, moderate, vigorous)
4. Time spent in different postures/locomotive activities (lying, sitting, standing, walking, running)
5. Distribution of PA during the day
6. Energy expenditure
7. Number of steps taken

With the help of the Global Positioning System (GPS), it is possible to determine speed as well as exact route and distance traveled. With GPS, the contextual information of outdoor activities can also be added to the results (Butte et al., 2012). While there are several different objective methods to measure PA, the decision concerning the selected monitor or method depends on research questions, target population as well as costs and logistics (Butte et al., 2012; Matthews et al., 2012). Also, measurement time and data management options affect the choice of measurement method (Hills, Mokhtar, & Byrne, 2014).

Although objective methods are commonly used to increase accuracy in the research field of PA compared to subjective methods, each of the objective methods have their own limitations. Those can be expensive, intrusive, require specialized training and the physical proximity of the participant, or might have risks of equipment failure or loss. One problem with the current objective methods is also the fact that they are not measuring identical properties or components of PA making the comparison between study results complicated. (Kohl III et al. 2000, Prince et al. 2008)

Pedometers

A pedometer is usually worn on the belt or waistband and it measures the number of daily steps taken by a person. The function of a pedometer can be based either on the use of a horizontal spring-suspended lever arm which moves along each step, or on a piezoelectric accelerometer mechanism that responds to vertical accelerations. The benefits of pedometers are their small size, low cost, low participant burden, ease of use, and simple nature of its output. (Tudor-Locke, Bassett, Shipe, & McClain, 2011) The traditionally used goal for daily steps is 10,000 for maintaining health (Hills et al., 2014). In recent years, it has been stated that positive health effects are achieved even with a smaller number of daily steps

(I. Lee et al., 2019). The limitations of pedometers are their inability to detect horizontal or upper body movement or the intensity of PA, limited validity for estimating EE, and the fact that the results of different pedometers are not comparable (Butte et al., 2012). While pedometers are most accurate at step counting, they should be used for monitoring ambulatory activities instead of trying to estimate distance or EE (Butte et al., 2012; Tudor-Locke et al., 2011).

Accelerometers

The use of accelerometer-based activity monitors for measuring PA objectively in free-living conditions has significantly increased, now being the most commonly used objective measurement method (Bassett et al., 2014; Corder et al., 2008). There is a number of different kinds of accelerometers with different attachment options available. Widely used brands in research include Actigraph, ActiHeart, ActivPAL, SenseWear, and GENEActive, with the different models of Actigraph being the most commonly used accelerometers in the research field of PA. (Bassett et al., 2014; Plasqui, Bonomi, & Westerterp, 2013)

Accelerometers are user-friendly, noninvasive, wireless, small, lightweight, and relatively low-cost. In addition, the power consumption of accelerometers is low, they do not interfere with daily PA and they are also able to capture short bouts of PA as well as incidental PA performed at lower intensity levels. (Bassett et al., 2014; Butte et al., 2012; Chen & Bassett Jr., 2005; Matthews, Hagströmer, Pober, & Bowles, 2012) Current technology enables the capture and storage of high-resolution raw acceleration signals, which further allow for the utilization of more advanced signal analysis (Troiano et al., 2014).

Despite their extensive use, accelerometers are also associated with limitations, such as the inability to identify body posture by most attachment sites, the inability to recognize the load exerted on the body by certain forms of exercise (e.g., weightlifting or hill walking), and a lack of information about the location or purpose of activities. In addition, data collection is dependent on attachment site and wear time compliance, and standard methods for data reduction and analysis are missing. (Butte et al., 2012; Matthews et al., 2012; Skender et al., 2016)

Heart rate and multi-unit monitors

Heart rate monitoring is also used for assessing PA. The measurement is based on the well-known linear relationship between heart rate and oxygen uptake during moderate-to-high intensity activities. By using heart rate, it is possible to evaluate EE as well as intensity, frequency, and duration of activity. The ease of data collection and small size are the strengths of the method. (Freedson & Miller, 2000) Heart rate is also useful during those activities in which an accelerometer has its challenges, such as during cycling and hill walking (Corder et al., 2008). Nowadays heart rate can also be measured optically, for example from the wrist, as an alternative to traditional ECG-based methods using a chest strap (Horton, Stergiou, Fung, & Katz, 2017). However, there are some restrictions that prevent the use of the method. It has been shown that the relationship between heart rate and EE is poor at low intensity activity levels. In addition, the method requires individual calibration, data processing is demanding, and there are other factors such as temperature, high humidity, some drugs, and stress that affect heart rate. (Butte et al., 2012; Corder et al., 2008; Freedson & Miller, 2000)

Multi-unit monitors refer to methods that combine one or more sensors to achieve an even more comprehensive picture of PA behavior. With these methods PA can be measured by using multiple accelerometers on different body parts or by combining an accelerometer with, e.g., an inclinometer or a heart rate or temperature sensor. Although the combination of sensors provides more comprehensive information, their use is limited by greater cost, battery and memory capacity, and demanding data processing. In addition, validation studies in free-living condition are limited. (Atkin et al., 2012; Brage et al., 2015; Butte et al., 2012)

Indirect calorimetry and doubly labeled water

Indirect calorimetry evaluates EE by measuring oxygen (O_2) consumption and/or carbon dioxide (CO_2) production, which result from the energy metabolism of the human body. For example, one liter of consumed O_2 is equivalent to the utilization of approximately 5 kilocalories. Usually, measurements are performed during a certain task or activity by using a gas collector, which is in the form of a facemask. The use of the method for long-term measurements in a free-living context is limited. (Hills et al., 2014)

In DLW total daily EE is evaluated based on CO_2 production, which is determined by utilizing the known difference in the rates of turnover of hydrogen (H) and oxygen (O) atoms in body water. First a subject will drink water containing isotopically-labeled H and O atoms, after which disappearance rates of these two isotopes, $_{2}H$ and $_{18}O$, are measured during the next few days or weeks, typically from urine. (Schoeller, 1988) Usually, the method is used for periods of 7 to 14 days. DLW is an accurate and noninvasive method and it enables the measurement of total EE in free-living conditions. However, DLW does not provide information concerning PA patterns or its daily variation. In addition, DLW is an expensive method and thus is not suitable for large-scale studies. (Hills et al., 2014)

2.2.3 Validation

The aim of validation is to find out the extent to which a used method measures the true exposure of interest. While there is no "gold standard" for measuring all aspects of PA behavior with a single method or monitor, the measurement of EE over a period of interest by calorimetry or DLW is considered to be the best reference method in the measurement of PA. An independent measurement of EE is justified as a criterion measure based on the original definition of PA, according to which PA always leads to an increase in EE through body movement. The use of EE is also supported by the fact that this outcome can be divided and related to different PA levels using widely-used MET-based thresholds. (Plasqui et al., 2013; Welk, McClain, & Ainsworth, 2012) However, calorimetry and DLW techniques cannot reveal specific patterns of PA behavior. Furthermore, participant burden and costs restrict the use of those two methods in large scale populations. (Welk et al., 2012)

Because of the restrictions of calorimetry and DLW and the wide variety of available PA monitors with different outputs, it is also reasonable to do the validation by comparing different activity monitors with each other. This kind of validation is called convergent validity. (Welk et al., 2012) Although there are some studies on convergent validity between different measurement methods of PA used in research (Esliger et al., 2011; John, Sasaki, Staudenmayer, Mavilia, & Freedson, 2013; Lee, Williams, Brown, & Laurson, 2015; Paul, Kramer, Moshfegh, Baer, & Rumpler, 2007; Rowlands et al., 2015; Welk, Blair, Wood, Jones, & Thompson, 2000), there is still a need for further equivalency studies to better cover the wide range of available measurement methods.

2.3 Accelerometers in the measurement of physical activity

In accordance with its name, an accelerometer measures acceleration produced by the movement of the body segment to which it is attached. Acceleration is measured in one or multiple axes including the vertical, anterior-posterior, and lateral axes.

In physics, acceleration reflects the change in speed with respect to time and its SI unit is m/s^2. However, in the field of biomechanics and exercise, acceleration is usually expressed based on gravitational acceleration units (g; 1 g = 9.81 m/s^2). (Chen & Bassett Jr., 2005) Human movement acceleration during a step is lower the further the measurement sensor is located from the ground contact. At waist level, human movement typically causes accelerations of up to 6 g. (Bouten, Koekkoek, Verduin, Kodde, & Janssen, 1997)

2.3.1 Operation principle

The common operation principle of an accelerometer is based on a mechanical sensing element, including a seismic mass and mechanical suspension system. The force produced by acceleration or gravity will deflect a seismic mass and this deflection can be measured electrically with respect to a reference frame. (Yang & Hsu, 2010) Modern accelerometers used in the monitoring of PA can broadly be divided in two groups: piezoelectric and capacitive accelerometers.

Piezoelectric accelerometer

A piezoelectric accelerometer can be either a piezoresistive (also known as a cantilever beam or strain gauge accelerometer, Fig. 1A) or a compression-based accelerometer (Fig. 1B). The function of both types of piezoelectric accelerometer is based on voltage generation. The charge is generated in the piezoelectric element when seismic mass is moving in the direction of the sensitive axis as a consequence of the measured acceleration. (Lowe & ÓLaighin, 2014) The strengths of modern piezoelectric accelerometers are their small size, long battery life, high sensitivity, and a large dynamic range (Chen & Bassett Jr., 2005). However, both of the piezoelectric accelerometer types have their own limitations. Piezoresistive accelerometers are associated with temperature-sensitive drift, while compression-based accelerometers are not able to respond to constant acceleration, such as gravity. (Yang & Hsu, 2010)

Capacitive accelerometer

In a capacitive accelerometer the movable seismic mass and the reference frame are often in the form of electrode fingers (Fig. 2). The measured acceleration causes the change in distance between these fingers, which further causes a measurable change in capacitance. The strengths of capacitive accelerometers are long battery life, high output, fast response to motions, and lack of temperature calibration requirements. In addition, capacitive accelerometers also detect constant acceleration. Thus, capacitive accelerometers are nowadays the most widely used type of accelerometer in electronic devices, such as smartphones and mobile systems. (Lowe & ÓLaighin, 2014; Yang & Hsu, 2010)

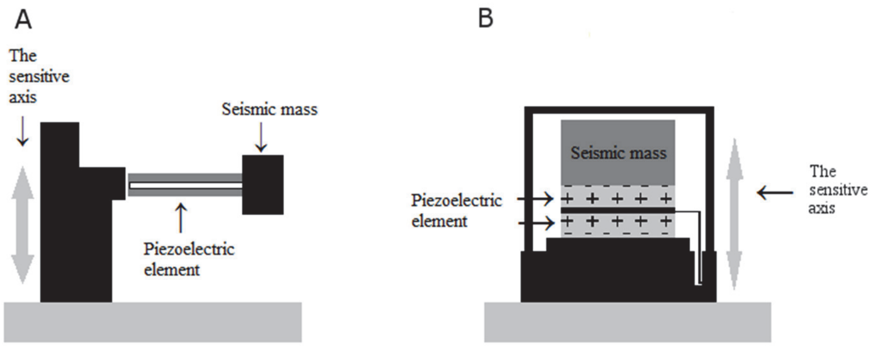

Fig. 1. The configurations of two common piezoelectric accelerometers. a) Piezoresistive accelerometer. b) Compression-based accelerometer. Modified from (Lowe & ÓLaighin, 2014).

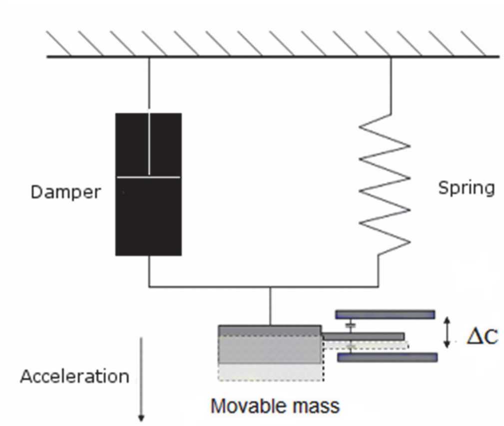

Fig. 2. The configuration of a capacitive accelerometer. ΔC, change in capacitance. Modified from (Deng et al., 2013).

Sampling frequency and filtering

An important feature of an accelerometer is the sampling frequency which determined the rate of data collection. According to the Nyquist criterion the sampling frequency should be at least twice the frequency of movement that needs to be detected. Usually, the sampling frequency of an accelerometer for measuring PA behavior varies between 1–64 Hz. Afterwards the sampled data is filtered by a band pass filter to reduce artifacts resulting from temperature changes and electrical noise, for example. The commonly used ranges for band pass filters in commercial PA monitors are somewhere between 0.25–7 Hz. Band pass filtering increases the linearity of the output relative to movement. (Chen & Bassett Jr., 2005)

2.3.2 Analysis of accelerometer data

Instead of producing raw acceleration data, accelerometer-based activity monitors often provide the measured data as counts per specific time period, i.e., epoch. There are different approaches for calculating counts from raw acceleration data: 1) counting how many times the signal crosses a preset threshold, 2) specifying the maximum value of signal during the epoch to represent the count, or 3) calculating the area under the curve. (Chen & Bassett Jr., 2005) The selected epoch length over which the signal is integrated has its own effect on the interpretation of data. The common duration for used epoch length is 1 min. However, when measuring the PA of children, a shorter epoch length, preferably as short as possible, is needed because of the sporadic nature of their PA behavior. (Corder et al., 2008; Trost, Mciver, & Pate, 2005) Because of differences in accelerometer design, filtering, and approaches for calculating counts, the problem in the field is that counts are not comparable across different devices. In addition, many of the manufacturers do not reveal how their monitor works exactly, which make the comparison even harder. (Ward, Evenson, Vaughn, Rodgers, & Troiano, 2005; Welk et al., 2012)

Activity counts are often converted into more relevant indicators of PA, such as EE or time spent on different intensity categories by using different estimation equations (resulted mainly from linear regression models) and thresholds. One classic example of count ranges corresponding to commonly used MET categories were established under laboratory conditions by Freedson et al. (1998). The problem with these approaches is that no consensus exists related to used PA intensity thresholds. Additionally, linear estimation equations used to predict EE from accelerometer-based PA data have been shown to give insufficiently accurate estimates when taking into account the wide range of different PA types and intensities. (Chen & Bassett Jr., 2005; Plasqui et al., 2013) The study by Watson et al. (2014) presents the wide variety of the used intensity thresholds that are determined using the Actigraph accelerometer and their impact on PA estimates. For example, the threshold for moderate-intensity activity varies from 191 to 2743 counts per minute, resulting in a 92% difference in the prevalence of meeting the global PA recommendation for adults (Watson, Carlson, Carroll, & Fulton, 2014).

Recently, more accurate results for estimating EE using accelerometers have been achieved by using more advanced methods such as machine learning and pattern recognition approaches with a raw acceleration signal. An important advance compared to traditional analysis methods is that these new methods are able to differentiate between PA types. (Farrahi, Niemelä, Kangas, Korpelainen, & Jämsä, 2019; Troiano et al., 2014; Trost, Wong, Pfeiffer, & Zheng, 2012) Thus, in future studies, researchers have been urged to move from count-based data and cut-point methods towards methods that utilize features of raw acceleration signals. The transparency of the used algorithms should also be ensured. (Freedson, Bowles, Troiano, & Haskell, 2012; Troiano et al., 2014)

2.3.3 Use of physical activity monitor

Monitor placement

Traditionally, monitors have been placed either on the waist or lower back. This way the monitor is as close to the center of the mass of the human body as possible, enabling the most accurate measurement of the whole-body movement. Monitors are usually worn on the waist with the help of an elastic belt or a clip. (Plasqui et al., 2013; Skender et al., 2016) However, the use of wrist-worn accelerometers has increased, which has improved the compliance of wearing an activity monitor among study participants (Troiano et al., 2014). Another advantage of wrist placement is the possibility to record low-intensity PA such as arm movements caused by household work (Hildebrand, Van Hees, Hansen, & Ekelund, 2014). The other used options for placement are thigh and ankle. The decision concerning monitor placement will be affected by the behavior under investigation and the selected monitor. (Matthews et al., 2012)

Wear time

Usually, accelerometers are instructed to be worn either 24 hours a day or during all waking hours, depending on the monitoring protocol (Corder et al., 2008). To define the actual wear time, the non-wearing time needs to be determined first. Usually, this is done by identifying a period of at least 60 consecutive minutes of zero output from the accelerometer data. (Troiano et al., 2008) Participant compliance with the monitoring protocol is an important factor for obtaining accurate measurement results. Different strategies to promote compliance include, for example, reminder calls or messages, PA feedback, and incentives such as money and extra credit (Audrey, Bell, Hughes, & Campbell, 2013; Trost et al., 2005). In addition, clear instructions concerning the use of the monitor and use of wear logs have been found to lead to good compliance in research (Matthews et al., 2012). Among young people, wear time is also affected by the appearance and usability of the monitor (Audrey et al., 2013).

Even today, no standards have been set concerning how many measurement days are needed and what should be the actual daily wearing time to obtain a reliable picture of PA behavior (Skender et al., 2016). However, some consensus has been found for using a seven-day measurement period in PA research. This time period has been found to be suitable for different age groups including children, adolescents, and adults. (Matthews et al., 2012; Skender et al., 2016; Trost et al., 2005) The definition of a valid measurement day varies between studies, 600 minutes per day being the most commonly used value (Matthews et al., 2012; Skender et al., 2016). The study conducted among 11-year-old children did not find any significant differences in results when using either 420 minutes or 600 minutes as a minimum required daily wearing time (Mattocks et al., 2008). Typically, four days has been used as the requirement for the minimum number of valid days to be included in the further analysis (Skender et al., 2016).

2.4 Technology for promoting physical activity in young

Traditional interventions, including face-to-face meetings, have been found to be effective for increasing PA in young people, especially when intervention is delivered during school hours or when other form of social support is included in the intervention (2018 Physical Activity Guidelines Advisory Committee, 2018; Hamel et al., 2011). However, traditional interventions consume time and money and are also associated with geographic restrictions (Wu, Cohen, Shi, Pearson, &

Sturm, 2011; Wylie-Rosett et al., 2001). The weakness of mass media campaigns is the inability to provide individualized feedback, which has shown to enhance the effectiveness of PA interventions (Hamel et al., 2011). Thus, there is a need for new interventions with high accessibility and personal relevance and ability to reach large groups of young people. The constantly increasing availability of information and communication technologies provide new innovative methods to promote regular PA.

2.4.1 Self-monitoring of physical activity

Through self-monitoring of PA, individuals become aware of their current PA behavior (Van Hoye et al., 2015). Self-monitoring has been shown to be an effective behavior-change strategy for increasing PA (Bravata et al., 2007; Conroy et al., 2011; Lubans et al., 2009; Mutrie et al., 2012). A previous study provided evidence that the use of a PA tracker is associated with increased PA among those adolescents who demonstrated a readiness to be active (Gaudet, Gallant, & Bélanger, 2017). In addition to the feedback received from tracking PA, goal setting appears to be an important motivational factor for promoting PA (Bort-Roig et al., 2014; Bravata et al., 2007; Conroy et al., 2011). Studies conducted among younger people provide promising results for using goal-setting with pedometers as an activation strategy, especially among less active adolescents (Lubans et al., 2009).

Conroy et al. (2011) revealed in their study that more frequent self-monitoring as well as more frequent feedback resulted in a more active lifestyle. Also, real-time and individualized feedback have been shown to enhance the effectiveness of PA-related interventions (Bort-Roig et al., 2014; Hamel et al., 2011). Accelerometer-based activity monitors provide a more comprehensive picture and, consequently, more accurate feedback concerning PA behavior compared to self-reports and pedometers (Bassett et al., 2014; Butte et al., 2012). Studies concerning the independent role of continuous feedback provided by accelerometers as a means to promote PA or reduce sitting time among adults are available (Godino et al., 2013; Lewis, Lyons, Jarvis, & Baillargeon, 2015; Van Hoye et al., 2015), but the number of studies conducted among young people is still low.

2.4.2 Web-based interventions

Intervention strategies

Access to the internet and to the other forms of information and communication technologies has expanded enormously around the world over just a few decades (Pratt et al., 2012). In Finland, 98% of young people aged 16–24 used the internet several times a day and 99% owned a smartphone in 2018 (Statistics Finland, 2018). The use of internet-based technologies (such as websites, mobile technologies, and email) for delivering PA interventions has several advantages over traditional intervention methods. These include, e.g., cost-effectiveness, flexibility and convenience of use of a service and information, the possibility to automatically collect data and provide individually tailored information and feedback, and the ability to use different kinds of graphics for delivering information (Fotheringham, Owies, Leslie, & Owen, 2000). To enhance personal relevance, tailoring based on behavioral determinants such as skills, intention, motivation, and stage of behavior change can be utilized (Broekhuizen, Kroeze, Van Poppel, Oenema, & Brug, 2012). PA advice delivered via the internet has been shown to be more agreeable than information delivered via telephone or print media (Ferney & Marshall, 2006). Furthermore, the results of the study conducted among adolescents aged 13 to 18 showed that computer-mediated communication was more effective at changing PA behavior than lectures and pamphlets (Casazza & Ciccazzo, 2007). In web-based intervention studies, PA is usually monitored using either an external device (e.g., pedometers or accelerometers) or native smartphone sensors (Bort-Roig et al., 2014).

While using a website or a smartphone for delivering PA intervention, ease of use, interactivity, and environmental context (such as information related to PA opportunities in the community) have been raised as potential strategies to enhance the usability of the intervention and to encourage change in terms of PA. In this context, interactivity refers, for example, to self-report progress charts as well as to online expert consultation and social support networking. (Bort-Roig et al., 2014; Ferney & Marshall, 2006) Additionally, the use of a theory of health behavior as a background to web-based intervention design has been highlighted as a convincing approach to increase effectiveness. Available theories include, e.g., social cognitive theory, the theory of reasoned action, the transtheoretical model, the health belief model, and the theory of planned behavior. (Fanning, Mullen, & Mcauley, 2012; Hamel et al., 2011)

Engagement and effects on physical activity behavior

Several previous studies investigating the effect of a web-based service or a mobile app for promoting PA or decreasing sedentary behavior have shown positive changes among study participants, including young people. However, the effects on PA behavior have been small and relatively short-lived. (Direito, Carraça, Rawstorn, Whittaker, & Maddison, 2017; Gal, May, van Overmeeren, Simons, & Monninkhof, 2018; Hamel et al., 2011; Slootmaker, Chinapaw, Seidell, van Mechelen, & Schuit, 2010) According to a recent review concerning digital interventions to promote PA and healthy diet among adolescents, website interventions might result in positive short-term changes in health behaviors among young people. However, the effectiveness of alternative media such as text messages, email, smartphone apps, and social media could not be confirmed. Goal setting, self-monitoring, and health education were found to be effective intervention components regardless of the digital platform used. (Rose et al., 2017)

The pilot study conducted among adolescents aged 11–14 used an activity monitor with an online incentive motivation system (the Zamzee system) and resulted in an increase of over 50% in daily MVPA in the intervention group compared to the control condition. The intervention effect was maintained throughout the six-week study period. (Guthrie et al., 2015) The study using PA monitoring and a tailored PA coaching website for increasing PA among adolescents aged 13–17 resulted in different results between boys and girls. Among girls, time spent in MPA differed significantly (411 min/week) between the intervention and control groups after three months. On the other hand, among boys, the difference between the groups in favor of the intervention group was seen in sedentary time (1801 min/week) at 8-month follow-up. (Slootmaker et al., 2010) Lubans et al. (2014) developed a smartphone app to promote PA and reduce sedentary behavior in adolescent boys. The app included separate functions for step monitoring, fitness challenges, assessment of resistance training skill competency, goal setting, and tailored motivational messaging, and it was used as part of a school-based obesity prevention program. In total, 44% of participants found the app enjoyable to use, with goal setting being the most commonly used function. However, the use of the app was occasional and only 30% of participants used the pedometer feature regularly.

The general problem with web-based interventions is that the engagement and retention of participants is poor, especially among young people (Flores-Mateo et al., 2015; Kohl, Crutzen, & De Vries, 2013; Vandelanotte, Spathonis, Eakin, &

Owen, 2007). The use of a behavior change theory and higher number of contacts with participants has been found to enhance efficacy among children and adolescents (Lau et al., 2011). In addition, school-based settings seem to be more effective compared to home-based settings, and social support, e.g., from teachers, parents, or peers has been seen to promote commitment to interventions involving computer- and web-based approaches (Hamel et al., 2011).

In many previous studies a control group design and objective measurement of PA have not been used, leading to poor quality. These limitations have complicated the investigation of the effect of interventions. (Bort-Roig et al., 2014; Lau et al., 2011) In addition, the intervention effect is usually reported as the change between the baseline and the completion of the intervention, and thus, the continuous change of PA during the intervention has rarely been reported (Van Hoye et al., 2015). Several review articles have also highlighted the lack of interventions targeted at young people, especially at young boys (Ashton et al., 2014; Hamel et al., 2011; Schoeppe et al., 2016).

2.4.3 Gamification

Gamification is one of the latest strategies used for fitness and health-related services to improve user experience, engagement, and reaching goals. Gamification refers to the use of game design techniques, game principles, and mechanics, such as rewards, feedback, progress visualization, social connection, and different kinds of challenges, in non-game contexts. (King et al., 2013) Those game mechanisms that allow for simultaneous enjoyment, competition, and self-evaluation were found to be most effective in a recent review article including 46 studies concerning gamified e-Health apps. Such mechanisms are social features, rewards, and progress tracking. Most gamified apps included in the review article were related to either chronic disease or PA. (Sardi, Idri, & Fernández-Alemán, 2017)

Although studies utilizing gamification in mobile apps as a part of PA interventions have been published, it has not been possible to confirm clinical effectiveness and the added value of gamification in changing daily PA. The majority of the studies focus on acceptability and feasibility among users, and the number of randomized controlled studies is still low. The theoretical foundation of gamified PA apps is also limited. (Sardi et al., 2017; Tabak, Dekker-Van Weering, Van Dijk, & Vollenbroek-Hutten, 2015) The review article concerning serious exergaming and its impact on PA found generally positive results, according to which the motivation and engagement for exercise can be enhanced by using virtual reality-based exergames. However, the lack of randomized controlled studies and theoretical bases, as well as short timeframes and small sample sizes of existing studies, were highlighted. (Matallaoui, Koivisto, Hamari, & Zarnekow, 2017)

The study conducted among participants aged 14–17 years did not find any differences in the change in fitness and PA among the intervention groups using either an immersive app with gamified elements or a nonimmersive app. However, the design and features of the immersive app were seen as more motivating. (Direito, Jiang, Whittaker, & Maddison, 2015) A recent pilot study suggested that a gamified intervention could foster a flow experience as well as a sense of interest and inspiration among young people (Kelders, Sommers-Spijkerman, & Goldberg, 2018). Of the gamification elements, young people consider competition, incentives, and the influence of friends to be the most important (Corepal et al., 2018). Some gender differences have been found in engagement with gamified apps. Men have been shown to be more interested in gamification features (Ryan, Edney, & Maher, 2017). In addition, young men seem to prefer team-based gamification elements while young women favor individual competition (Corepal et al., 2018).

3 Aims of the study

The purpose of the present study was to examine the convergent validity between three different accelerometer-based PA measurement methods, and to evaluate the effectiveness of an activity monitor and a web-based mobile service in promoting PA and decreasing sedentary behavior among young men. The specific aims were:

1. To examine the agreement in time spent at different PA intensity levels using three different activity monitoring methods (Polar Active, mean amplitude deviation for raw acceleration data, and Actigraph with Freedson equation) among adults under free-living conditions.
2. To evaluate the effectiveness of a wrist-worn activity monitor providing feedback on PA and sedentary time among young men.
3. To evaluate the feasibility and effectiveness of an automated, gamified, tailored web-based mobile service aimed at promoting PA behavior among young men.

4 Materials and methods

Study I is part of the pilot study of the 46-year data collection of the Northern Finland Birth Cohort 1966 (NFBC1966). Studies II and III are related to the three-month and six-month trials of the MOPO study, in which the goal was to develop a gamified mobile service for promoting PA and health in young men (Ahola et al., 2013). Table 1 presents the summary of the study design, subjects, and methods used in each study.

Table 1. Summary of study design, subjects, and methods.

Study	Design	N	Sex F/M	Age [years]	Duration	Accelerometer	Additional data
I	Pilot study	27/45	20/7	47.6 (0.6)	2 weeks	Actigraph, Hookie, Polar Active	Anthropometrics
II	Randomized, controlled	102/137 int 107/139 c	–/209	17.9 (0.7)	3 months	Polar Active	Questionnaire, anthropometrics, fitness
III	Population-based, randomized, controlled	187/250 int 167/246 c	–/354	17.8 (0.6)	6 months	Polar Active	Log data, questionnaire, anthropometrics, fitness

N number of subjects (the number of subjects used in the analysis/the total number of the study participants), F female, M male, INT intervention group, C control group. Age is presented as mean (SD).

4.1 Subjects

All study participants were volunteers who were provided with written and oral information about the study, after which they were asked to provide written consent. All studies were done in accordance with the Declaration of Helsinki and all study protocols were approved by the Ethics Committee of the Northern Ostrobothnia Hospital District. The protocol of the MOPO study has been registered with the clinical trials register (NCT01376986, ClinicalTrials.gov).

4.1.1 Validation study (I)

The pilot study, which was part of the 46-year data collection of NFBC1966, was conducted in the city of Oulu, northern Finland, in 2012. The subjects of study I were 27 middle-aged adults, who completed the pilot study, and who had at least four valid days of activity data from all three accelerometers available. Originally, 150 invitations were sent to adults selected randomly from the national population register, born in 1964–65 and living in the Oulu area or in neighboring municipalities. In total, 45 subjects were recruited, of whom 41 participated the baseline visit and agreed to use the accelerometers for two weeks. Of the subjects who agreed to use the accelerometers, 14 were excluded from the final analysis of this study. Three participants did not wear the monitors, in four cases the battery of one of the monitors had discharged, and in seven cases one of the monitors had malfunctioned and activity data were thus either missing or invalid.

During the baseline visit, body mass and height were measured, and all three accelerometers were delivered with oral and written instructions. Mean (SD) height was 164.6 (6.3) cm among females and 177.7 (6.7) cm among males. Mean body mass was 72.6 (13.6) kg and 80.9 (8.3) kg, respectively.

4.1.2 Randomized controlled trials of the MOPO study (II, III)

Two different randomized controlled trials (RCT) of the MOPO study were included in this study. The three-month RCT (II) was conducted in fall 2012 and the larger six-month population-based RCT (III) between September 2013 and March 2014. The recruitments of study subjects were carried out during military call-ups in Oulu for both RCT studies. The Finnish Defense Forces organize conscriptions every year, and all boys turning 18 are required to participate. All men participating in the call-ups in Oulu were invited to go through anthropometry and fitness measurements and fill in a health and lifestyle questionnaire. All those who went through the measurements were asked to participate in the RCT, either in study II or III depending on the year. In both RCTs, the subjects were randomly assigned to an intervention or a control group. The flow of the subjects in each trial is presented in Fig. 3.

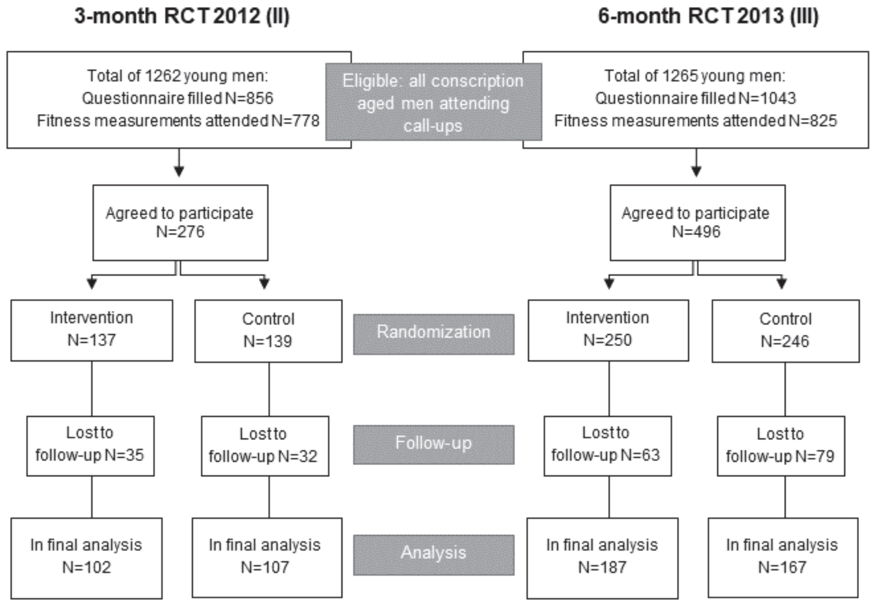

Fig. 3. Flow of participants in the randomized controlled trials of the MOPO study.

During the anthropometry and fitness measurements, height, weight, waist circumference, body composition (Inbody 720), and maximal isometric grip strength (Saehan) were measured. In addition, the Polar Fitness Test was conducted using an FT80 heart rate monitor to evaluate the aerobic fitness of the study participants (Peltola et al., 2000; Väinämö, Nissilä, Mäkikallio, Tulppo, & Röning, 1996). The same set of anthropometry and fitness measurements were also performed at the end of both RCTs.

The self-administrative questionnaires inquiring about the health and lifestyle of the study participants were filled in at baseline and at the end of both trials. The items included in the analyses were related to alcohol use (II-III), smoking habits (II-III), self-reported sitting time and PA (II), self-perceived physical fitness and health (II), as well as a stage of exercise behavior change (III). In addition, the questions related to the gamified mobile service were included in the questionnaire at the end of the six-month trial (III). Self-reported PA was assessed as: low (no regular PA, occasional walking, < 0.5 h/week), middle (regular recreational PA or moderate occupational PA, 0.5–2 h/week), high (regular heavy physical exercise, 2–4 h/week), or top (heavy physical exercise at least 5 times a week, > 4 h/week) (Borodulin et al., 2004). Daily sitting time in hours was asked separately for leisure time and school or working hours.

The baseline characteristics of the study participants for both RCT studies are presented in Table 2. There were no significant differences in the variables between the intervention and control groups at baseline.

Table 2. Baseline characteristics of the study participants in studies II and III.

Variables	Study II		Study III	
	Intervention group (N = 137)	Control group (N = 139)	Intervention group (N = 250)	Control group (N = 246)
Age, years	17.9 (0.8)	18.0 (0.9)	17.9 (0.7)	17.8 (0.6)
Height, cm	178.7 (6.1)	177.4 (6.1)	177.9 (6.7)	178.1 (6.0)
Weight, kg	74.8 (15.0)	74.6 (15.8)	73.4 (15.0)	72.9 (14.0)
BMI, kg/m^2	23.2 (4.2)	23.5 (4.8)	23.2 (4.5)	23.0 (4.2)
Waist circumference, cm	82.5 (10.3)	82.8 (11.5)	81.9 (10.9)	81.9 (10.1)
Body fat, %	16.2 (7.5)	17.0 (9.0)	16.5 (8.5)	16.7 (8.3)
Muscle mass, %	47.2 (4.3)	46.7 (5.3)	47.1 (4.9)	46.9 (4.9)
Grip strength (mean), kg	46.2 (8.2)	46.9 (8.4)	45.6 (8.1)	45.6 (7.3)
Estimated aerobic fitness, ml/min/kg	52.7 (7.1)	52.6 (7.6)	53.6 (7.3)	53.0 (6.8)
Current smoker, n (%)	34 (28.3)	27 (20.5)	45 (19.6)	48 (21.3)
Alcohol intake (at least 6 servings ≥ once a week), n (%)	13 (10.1)	5 (3.8)	43 (20.3)	43 (19.2)

Values are mean (SD) unless otherwise specified.

4.2 Physical activity measurements

In this study, three different activity monitors, Polar Active (I-III), Hookie AM20 (I), and Actigraph GT3X (I), were used. The operation of all three monitors is based on measuring acceleration. Polar Active represents a wrist-worn activity monitor with high user-friendliness, and it calculates the acceleration signals to METs using sex, age, weight, and height as input (Brugniaux et al., 2010; Kinnunen, Tanskanen, Kyröläinen, & Westerterp, 2012; Kinnunen et al., 2019). Hookie allows an analysis of raw triaxial acceleration signals (Vähä-Ypyä et al., 2015) and Actigraph is the most widely used accelerometer for research purposes (Migueles et al., 2017). The measurement features of each monitor are shown in Table 3.

Table 3. The measurement features of the used activity monitors.

Activity monitor	Mass [g], Size [cm]	N of axes	Range	Sampling frequency [Hz]	Site	Water-proof	Output
Polar Active	45 3.8 x 3.8 x 1.1	1	–	50	wrist	yes	METs
Hookie AM20	15 6.6 x 2.7 x 1.3	3	±16 g	100	waist	no	raw acceleration
Actigraph GT3X	27 3.8 x 3.7 x 1.8	3	0.05–2.5 g	30	waist	no	activity counts

N number, METs metabolic equivalents. The range for Polar Active is not specified by the manufacturer.

4.2.1 Validation study (I)

In study I, the PA of the study participants was measured using all three activity monitors continuously for two weeks without any feedback on PA behavior. The participants were advised to wear Polar Active on the non-dominant wrist for 24 h a day (expect in the sauna) and the two other devices on the same belt on the right side of the waist during waking hours (expect during sauna, bath, shower, or other water activities). The used epoch length was 30 s for Polar Active and Hookie and 10 s for Actigraph. However, for Actigraph counts, the epoch length was transformed to 30 s for further analysis.

During the data analysis, mean amplitude deviation of the acceleration signal (MAD) was calculated and converted to METs for each epoch of the raw acceleration data from Hookie. MAD describes the mean variation of the dynamic acceleration component around the static component and it is calculated from the resultant of the three orthogonal accelerations. (Migueles, Cadenas-Sanchez, Rowlands et al., 2019; Vähä-Ypyä, Vasankari, Husu, Suni, & Sievänen, 2015; Vähä-Ypyä et al., 2015) For Actigraph, only the data from the vertical axis was included in further analysis. Actigraph counts were divided into MET-based PA classes using ≤ 100 counts/min for sedentary time (Matthews et al., 2008) and the Freedson thresholds for LPA, MPA, and VPA (Freedson, Melanson, & Sirard, 1998). For both MAD and Polar Active, two different sets of MET-based thresholds were used for calculating the daily time spent at different PA levels. SET 1 is widely used

(Gibbs et al., 2015; Plasqui et al., 2013) whereas SET 2 is standard in Polar Active software and analyses. Table 4 presents all the thresholds used in this study.

Table 4. The used thresholds for different physical activity levels.

PA data	Sedentary	Light PA	Moderate PA	Vigorous PA	MVPA
METs					
SET 1	≤ 1.5	1.51–2.99	3–5.99	≥ 6	≥ 3
SET 2	< 2	2–3.49	3.5–4.99	≥ 5	≥ 3.5
Actigraph counts	≤ 100	101–1951*	1952–5724*	≥ 5725*	≥ 1952*

PA physical activity, MET metabolic equivalents, MVPA moderate-to-vigorous physical activity. *The Freedson threshold (Freedson et al. 1998).

After the data was divided into different PA levels, the personal mean values over the period of valid data were calculated. To be eligible for the analyses, all accelerometers had to be used simultaneously for at least four valid days; a valid day being at least 500 min of wearing time per day. The non-wearing time was defined as at least a 60-minute period of consecutive zeros. The comparisons of different measurement methods were performed both at the method level and the individual level.

4.2.2 Randomized controlled trials of the MOPO study (II, III)

In studies II and III, Polar Active was used for measuring PA behavior during the trials. All study subjects were advised to wear the device on the non-dominant wrist for at least all waking hours and to upload PA data manually to the research database through Polar FlowLink® at least every three weeks in order to avoid exceeding the memory of the monitor. Personal mean values over separate study weeks were calculated using MET-based threshold SET 2 for sedentary time, LPA, MPA, and VPA as the standard in Polar Active software and analyses. MVPA was defined as the sum of moderate and vigorous PA. The minimum number of valid days (≥ 500 min of data) out of seven required to be included in the analysis of each week was four in study II and three in study III (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013).

4.3 Interventions (II, III)

In study II, the intervention was based on the use of a wrist-worn Polar Active monitor that delivered feedback on PA levels for the subjects in the intervention group. By default, the monitor displayed the accumulated daily MVPA time and achievement of daily activity target (60 min/day) as a filling bar. In addition, the time spent at different PA levels, steps, and calories for each day were available for the user through the monitor's diary. Additionally, the pilot version of the gamified mobile service (Luoto et al., 2014) was also offered. The service utilized measured activity data and it was developed to promote the physical and social activity of the users. Through the service, the user could, for example, review their own PA data, chat online with other users, play the game *Clans of Oulu* (see paragraph 4.3.2), as well as receive information concerning local sports opportunities and social events. Based on the user experiences of the three-month intervention, the service was further developed for the larger population-based six-month trial. The technical implementation, usability, data transfer, and content of the service were improved. In addition, the game was further developed and integrated more into the service. The graphic layout of the service and the game was also harmonized.

The timeline and the contents of the six-month trial (III) are presented in Fig. 4. In study III, the subjects in the intervention group had access to the final version of the gamified, tailored web-based mobile service (MOPOrtal, see the paragraph 4.3.1). Alongside the service, the intervention group subjects used wrist-worn Polar Active monitors in the same way as in study II. However, during the first week of the six-month trial, the activity monitor did not provide any feedback and access to the MOPOrtal service was also blocked in order to get baseline information at the PA level.

Through both trials (II, III), PA of the control group subjects was measured continuously with a blinded Polar Active monitor providing only the time of day. Otherwise the subjects in the control group continued their normal lives. During study III, both groups received a text message every three weeks as a reminder to upload the PA data. Two movie tickets were also raffled once a month as incentives among all those participants who had uploaded activity data. Only two face-to-face meetings with the participants were arranged during the trials, one at baseline and one at the end of trials, during which anthropometry and fitness measurements were performed and questionnaires were completed.

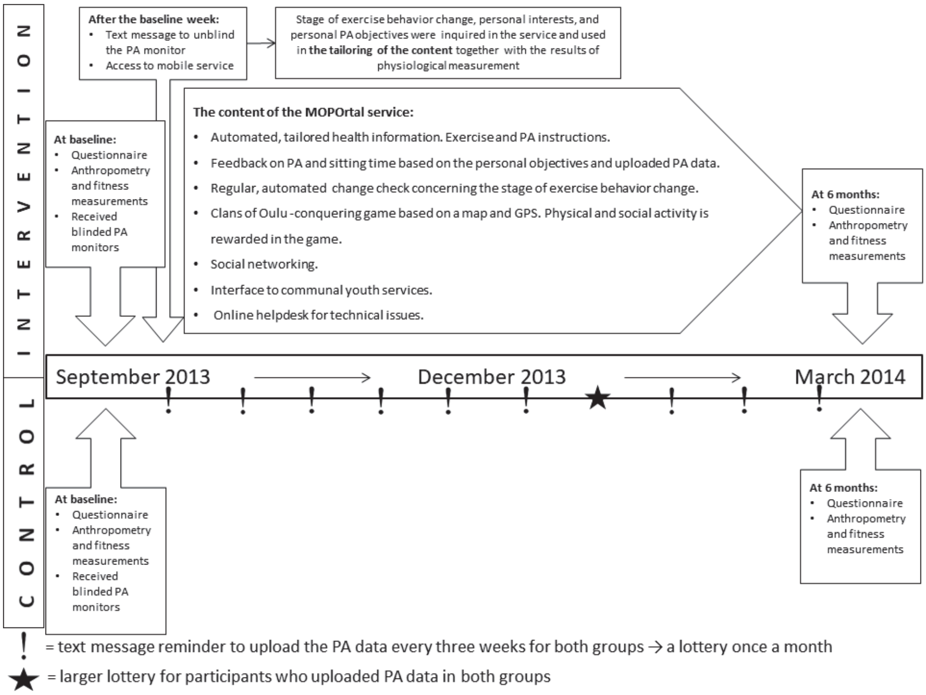

Fig. 4. Timeline of study III. Modified from (Pyky et al., 2017)

4.3.1 Gamified mobile service

The gamified MOPOrtal service (Fig. 5) was established for this particular trial in the multidisciplinary MOPO study (Luoto et al., 2014). The requirements for the service were defined between 2009 and 2012. The young men who attended the call-ups each year were asked to fill out questionnaires and were interviewed regarding the different elements of the service. Two pilot interventions were carried out in 2011 and 2012 in order to test the functionalities of the service and make improvements according to the users' feedback. Additionally, young men aged 16–20 from local school classes, voluntary courses, and youth workshops for the unemployed were involved in developing the service.

The service was running on a web browser but optimized for mobile use (HTML5), which enabled to use the service either on a mobile phone or on a computer. For identifying the user, personal user codes were used to log in to the service. The service used PA data (from Polar Active or manually entered), personal interests, personal PA objectives, and the results of physiological measurement to tailor the feedback and information delivered by the service. The tailoring of the automated health information and feedback was based on the transtheoretical model (TTM) of behavior change (Prochaska & DiClemente, 1983). TTM includes five different stages for PA adaptation and maintenance: precontemplation, contemplation, preparation, action, and maintenance. During this trial, the stage of change was assessed during the first visit to the service and updated once a month after that. (Pyky et al., 2017) The MOPOrtal service included the following parts:

1. Feedback on PA and sitting time based on the personal objectives and uploaded PA data
2. Exercise and PA instructions and guidelines for aerobic- and muscle-fitness improvement and weight management
3. Automated, tailored health information and feedback messages based on TTM
4. The *Clans of Oulu* game
5. Social networking opportunities in the form of chat and a photo gallery
6. Interface to communal youth services (including e.g., tailored city news and events)
7. Web-based helpdesk for technical issues

PA feedback was provided in text and graphic form and it was based on weekly, daily, and two-hourly activity metrics. Personal weekly activity metrics were compared to the global recommendation (60 min/day), to the PA behavior of other users (normative feedback), and to users' own prior behavior (ipsative feedback). The overall feedback of daily activity was provided showing a thumb either up, sideways, or down, depending on the fulfillment of the global PA recommendation and whether the day included over two hours of sedentary periods or not. Accumulated minutes at different PA levels for every two-hour period for each day were also offered. The compliance of the service was tracked based on the personal log data recorded in the research database. Feasibility of the service was also evaluated via the questionnaire implemented at the end of the six-month trial.

Fig. 5. The MOPOrtal service and the Clans of Oulu game.

4.3.2 The Clans of Oulu game

The service included a mixed-reality conquering game called *Clans of Oulu* (Fig. 5) (LudoCraft Ltd., 2019), which was based on the location of a user tracked using their mobile phone's GPS and played in five different clans. The basic idea was that by moving physically within the districts of the city of Oulu, players could conquer areas for their own clan. To promote PA through the game, many kinds of activities were rewarded by delivering more points to the game to conquer new areas. For example, players were rewarded based on the amount of uploaded PA data and their PA behavior. More points were earned when a player reached the daily PA recommendation, increased weekly PA, or reduced weekly sedentary time. In addition, by reading facts and health information delivered by the service and inviting friends to join the game, players received new points. Instead of traditional information delivery, health messages were presented as playing cards in the conquering game, and the messages were written in the language used by young people. During the trial, there were some events in the *Clans of Oulu* game, such as a geocaching campaign and a most active clan of the week competition.

The *Clans of Oulu* game included different kinds of game design elements, such as competition (personal and team ranks), conflict (task to be solved and combats with another team), cooperation (within the team), strategy (points earned based on activity), esthetics (visual appearance for each clan), theme (clan game, youth cultures, and conquering), resources (points for conquering areas), time (outdating of points), and rewards (points for PA and completing tasks). On the service side, a similar visual appearance was used as in the game. In addition, the main game actions (e.g., an area occupation from a person's own clan) were displayed in the service without the need to log in to the game itself. A more detailed description of the game can be found elsewhere (Luoto et al., 2014).

4.4 Statistical analysis

The results were analyzed using IBM SPSS Statistic software (SPSS 19 for Windows, SPSS Inc, Chicago, Illinois). A *p*-value of below 0.05 was considered statistically significant.

In study I, the between-method differences in time spent at different PA levels were analyzed using a repeated measure analysis of variance (ANOVA) test. Cohen's *d*-values were used to determine the effect sizes. At the individual level, intra-class correlation coefficients (ICC) and the Bland-Altman method were used for assessing agreement in time spent at different activity levels between different methods. The mean difference, standard deviation of the difference, and 95% limits of agreement were also calculated. For comparing the fulfillment of MVPA recommendation (60 min daily), receiver operating characteristics (ROC) graphs were created by using each of the three methods in turn as a reference. The area under the ROC curve (AUC) was calculated to estimate the discriminatory accuracy of each method.

In studies II and III, an independent sample t-test (or Mann-Whitney test for not normally distributed variables) was used to compare intervention and control groups. For the categorical variables, comparison was performed using chi-squared test (II). Paired sample t-test (or Wilcoxon test) was used to analyze the change from the baseline within study groups (II, III). While studying the group differences over time in the change in time spent at different PA levels, all available personal weekly averages for the intervention and control group were included in the analyses (II, III). In study II, the group differences were analyzed using the generalized estimation equation (GEE) with an unstructured working correlation matrix. In study III, the difference in the change in MVPA was analyzed using multiple linear mixed model with full maximum likelihood, compound symmetry, and Bonferroni correction. Pearson's correlation coefficient (*R*) was used to evaluate which variables measured at baseline were significantly associated with the change in daily MVPA time in the intervention group (III). The relationship between the usage frequency of the mobile service and the change in daily MVPA time was studied using the Spearman rank correlation coefficient (ρ) (III).

For study III, the power calculation was based on the estimation that during the trial the number of inactive men will decrease by one third in the intervention group with no change in the control group. Based on the data from the 2009 call-ups, the proportion of inactive men at baseline was 27.6%. Thus, the calculated sample size was $[(27.6 \times (100–27.6) + 18.5 \times (100–18.5))/(27.6\text{-}18.5)^2] \times 7.9 = 335$ persons per group with a study power of 80% and a significance level of 5%.

5 Results

5.1 Validation study (I)

In study I, the average number of valid days per person when all three accelerometers were in use was 14 (SD 2.0), while the mean wearing time was 15.1 (SD 1.4) h per day. The mean values for time spent at different PA levels are shown in Table 5, including the results based on the Freedson's thresholds for Actigraph and both MET threshold sets for MAD and Polar Active.

Table 5. Mean daily time (min/d) spent on different activity levels.

Measurement method	Sedentary	LPA	MPA	VPA
MAD				
SET 1	665.7 (85.5)	160.3 (46.0)	63.6 (24.1)	1.0 (1.8)
SET 2	763.8 (79.0)	94.7 (36.4)	27.9 (13.9)	4.2 (6.1)
Polar Active				
SET 1	428.9 (126.4)	391.0 (74.5)	82.7 (27.9)	18.9 (19.2)
SET 2	636.6 (114.0)	226.5 (74.2)	27.1 (11.7)	31.4 (21.6)
Actigraph				
The Freedson thresholds	643.5 (100.5)	234.8 (59.6)	31.8 (17.8)	0.5 (1.1)

Mean (SD). LPA light physical activity, MPA moderate physical activity, VPA vigorous physical activity. SET 1: Sedentary ≤ 1.5 METs, LPA 1.51–2.99 METs, MPA 3–5.99 METs, VPA ≥ 6 METs; SET 2: Sedentary < 2 METs, LPA 2–3.49 METs, MPA 3.5–4.99 METs, VPA ≥ 5 METs.

Significant differences ($p < 0.001$, repeated measures ANOVA) between all measurement methods were found at all activity levels except in MPA with the threshold SET 2 ($p = 0.170$). Overall, Polar Active resulted in the highest amount of MVPA and lowest amount of sedentary time with both MET threshold sets compared to the other two methods. In pairwise comparisons for threshold SET 1, there was no difference between MAD and Actigraph in VPA (mean difference 0.5 min/d, 95% CI −1.3–0.4, $p = 0.526$). With threshold SET 2, Polar Active and Actigraph were close to each other in sedentary time (mean difference 7.0 min/d, 95% CI 17.8–31.7, $p = 1.0$) and in LPA (mean difference 8.2 min/d, 95% CI 12.9–29.4, $p = 0.985$).

Fig. 6 presents the Bland-Altman plots for sedentary time and MVPA (analyzed with the threshold SET 1) illustrating the agreement at the individual level between the three different measurement methods. The highest agreement was found between Actigraph and MAD on sedentary time (ICC = 0.922).

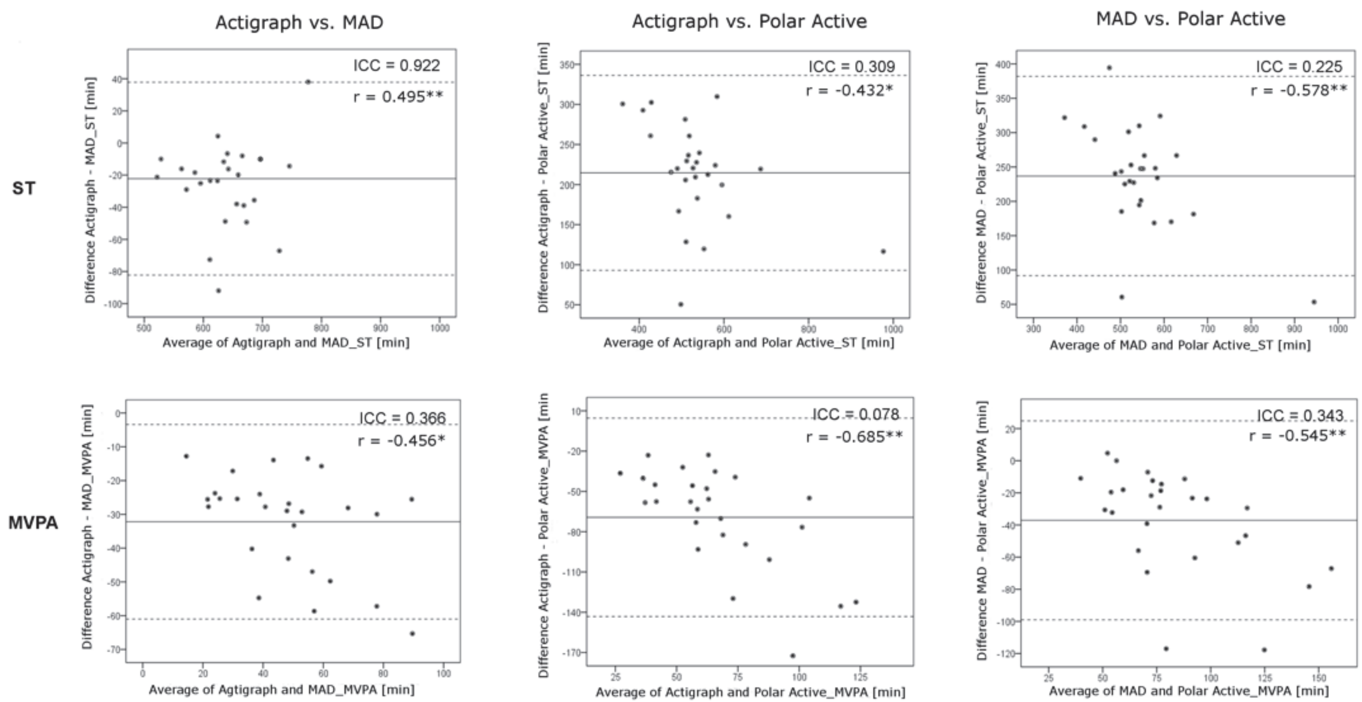

Fig. 6. The agreement between methods at sedentary time (ST, ≤ 1.5 METs) and time spent in moderate-to-vigorous physical activity (MVPA, ≥ 3 METs). ICC intra-class correlation coefficient, MET metabolic equivalent. ****p* **< 0.05, *****p*** **< 0.01 for the significance level of correlation coefficients. Modified from publication I.**

In the ROC analyses for comparing the fulfillment of MVPA recommendation measured with three different methods, moderate-to-high agreement was found in all comparisons. The calculated values for area under the ROC curves (AUC) are shown in Table 6. The highest convergence was found between Actigraph and MAD when the 3.5 MET threshold was used for MVPA and Actigraph as the reference method (AUC = 0.963, 95% CI 0.934–0.991).

Table 6. Values for area under the ROC curves while comparing the fulfillment of MVPA recommendation (60 min daily) measured by MAD, Polar Active, and Actigraph with the Freedson threshold.

Reference method	MVPA ≥ 3 MET			MVPA ≥ 3.5 MET		
	MAD	Polar Active	Actigraph	MAD	Polar Active	Actigraph
MAD	–	0.852	0.880	–	0.894	0.952
Polar Active	0.864	–	0.824	0.820	–	0.810
Actigraph	0.919	0.806	–	0.963	0.895	–

MVPA moderate-to-vigorous physical activity, MET metabolic equivalent.

5.2 Effects of wrist-worn activity monitor feedback on physical activity behavior, anthropometry, and fitness (II)

In study II, a total of 102 (74%) participants in the intervention group and 107 (77%) in the control group completed the study (Fig. 3). The rest did not participate in the final measurements of anthropometrics and fitness and were excluded from the final analysis. The total number of valid days of objectively measured activity data was 6,132 (87% of all the uploaded data). At least one valid week of data was obtained from 146 (52.9%, 146/276) participants, while the average number of valid weeks per person was five in the intervention group and six in the control group. The mean wear time was 13.7 and 14.0 h/d, respectively. The number of active users of the MOPOrtal prototype remained low, twenty-four (18%) participants logging on the service at least four times.

The objectively measured mean daily sedentary time and mean time spent in MVPA for each study week during the three-month trial (II) is shown in Figure 7. MVPA increased (GEE, $p = 0.012$) and sedentary time decreased (GEE, $p = 0.032$) over time in the intervention group compared with the control group (Fig. 7). During the first week, the participants in the intervention group spent an average of 12 minutes more time in MVPA compared to the controls (t-test, $p = 0.034$). Sedentary time was on average one hour less in the intervention group compared with the control group during the first seven weeks (t-test, $p < 0.05$). There were no statistically significant differences over time in LPA between the study groups (GEE, $p = 0.688$).

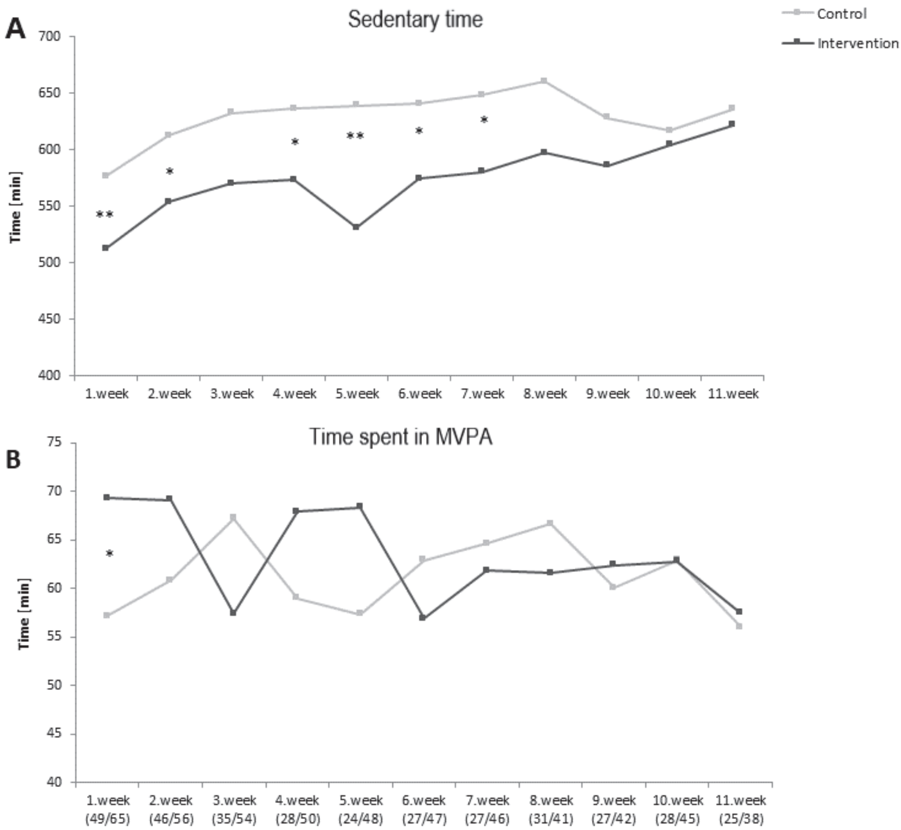

Fig. 7. The mean daily sedentary time and mean daily time spent in moderate-to-vigorous physical activity (MVPA, ≥ 3.5 METs) as measured by Polar Activity during the three-month trial (II). The weeks represent individual weeks from the baseline. The number of participants included to analysis for each week is presented in brackets as (intervention/control). *$p < 0.05$ and **$p < 0.01$ (independent samples t-test) for the weekly difference between two groups. Modified from publication II.

Among completers, there was no difference in the change in anthropometry and fitness measurements from baseline between the intervention and control groups. In both groups, mean body fat and grip strength increased and muscle mass decreased (paired samples t-test, $p < 0.05$). Self-reported PA ($p = 0.029$) and fitness

($p = 0.012$) improved within the intervention group during the trial. The changes in these variables were also statistically significant in relation to the control group ($p = 0.030$ and $p = 0.012$, respectively). In the intervention group, the proportion of participants having less than 0.5 h active time per week decreased from 27.6% to 10.2%. Self-reported sitting time decreased within both groups (1.3 h in the intervention group and 1 h in the control group); however, the change was only statistically significant in the intervention group ($p = 0.008$). More accurate results for occurred changes in self-reported fitness, PA, and sitting time as well as for anthropometry and fitness measurements are presented in study II.

5.3 Feasibility of the mobile service (III)

In study III, a total of 187 (75%, 187/250) participants in the intervention group and 167 (68%) in the control group completed the study and attended the final measurements (Fig. 3). During the whole trial, 1044 visits to the MOPOrtal service were registered by 161 (64%) participants (median: 3, range: 1–202). From those participants, 118 logged on the service more than once and 41 more than five times. The *Clans of Oulu* game was used by 56 subjects. Based on the questionnaire and the log data, the most popular functionalities of the service were PA feedback and diary. In addition, 11% of respondents considered instructions, test, and goals on PA as well as general information on health as important functionalities.

The most common reasons for not logging in to the service were lack of interest or laziness, forgetting, and technical problems. The most common reasons for low usage among those participants who had used the MOPOrtal service were technical problems or discomfort with the PA monitor. Based on the feedback received through the final questionnaire, the development suggestions for the service were a clearer and more visual user interface, more interesting content, as well as a simpler or technically more solid and mature solution.

Those men who visited the MOPOrtal service at least once had a slightly higher body mass index (BMI) (mean difference of 1.2 kg/m^2, 95% CI 0.1 kg/m^2–2.2kg/m^2) and body fat percentage (mean difference of 2.2%, 95% CI 0.1%–4.2%) at baseline compared with the rest of the intervention group. Any other differences were not found in anthropometry and fitness variables at baseline between these two groups.

The total number of valid days measured by Polar Active was 15,364 (76% of all the uploaded data). PA data including at least one valid week was provided by 230 (46.4%, 230/496) participants, the average number of valid weeks per person being ten in the intervention group and seven in the control group. The mean wear time per day was over 15 h in both study groups. By the end of the trial, 178 men in the intervention group (95% of those who completed the study) had unlocked the screen of the PA monitor to show their daily activity. Mean daily time occupied in sedentary behavior at baseline was significantly higher in those participants who uploaded PA data until the end of the trial (n=73) compared with the participants who stopped delivering data (n=94) during the trial (mean 10.7 h vs 10.0 h; (p = 0.024).

5.4 Effects of the mobile service on physical activity, anthropometry, and fitness (III)

Figure 8 presents the objectively measured mean daily time spent in MVPA for the intervention and control groups during the six-month trial. The number of participants with valid PA data for every other week is also presented. Among participants with valid PA data, there was a borderline difference in the change in MVPA between the intervention and control groups (linear mixed model, $p = 0.055$). At the end of the trial (during study weeks 22, 24, and 25), the intervention group spent more time in MVPA compared with the control group (mean difference 11.0–21.7 min/d, $p < 0.05$). The change from baseline was 11.9 (SD 29.2) min in the intervention group and −9.2 (SD 27.5) min in the control group (t-test, $p = 0.004$). During the Christmas period, the intervention group succeeded in maintaining their PA level, whereas the MVPA of the control group dropped during the holidays (t-test, $p < 0.05$; Fig. 8).

The usage frequency of the mobile service was not associated with the change from baseline in the mean daily time spent in MVPA (ρ=0.045, $p = 0.77$). Instead, baseline VPA was inversely associated with the change in daily MVPA time during the trial ($R = -0.382$, $p = 0.01$). There were no statistically significant differences over time in LPA (linear mixed model, $p = 0.527$) or time spent in sedentary behavior ($p = 0.220$) between the study groups (unpublished data). Among those who completed the study (n=354), there was no significant difference in the change in anthropometrics and fitness measurements from baseline between the intervention and control groups. In both groups, weight, waist circumference, body fat, muscle mass, and grip strength increased while estimated maximal aerobic fitness decreased during the trial (data not shown). Within the intervention group, the change in waist circumference differed between those young men who were classified as inactive and active based on TTM (mean change -0.3cm vs 1.7cm, $p = 0.01$).

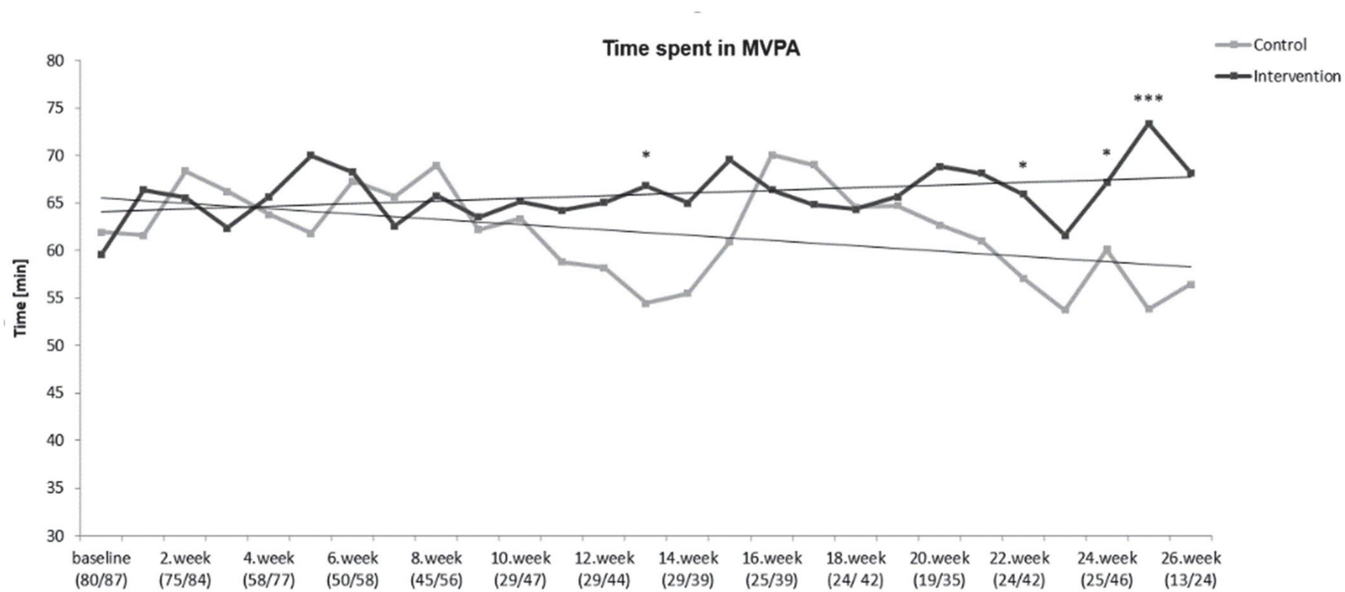

Fig. 8. The mean daily time spent in moderate-to-vigorous physical activity for both study groups as measured by Polar Active during each week of the trial. The weeks represent individual weeks from the baseline. The number of participants included to analysis for every other week is presented in brackets as (control/intervention). *p < 0.05, ***p < 0.001 (independent samples t-test) for the weekly difference between two groups. Modified from publication II

6 Discussion

6.1 Validation study (I)

Study I revealed that in daily life conditions, the agreement in time spent in different PA intensity levels between the mean amplitude deviation (MAD) of raw acceleration from the hip, wrist-worn Polar Active, and hip-worn Actigraph with the Freedson thresholds is dependent on the selected activity thresholds and PA intensity among middle-aged people. However, good agreement between the used methods was found for the fulfillment of the daily recommendation for MVPA of 60 min.

Overall, the wrist-worn Polar Active resulted in the highest amount of MVPA and the lowest amount of sedentary time with both MET threshold sets compared to the other two methods. In MVPA time, the difference was most evident for vigorous activity. The results of Polar Active were more in line with the results of the other methods when the standard Polar Active thresholds were used. These results are in accordance with the previous findings. In a previous study conducted among children, Polar Active with the Polar-defined threshold (< 2METs) overestimated sedentary time, whereas Polar Active with the widely used threshold (< 1.5METs) underestimated sedentary time compared to hip-worn Actigraph GT3X+ and wrist-worn Actigraph GT9X (Kim & Lochbaum, 2018). In contrast to our study, Kim and Lochbaum (2018) used Evenson's cut-points for Actigraph GT3X+ and Chandler's cut-points for Actigraph GT9X in their study. Previous studies have shown that wrist-worn monitors measure higher activity output than hip-worn monitors (Hildebrand et al., 2014), regardless of whether a dominant or non-dominant hand has been used as a placement site (Dieu et al., 2017). In addition, a study using an Actigraph monitor placed both on the wrist and hip to determine sedentary time showed that wrist-worn methods underestimate time spent in sedentary behavior (Marcotte et al., 2020). When indirect calorimetry has been used as the criterion measure, hip-worn monitors have been shown to be more accurate in comparison to wrist-worn monitors in classifying activities into intensity categories and estimating activity EE (Rosenberger et al., 2013). However, there is evidence that the outcomes are very similar between hip and wrist when appropriate site-specific equations are used (Crouter, Flynn, & Bassett, 2015; Trost, Zheng, & Wong, 2014).

In study I, deviating results were also observed between the two hip-worn methods. With both used thresholds for LPA, MAD resulted in significantly lower outcomes compared to Actigraph. However, comparable results between the monitors might have been achieved if the raw Actigraph data had been analyzed with the universal MAD approach (Aittasalo et al., 2015; Vähä-Ypyä et al., 2015). However, due to the long-term data collection, raw data for the Actigraph monitor was not available. Of all the used methods, Actigraph resulted in the lowest amount of VPA. One explanatory factor might be the used filter in Actigraph that detects accelerations from a frequency range of 0.25–2.5 Hz. However, a human body can produce accelerations up to 3.4 Hz when performing VPA and the device is attached to the hip (higher frequencies are achieved when measured from the wrist). As a result, the filtering process of Actigraph might remove accelerations associated with VPA, and consequently, minutes in VPA might be misclassified as MPA. (Migueles et al., 2017)

Another factor that affects the results even more than the location of the monitor is the used thresholds (Migueles, Cadenas-Sanchez, Tudor-Locke et al., 2019; Rowlands et al., 2014). The Freedson thresholds have been stated to overestimate resting and LPA by 13% and underestimate MPA by 60%, compared to the results from the portable metabolic measurement system (Strath, Bassett Jr., & Swartz, 2003). The Freedson thresholds were developed based on treadmill walking and running (Freedson et al., 1998), and the results from a recent study (Matthews et al., 2018) showed that MVPA estimates derived from ambulatory calibration methods are substantially lower than those derived from methods designed to capture a broader range of activities.

In our study, the ROC analyses showed moderate to high agreement between the different methods for the fulfillment of the recommendation for daily MVPA. In the study conducted among children using ActiGraph GT3X+ accelerometers on the hip and non-dominant wrist, the fulfillment of recommendations varied much more between different measurement and analysis methods, from almost zero to nearly everyone meeting the guidelines (Migueles et al., 2019). Zenko et al. (2019) showed in their study that compliance with the PA recommendations among adults is greatly influenced by the 10-min bout requirement and whether the thresholds representing lifestyle activities or ambulatory activities is used. While estimating the fulfillment of PA recommendations among different populations, it is always worth noting that the current recommendations have been defined on the basis of self-reported data. Moreover, in the light of recent research findings, even light PA is better for health than sitting still (Farrahi et al., 2021; Füzéki et al., 2017), and thus, in the future it might be appropriate to promote PA in reference to one's own current behavior instead of the general recommendations based on time spent in MVPA (Zenko, Willis, & White, 2019). In terms of data analysis, in general, it is nowadays recommended to use raw acceleration data and PA indicators which are not influenced by thresholds (e.g., mean of the acceleration metric per day) enabling better comparability between the results measured with different devices and between different studies (Freedson et al., 2012; Migueles et al., 2019).

6.2 Compliance with wearing wrist-worn activity monitors (II, III)

The overall compliance with wearing PA monitor in studies II and III remained rather low. The number of participants who provided accelerometer data including at least one valid week during the trials was 53% in study II and 46% in study III. The actual frequency of wearing the activity monitor is not known based on the available results. Most probably some participants used the activity monitor but did not provide the data to the database. However, based on the uploaded activity data, the average usage time of the monitor per day covered the waking hours in both trials effectively. The number of participants with valid week data decreased markedly in studies II and III until the end of trial compared with the first week. In study III, adherence to uploading PA data was higher among those participants whose baseline sedentary time was higher.

Also, in previous studies adolescents and young adults have been shown to have poor compliance with a monitoring protocol (Lee, Macfarlane, & Lam, 2013; Lubans, Smith, Skinner, & Morgan, 2014; Troiano et al., 2008). In the study of Lee et al. (2013), compliance with wearing the activity monitor was lower the younger the participant was, among participants over 15 years of age. The results of a study conducted among high-school students showed that older students showed poorer compliance with wearing the accelerometer compared to younger students. Based on the results, it might be possible to improve compliance by delivering contingent compensation. (Sirard & Slater, 2009) The compliance to provide accelerometer data in studies II and III correspond well with the results of the three-month intervention study by Slootmaker et al. (2010), in which 56% of the accelerometer users uploaded their activity data to the coaching service, with only 24% doing it regularly. In a study which reported the development and implementation of a smartphone app to promote PA among adolescent boys, 30% of participants self-monitored their PA regularly with a pedometer (Lubans et al., 2014). During our six-month trial (III), 22% of participants uploaded activity data regularly while in the three-month trial (II) the amount was 31% (PA data was available for around four-fifths of the study weeks).

In our study, a wrist-worn activity monitor was chosen because of its user-friendliness to increase wear compliance (Troiano et al., 2014). Adolescents have been shown to find wrist-worn monitors more comfortable and less embarrassing compared to monitors worn on hip (Scott et al., 2017). In study III, user-friendliness was increased by allowing participants to choose a more preferred color of monitor from two options (black or white). The compliance to provide accelerometer data could have been enhanced with a simpler and more advanced communication system, such as wireless Bluetooth. In addition, the use of an inbuilt accelerometer on a mobile phone could have increased compliance among young men. However, although utilizing a mobile phone for recording PA does not require the wearing of an extra monitor, the challenge can be to carry the mobile phone alongside you during all daily activities.

In both studies II and III, the participants of both study groups met the PA recommendation by achieving approximately 60 minutes of MVPA per day. The proportion is higher than in previous national studies (Ministry of Social Affairs and Health, 2013). As highlighted in the previous paragraph, this may be partly explained by the used wrist-worn measurement method. One challenge with wrist-worn methods is that wrist movements may exist during sedentary behavior without any changes in total EE (Rosenberger et al., 2013). The average sedentary time in both of our studies was around 10 h per day, which corresponds well with earlier findings concerning the sitting habits of adolescents (Matthews et al., 2008).

6.3 Effects of wrist-worn activity monitor feedback on physical activity behavior, anthropometry, and fitness (II)

In study II, the three-month intervention had a short-term positive effect on measured daily PA and sedentary time among young men aged 18 years. The positive change remained longer in sedentary behavior than in MVPA. Self-perceived fitness improved within the intervention group; however, there was no difference in the change in measured fitness and anthropometry from the baseline between the two study groups. Only a low number of participants in the intervention group visited the pilot version of the gamified mobile service (Luoto et al., 2014), and therefore, observed changes in outcome variables can be assumed to result primarily from the use of the wrist-worn PA monitor providing activity feedback.

Our study was one of the first intervention studies in which the objective measurement of PA with continuous feedback has been used with the aim of increasing PA and decreasing sedentary behavior among young men. A previous review article has shown that wearable activity trackers have the potential to increase activity levels in the short-term among young people (Ridgers, McNarry, & Mackintosh, 2016). However, most of the studies included in the review were conducted among children. The results from the study by Slootmaker et al. (2010) support our findings regarding sedentary behavior. They used accelerometers showing feedback in the form of activity scores in their three-month trial among adolescents aged 13–17, resulting in positive change in sedentary behavior among the boys. The statistically significant difference between the intervention and control groups (30 h/week) was revealed at follow-up after 8 months. However, in contrast to study II, the participants were relatively inactive adolescents, and the intervention effect was evaluated based on self-reported PA only. (Slootmaker et al., 2010) The change that occurred in time spent on sedentary behavior is an important result. In light of recent research findings, movement of any intensity is better than time spent being sedentary (Farrahi et al., 2021; Matthews et al., 2015).

The results of previous studies using a pedometer for self-monitoring are in line with our findings. A systematic review found that the use of pedometers increased PA by 2,500 steps per day in adults (Bravata et al., 2007). Similar results have been observed among children and adolescents. Based on the review by Lubans et al. (2009), it seems that among adolescents, especially those individuals who are less active at the baseline, improve their PA more in pedometer-based interventions. The same effect was revealed in our study while the proportion of the most inactive men (< 0.5 h/week) decreased by 17% based on self-reports in the intervention group during the trial. Contradictory results have also been published, as a recent study demonstrated that a minimalist PA tracker-based intervention was most effective among those young adolescents who were already active at baseline (Gaudet et al., 2017).

The short-term effect of our three-month trial on daily PA-related behavior may be partly explained by the fact that self-monitoring alone is not enough to keep young people motivated. In a three-month trial called Raising Awareness of Physical Activity (RAW-PA), which was targeted at inactive adolescents (mean age 13.7 years), the participants agreed that the use of a wearable activity monitor increased their PA motivation and awareness. However, the motivation to achieve a daily activity goal was maintained for only a short time. (Koorts et al., 2020) In a recent review article (Brickwood, Watson, O'Brien, & Williams, 2019), consumer-based wearable activity trackers were found to be an effective way of increasing activity among people over the age of 18. However, an intervention effect was found to be greater when the wearable activity tracker was used as part of a broader multifaceted intervention.

In terms of measured physical fitness and anthropometry, the three-month trial had similar effects on both study groups. The intervention may have been too short in terms of time to reveal any positive changes in measured fitness, even if lifestyle changes had taken place. During the trial, fall turned into a cold winter, which may have affected the PA behavior and nutrition habits of the participants (Tucker & Gilliland, 2007). These possible changes could explain the negative changes that occurred in body fat and muscle mass. The increment in grip strength could be partly explained by the learning effect.

6.4 Feasibility of the mobile service (III)

During the six-month trial (III), the overall compliance with the MOPOrtal service remained relatively low. The functionalities related to PA were perceived as the most important and motivating parts of the service by MOPOrtal users. Nevertheless, as mentioned earlier, adherence to uploading activity data to the service was low among participants. The usability of the service was reduced by technical problems, fragmented functionalities, and to some degree immature user interface design.

The low usage of behavioral change services has been identified as one of the biggest problems while using internet-based interventions (Kohl et al., 2013). In several studies the use of an app or a service dropped after the first month (Flores-Mateo et al., 2015). In a study where a mobile phone app was used together with a face-to-face school-based program in adolescent boys, the overall use of the app was occasional and 20% of participants did not use the app at all during the 20 study weeks (Lubans et al., 2014). In Portugal, the technology acceptance of a mobile app called TeenPower, developed to promote healthy behaviors, was studied among adolescents with a mean age of 13 years. Although young people found the app useful and easy to use, only 33% activated their profile. (Dias, Frontinia, & Sousa, 2019) In our study, 64% of the intervention group participants registered with the service but only 16% logged on to the service more than five times. Adherence to accelerometer-linked web-based intervention protocols has been better in shorter studies (Guthrie et al., 2015) and among older participants (Ashton, Morgan, Hutchesson, Rollo, & Collins, 2017; Harries et al., 2016; Hurling et al., 2007; Middelweerd et al., 2020).

In our study, anthropometry as well as sedentary time at baseline were related to the use of the MOPOrtal service. Participants who visited the service at least once during the trial had a slightly higher BMI and body fat percentage compared to the rest of the intervention group participants. In addition, higher sedentary time at baseline was associated with the participant continuing to upload activity data until the end of the trial. The presence of several behavioral risk factors, such as high BMI and insufficient PA, has been shown to be positively related to a willingness to use technology for health promotion purposes among adolescents (Tercyak, Abraham, Graham, Wilson, & Walker, 2009).

In the MOPOrtal service, both gamification and tailoring were utilized to make the service more attractive, relevant, and interesting. The service contained game mechanics that have been found to be the most effective in gamified e-Health apps such as social features, progress tracking, and rewards (Sardi et al., 2017). The most important gamification elements considered by the young people (e.g., competition and incentives) were also present in the *Clans of Oulu* game, even in the team-based form which is particularly favored by young men (Corepal et al., 2018). However, the game was played by only 22% of the participants in the intervention group. Even though the idea of the *Clans of Oulu* game received positive feedback by the young people who took part in the study, the lack of activity and competition in the game reduced its appeal (Luoto et al., 2014).

In our study, interest and frequency of use of the service could potentially have been increased by providing greater social support, for example, via email or telephone (Brouwer et al., 2011; Hamel et al., 2011). Additional training in the use of the MOPOrtal service could also have been beneficial as the recruitment situation in the call-ups included a lot of information and activities as well as excitement concerning one's own future, which could confuse some of the participants (Luoto et al., 2014). In the future, usability and feasibility could be improved by enabling the monitoring of PA on multiple different monitors and devices. In addition, the automatic synchronization of activity data from a monitor to the service, as is the case today, would increase usability.

6.5 Effects of the mobile service on physical activity, anthropometry, and fitness (III)

In study III, among completers with valid PA data, a positive trend in favor of the intervention group was observed in daily time spent in MVPA over the six-month trial. No differences were found in time spent in LPA or in sedentary behavior between the study groups. A low amount of daily VPA at baseline was associated with an increase in MVPA. The mobile service had no effect on anthropometry or fitness, except reduced waist circumference in the most inactive young men within the intervention group.

Our study was one of the first web-based intervention studies related to PA and implemented in a home setting among young men (Ashton et al., 2014). Unlike in many previous studies (Hamel et al., 2011; Lau et al., 2011), any face-to-face meetings after the baseline measurements were not included in our study. This study design allows the evaluation of the impact based on the web-based service only. However, we are not able to distinguish whether the intervention effect is a result of the MOPOrtal service, or the feedback given by the Polar Active monitor. What we do know is that the usage frequency of the mobile service was not associated with a change from baseline in the mean daily time spent in MVPA.

Overall, previous health interventions have obtained only modest evidence for the efficacy of mobile apps to improve PA and sedentary behavior (Direito et al., 2017; Schoeppe et al., 2016). In a review article concerning the efficacy or effectiveness of mHealth technologies to promote PA in adolescents, five of the 13 studies that included a control condition showed significant improvement in PA measures (A. M. Lee et al., 2019). Including goal-setting, self-monitoring, and feedback in the design of the application, as was done also in our study, has been shown to lead to better results (Eckerstorfer et al., 2018; Schoeppe et al., 2016). A 12-week app-based intervention study aiming to increase weekly levels of MVPA had no positive effect on main outcome compared with the control condition in a recent study conducted in the Netherlands among young adults. The implementers raised the technical problems related to the app as one of the major challenges occurred during the intervention. (Middelweerd et al., 2020) Also in our study, technical problems were one of the most common reasons for not using the service.

More promising results have also been obtained. In a six-week pilot intervention study (Guthrie et al., 2015) conducted among adolescents aged 11–14 years and in which an activity monitor was used together with an online incentive motivation system (the Zamzee system), participants in the intervention group spent approximately 50% more time in MVPA per day compared with the participants of the active and passive control groups (15.3 min vs. 9.1/10.3 min per day). The intervention effect remained the same throughout the trial and a sex difference was revealed in the magnitude of intervention effects in favor of the male participants. (Guthrie et al., 2015) Harries et al. (2016) implemented an eight-week intervention study among men aged 22–40 years using a series of automated text messages and an always-on accelerometer-based smartphone app that delivered feedback on step counts. Compared to the control group, the number of daily steps increased in both intervention groups who received feedback. One intervention group received feedback based on their own walking and the other group received both personal and group-level feedback. (Harries et al., 2016) A fully automated web-based behavior change system including continuous-time measurement of PA was tested among adults in a nine-week intervention study. The intervention resulted in a 20 min difference per day in the time spent in MPA in the intervention group compared with the control group. (Hurling et al., 2007)

In previous studies, the use of an app in conjunction with other intervention strategies, such as SMS, motivational email, telephone coaching, and/or face-to-face meetings, have been shown to lead to better and more permanent results concerning the change in PA behavior (Schoeppe et al., 2016; Van Hoye et al., 2015). In a three-month intervention which contained similar elements to our study e.g., website, wearable device, and health information but also face-to-face sessions, weekly MVPA increased significantly in the intervention group compared to the control group among young men aged 18–25 years (128 min/week difference in a mean change between the study groups at 3 months) (Ashton et al., 2017).

Confirming the clinical effectiveness and the added value of gaming in changing daily PA has not been possible. One reason is the lack of a theoretical foundation of gamified PA apps. (Sardi et al., 2017) Our gamified service was built utilizing a well-founded theory. However, we used the same gamification elements regardless of which stage of change according to the TTM a participant was at. Some evidence exists that the same gamification elements may have different effects on individuals in different stages (Schmidt-Kraepelin, Warsinsky, Thiebes, & Sunyaev, 2020). In our study, the impact of gamification on results is challenging to assess while gamification elements were an integral part of the MOPOrtal service. A previous study that compared the effectiveness of the quantified and gamified approaches (virtual rewards and social comparison) to present PA data using an accelerometer-based mobile app called StepByStep did not result in any differences between the outcome measures obtained by different methods among young adults aged 20–27 years (Zuckerman & Gal-Oz, 2014). A fully-automated eight-week training program conducted among participants aged 14–17 years found no significant differences in the change in fitness and PA among the intervention groups using either an immersive app with gamified elements or a nonimmersive app compared to the control group. However, the design and features of the immersive app were seen as being more motivating. (Direito et al., 2015) A seven-week intervention study among undergraduate students in China utilized game elements such as peer support, accountability, competition, and reward on a social media platform (WeChat) and resulted in a significant increase in self-assessed MPA and VPA in the intervention group (Mo et al., 2019).

One factor suggesting that we were on the right track is the Pokémon GO game, which gained popularity around the world a few years ago. There are a lot of similar elements in the games of Clans of Oulu and Pokémon GO. Both are played on a mobile phone and based on the location of a user tracked using the mobile phone's GPS. In addition to conquering areas, one of the tasks of the Clans of Oulu game was to collect stars and cards based on the locations shown on the map. Pokémon GO has been shown to increase PA in all age groups but especially in the 10–30 age group (Althoff, White, & Horvitz, 2016). Several studies have also shown that Pokémon GO activates those who are more inactive at baseline in particular (Althoff et al., 2016; Ma et al., 2018).

In contrast to study II, in this six-month study (III) no changes were revealed in the sedentary behavior of young men. The result is similar to the findings of a recently published systematic review and meta-analysis (Brickwood et al., 2019) showing that interventions using only wearable activity monitors had a greater positive effect on sedentary behaviors than multifaceted interventions. One explanatory factor may be the longer duration of the multifaceted interventions compared to those interventions that included only the use of an activity monitor (Brickwood et al., 2019). In a 12-month intervention study among adolescents at risk of type 2 diabetes (Patrick et al., 2013), a decrease in sedentary time (from 4.9 to 2.8 h/d) was observed among those participants who only had access to the program website with no change in the other two intervention groups, one of which included weekly text messages and the other monthly group sessions in addition to the use of the website. In the review article by Scoeppe et al. (2016), which focused on the efficacy of health and fitness apps, two of the five interventions which were targeted at decreasing sedentary behavior reported positive changes in the main outcome.

In study III, the participants of the control group showed a clear decrease in the amount of MVPA during the Christmas holidays. A similar change did not occur in the intervention group. In a previous study, the holiday season in December has been shown to have a negative impact on body fat in college students (Hull, Hesterand, & Fields, 2006). In addition, PA behavior has been shown to have seasonal differences among adolescents, young adults, and adults. After the summer, PA usually starts to decline, reaching its lowest level during the winter months (Carson & Spence, 2010; Merchant, Dehghan, & Akhtar-Danesh, 2007; Pivarnik, Reeves, & Rafferty, 2003). In study III, the corresponding trend can be seen among the control group, as the trial began in the fall and ended at the end of the winter season.

The low adherence to the use of the MOPOrtal service and the minor addition in MVPA time might be reasons why our intervention had no positive effect on anthropometry and fitness among the completers. Our study may also have been too short for revealing changes in fitness variables. A 12-week pilot mHealth intervention aimed at improving body weight, BMI, nutrition, and PA resulted in positive changes in body weight and LPA among young adults. However, the results of the intervention group did not differ from the changes observed in the control group. (Hebden L. et al., 2014) A systematic review and meta-analysis by Flores-Mateo et al. (2015) found evidence of a positive effect of mobile interventions on weight and BMI, but mainly among adults at increased risk of obesity. A more recent meta-analysis including 12 studies involving an mHealth intervention revealed significant changes in body weight and BMI regardless of the age group (Islam, Poly, Walther, & Li, 2020). In addition to the mobile application, some level of face-to-face counseling has been shown to support the development of anthropometry and fitness (Allen, Stephens, Dennison Himmelfarb, Stewart, & Hauck, 2013), also among young men (Ashton et al., 2017).

In study III, most of the intervention group participants (74%) were already at the maintenance or action stage of PA adaptation at the baseline of the trial. This can partially explain the small intervention effect. In addition, it can be discussed whether the used behavior change model (TTM), which has been originally developed for changing unhealthy behavior (Prochaska & DiClemente, 1983), is the best option for a situation where participants are already active at the beginning of the trial. The results could have been different if only inactive young men had been recruited for the study. This is supported by the difference in change in waist circumference between inactive and active participants as well as by the fact that MVPA time increases especially among those who spend less time in VPA at baseline. Additionally, adherence to uploading PA data until the end of the trial was higher in those participants whose baseline sedentary time was higher. It has also been shown that during our six-month trial, self-rated health and life satisfaction improved most among those participants of the intervention group who perceived these variables to be weaker at baseline (Pyky et al., 2017).

6.6 Strengths, limitations, and future perspectives (I–III)

The main strength of study I was the long two-week measurement period in free-living conditions. In addition, the monitors were conscientiously used by the study participants, the mean wear time effectively covering waking hours as well as the whole measurement period. The main strengths of studies II and III were the large sample size, the randomized controlled design as well as the long-term and continuous measurement of PA behavior within both study groups. The continuous PA measurement allowed an objective assessment of the change in PA behavior as well as real-time feedback on the intervention group. Most studies aimed at promoting PA have used either self-reports, pedometers, or periodic measurement of PA with accelerometers to reveal the possible occurred changes in PA behavior (Bort-Roig et al., 2014; Direito et al., 2017). In addition, compared to the more often used school-based programs, the home-based setting without any face-to-face-meetings after the baseline measurements allows for better generalizability of the intervention (Ashton et al., 2014).

The recruitment of the study participants in connection with the annual military call-ups poses its own challenges but provides a unique way to obtain a large, truly population-based study sample. In the six-month trial (III), no differences were revealed in anthropometry and fitness between the study participants and those conscription-aged men who only took part in the fitness measurement during the call-ups. Although the study group with 496 participants is large compared to the other studies in the field, we did not achieve a study sample large enough based on the power calculation (335 persons per group). Thus, with a larger sample size the achieved results could have been stronger. Motivated participants are a prerequisite for a successful eHealth intervention. However, the high percentage of young men who declined to participate in the six-month trial during the call-ups showed a limited level of motivation among conscription-aged men. In addition, some of the participants might not participate in the study because of their own interests but rather as a result of pressure from the environment (participating with a group of friends or because they thought participation was mandatory) (Luoto et al., 2014).

On the other hand, launching the trial at the military call-ups could be a confusing factor, as the upcoming military service may have motivated young men to increase their daily PA. In addition, since the annual call-ups are arranged in September, the findings are confounded by the seasonal variations in PA (Carson & Spence, 2010).

Concerning the validation study (I), one limitation was the fact that we did not use indirect calorimetry or doubly labeled water as a reference method. However, these two methods provide the mean EE over the period of interest but those cannot reveal specific patterns of PA behavior. The technical problems encountered in the used monitors during the measurement period of study I further reduced the limited number of participants included in the analyses (27 participants out of 41). Including only the vertical axis from the Actigraph in the analysis can also be seen as a limitation. However, a previous study showed consistent results when uniaxial and triaxial Actigraph data were compared (Kelly et al., 2013). In addition, originally the regression equation of Freedson et al. (1998) has been created with a uniaxial accelerometer. In study I, some consistency between the used devices were found at group level, but it is important to note that differences at an individual level could still be quite large. In study II, one limitation was the lack of a baseline week before the trial onset. However, there were no differences between the intervention and control groups in self-reported baseline PA levels. In both studies II and III, one of the major limitations was the missing PA data, the amount of which increased toward the end of the trials. Because of the limited memory of the Polar Active monitor, PA data needed to be uploaded to the database at least every three weeks by the study participants, otherwise older data would be overwritten by new activity data. The participants of the intervention groups got some level of PA feedback straight from the activity monitor, which may have contributed to the fact that some of the participants did not see a need to provide their PA data to the database. In study III, the requirement for the number of valid days (three days out of seven) was lower than what is generally recommended (a minimum of four days) (Migueles et al., 2017). However, the three valid day criterion has also been used in studies conducted among young people to achieve the best compromise between sample size and reliability of the measure (Cain et al., 2013). For all three studies (I–III), one limiting factor was the narrow age ranges of the participants, limiting the generalizability of the findings.

The development of the MOPOrtal service on the whole was an ambitious goal. We wanted to create a fully automated service that leverages gamification elements and a strong theoretical background. We piloted the service and involved people representing the actual target age group in the design of the service. In future studies, gamification should be an inseparable and coherent part of the mobile service. In addition, the integration of activity data into the service, especially regarding data transfer, should be further developed in order to reduce the incidence of technical problems. To motivate those young men who are not interested in PA but might benefit from PA information and guidance, more persuasive and behavior-change-supporting intelligence should be implemented. Additional tailoring based, for example, on PA profiling (Pyky et al., 2015) should be considered. Additional improvements are also needed to engage the user to maintain the interest in using the service for a longer time. In addition, mobile services need to be further examined among other target populations, and more research is needed to determine what elements and features make an intervention effective.

7 Conclusions

The present study examined the convergent validity between three different accelerometer-based PA measurement methods and evaluated the effectiveness of a wrist-worn activity monitor and a gamified web-based mobile service in promoting PA and decreasing sedentary behavior among young men. Based on the aims of this study, it can be concluded that:

1. In daily life conditions, the agreement between Polar Active, mean amplitude deviation for raw acceleration data, and Actigraph with Freedson equation varied by the selected thresholds as well as by the intensity of PA. However, moderate to high agreement between these three methods was found for the fulfillment of the recommendation for daily MVPA of 60 min.
2. The use of a wrist-worn PA monitor had a short-term positive effect on measured daily PA and sedentary time in a representative sample of young Finnish men aged 18 years. The positive change in sedentary behavior remained longer than the change in MVPA.
3. The six-month gamified mobile intervention including the use of a wrist-worn PA monitor resulted in a borderline difference in the change in mean daily time spent in MVPA in favor of the intervention group. A low amount of daily VPA at baseline was associated with an increase in MVPA during the trial. Any changes were not revealed in daily sedentary time or LPA of the participants. The overall compliance of the gamified mobile service remained low. The service functionalities related to PA were the most important to users.

The information provided by this study can be utilized in the future development of tailored gamified services for activating young people. Promoting PA behavior at a young age provides early intervention for preventing any future adverse health effects.

References

2018 Physical Activity Guidelines Advisory Committee. (2018). *2018 Physical activity guidelines advisory committee scientific report.* Washington, DC: U.S. Department of Health and Human Services.

Adams, S. A., Matthews, C. E., Ebbeling, C. B., Moore, C. G., Cunningham, J. E., Fulton, J., & Hebert, J. R. (2005). The effect of social desirability and social approval on self-reports of physical activity. *American Journal of Epidemiology, 161*(4), 389-398. doi:10.1093/aje/kwi054

Ahola, R., Pyky, R., Jämsä, T., Mäntysaari, M., Koskimäki, H., Ikäheimo, T. M., . . . Korpelainen, R. (2013). Gamified physical activation of young men - a multidisciplinary population-based randomized controlled trial (MOPO study). *BMC Public Health, 13*, 32-2458-13-32. doi:10.1186/1471-2458-13-32; 10.1186/1471-2458-13-32

Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett Jr., D. R., Tudor-Locke, C., . . . Leon, A. S. (2011). 2011 compendium of physical activities: A second update of codes and MET values. *Medicine and Science in Sports and Exercise, 43*(8), 1575-1581. doi:10.1249/MSS.0b013e31821ece12

Aittasalo, M., Vähä-Ypyä, H., Vasankari, T., Husu, P., Jussila, A., & Sievänen, H. (2015). Mean amplitude deviation calculated from raw acceleration data: A novel method for classifying the intensity of adolescents' physical activity irrespective of accelerometer brand. *BMC Sports Science, Medicine and Rehabilitation, 7:18.* doi:10.1186/s13102-015-0010-0

Allen, J. K., Stephens, J., Dennison Himmelfarb, C. R., Stewart, K. J., & Hauck, S. (2013). Randomized controlled pilot study testing use of smartphone technology for obesity treatment. *Journal of Obesity, 2013.* doi:10.1155/2013/151597

Althoff, T., White, R. W., & Horvitz, E. (2016). Influence of Pokémon GO on physical activity: Study and implications. *Journal of Medical Internet Research, 18*(12). doi:10.2196/jmir.6759

Ashton, L. M., Hutchesson, M. J., Rollo, M. E., Morgan, P. J., & Collins, C. E. (2014). A scoping review of risk behaviour interventions in young men. *BMC Public Health, 14*(1). doi:10.1186/1471-2458-14-957

Ashton, L. M., Morgan, P. J., Hutchesson, M. J., Rollo, M. E., & Collins, C. E. (2017). Feasibility and preliminary efficacy of the 'HEYMAN' healthy lifestyle program for young men: A pilot randomised controlled trial. *Nutrition Journal, 16*(1), 1-17. doi:10.1186/s12937-017-0227-8

Atkin, A. J., Gorely, T., Clemes, S. A., Yates, T., Edwardson, C., Brage, S., . . . Biddle, S. J. H. (2012). Methods of measurement in epidemiology: Sedentary behaviour. *International Journal of Epidemiology, 41*(5), 1460-1471. doi:10.1093/ije/dys118

Audrey, S., Bell, S., Hughes, R., & Campbell, R. (2013). Adolescent perspectives on wearing accelerometers to measure physical activity in population-based trials. *European Journal of Public Health, 23*(3), 475-480. doi:10.1093/eurpub/cks081

Bassett, D. R., Troiano, R. P., Mcclain, J. J., & Wolff, D. L. (2014). Accelerometer-based physical activity: Total volume per day and standardized measures. *Medicine and Science in Sports and Exercise, 47*(4), 833-838. doi:10.1249/MSS.0000000000000468

Borodulin, K., Lakka, T., Laatikainen, T., Laukkanen, R., Kinnunen, H., & Jousilahti, P. (2004). Associations of self-rated fitness and different types of leisure time physical activity with predicted aerobic fitness in 5979 Finnish adults. *Journal of Physical Activity and Health, 1*(2), 142-153. doi:10.1123/jpah.1.2.142

Bort-Roig, J., Gilson, N. D., Puig-Ribera, A., Contreras, R. S., & Trost, S. G. (2014). Measuring and influencing physical activity with smartphone technology: A systematic review. *Sports Medicine, 44*(5), 671-686. doi:10.1007/s40279-014-0142-5

Bouten, C. V. C., Koekkoek, K. T. M., Verduin, M., Kodde, R., & Janssen, J. D. (1997). A triaxial accelerometer and portable data processing unit for the assessment of daily physical activity. *IEEE Transactions on Biomedical Engineering, 44*(3), 136-147. doi:10.1109/10.554760

Brage, S., Westgate, K., Franks, P. W., Stegle, O., Wright, A., Ekelund, U., & Wareham, N. J. (2015). Estimation of free-living energy expenditure by heart rate and movement sensing: A doubly-labelled water study. *PLoS ONE, 10*(9). doi:10.1371/journal.pone.0137206

Bravata, D. M., Smith-Spangler, C., Sundaram, V., Gienger, A. L., Lin, N., Lewis, R., . . . Sirard, J. R. (2007). Using pedometers to increase physical activity and improve health: A systematic review. *Journal of the American Medical Association, 298*(19), 2296-2304. doi:10.1001/jama.298.19.2296

Brickwood, K., Watson, G., O'Brien, J., & Williams, A. D. (2019). Consumer-based wearable activity trackers increase physical activity participation: Systematic review and meta-analysis. *Journal of Medical Internet Research, 21*(4). doi:10.2196/11819

Broekhuizen, K., Kroeze, W., Van Poppel, M. N. M., Oenema, A., & Brug, J. (2012). A systematic review of randomized controlled trials on the effectiveness of computer-tailored physical activity and dietary behavior promotion programs: An update. *Annals of Behavioral Medicine, 44*(2), 259-286. doi:10.1007/s12160-012-9384-3

Brouwer, W., Kroeze, W., Crutzen, R., de Nooijer, J., de Vries, N. K., Brug, J., & Oenema, A. (2011). Which intervention characteristics are related to more exposure to internet-delivered healthy lifestyle promotion interventions? A systematic review. *Journal of Medical Internet Research, 13*(1), e2. doi:10.2196/jmir.1639

Brugniaux, J. V., Niva, A., Pulkkinen, I., Laukkanen, R. M. T., Richalet, J., & Pichon, A. P. (2010). Polar activity watch 200: A new device to accurately assess energy expenditure. *British Journal of Sports Medicine, 44*(4), 245-249. doi:10.1136/bjsm.2007.045575

Butte, N. F., Ekelund, U., & Westerterp, K. R. (2012). Assessing physical activity using wearable monitors: Measures of physical activity. *Medicine and Science in Sports and Exercise, 44*(1 Suppl 1), S5-12. doi:10.1249/MSS.0b013e3182399c0e; 10.1249/MSS.0b013e3182399c0e

Cain, K. L., Sallis, J. F., Conway, T. L., Van Dyck, D., & Calhoon, L. (2013). Using accelerometers in youth physical activity studies: A review of methods. *Journal of Physical Activity & Health, 10*(3), 437-450. doi: 10.1123/jpah.10.3.437

Carson, V., & Spence, J. C. (2010). Seasonal variation in physical activity among children and adolescents: A review. *Pediatric Exercise Science, 22*(1), 81-92. doi:10.1123/pes.22.1.81

Casazza, K., & Ciccazzo, M. (2007). The method of delivery of nutrition and physical activity information may play a role in eliciting behavior changes in adolescents. *Eating Behaviors, 8*(1), 73-82. doi:10.1016/j.eatbeh.2006.01.007

Caspersen, C. J., Powell, K. E., & Christenson, G. (1985). Physical activity, exercise and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports, 100*(2), 126-131.

Cerin, E., Cain, K. L., Oyeyemi, A. L., Owen, N., Conway, T. L., Cochrane, T., . . . Sallis, J. F. (2016). Correlates of agreement between accelerometry and self-reported physical activity. *Medicine and Science in Sports and Exercise, 48*(6), 1075-1084. doi:10.1249/MSS.0000000000000870

Chau, J. Y., Grunseit, A. C., Chey, T., Stamatakis, E., Brown, W. J., Matthews, C. E., . . . Van Der Ploeg, H. P. (2013). Daily sitting time and all-cause mortality: A meta-analysis. *PLoS ONE, 8*(11) doi:10.1371/journal.pone.0080000

Chen, K. Y., & Bassett Jr., D. R. (2005). The technology of accelerometry-based activity monitors: Current and future. *Medicine and Science in Sports and Exercise, 37*(11 SUPPL.), S490-S500. doi:10.1249/01.mss.0000185571.49104.82

Conroy, M. B., Yang, K., Elci, O. U., Gabriel, K. P., Styn, M. A., Wang, J., . . . Burke, L. E. (2011). Physical activity self-monitoring and weight loss: 6-month results of the SMART trial. *Medicine and Science in Sports and Exercise, 43*(8), 1568–1574. doi:10.1249/MSS.0b013e31820b9395

Corder, K., Ekelund, U., Steele, R. M., Wareham, N. J., & Brage, S. (2008). Assessment of physical activity in youth. *Journal of Applied Physiology, 105*(3), 977-987. doi:10.1152/japplphysiol.00094.2008

Corepal, R., Best, P., O'Neill, R., Tully, M. A., Edwards, M., Jago, R., . . . Hunter, R. F. (2018). Exploring the use of a gamified intervention for encouraging physical activity in adolescents: A qualitative longitudinal study in northern ireland. *BMJ Open, 8*(4). doi:10.1136/bmjopen-2017-019663

Crouter, S. E., Flynn, J. I., & Bassett, D. R. (2015). Estimating physical activity in youth using a wrist accelerometer. *Medicine and Science in Sports and Exercise, 47*(5), 944-951. doi:10.1249/MSS.0000000000000502

Deliens, T., Deforche, B., De Bourdeaudhuij, I., & Clarys, P. (2015). Determinants of physical activity and sedentary behaviour in university students: A qualitative study using focus group discussions. *BMC Public Health, 15*(1). doi:10.1186/s12889-015-1553-4

Deng, L., Kundur, V., Naga, N. S. J., Ozel, M. K., Yilmaz, E., Ozev, S., . . . Dar, T. (2013). Electrical calibration of spring-mass MEMS capacitive accelerometers. Paper presented at the *Proceedings -Design, Automation and Test in Europe,* Grenoble, France, 571-574. doi: 10.7873/DATE.2013.126

Dias, S. S., Frontinia, R., & Sousa, P. (2019). Implementation of a mobile app (TeenPower) to prevent overweight and obesity: Preliminary results regarding lifestyle and usability. *Procedia Computer Science, 164*, 581-586. doi: 10.1016/j.procs.2019.12.223

Dieu, O., Mikulovic, J., Fardy, P. S., Bui-Xuan, G., Béghin, L., & Vanhelst, J. (2017). Physical activity using wrist-worn accelerometers: Comparison of dominant and non-dominant wrist. *Clinical Physiology and Functional Imaging, 37*(5), 525-529. doi:10.1111/cpf.12337

Direito, A., Carraça, E., Rawstorn, J., Whittaker, R., & Maddison, R. (2017). mHealth technologies to influence physical activity and sedentary behaviors: Behavior change techniques, systematic review and meta-analysis of randomized controlled trials. *Annals of Behavioral Medicine, 51*(2), 226-239. doi:10.1007/s12160-016-9846-0

Direito, A., Jiang, Y., Whittaker, R., & Maddison, R. (2015). Apps for IMproving FITness and increasing physical activity among young people: The AIMFIT pragmatic randomized controlled trial. *Journal of Medical Internet Research, 17*(8). doi:10.2196/jmir.4568

Eckerstorfer, L. V., Tanzer, N. K., Vogrincic-Haselbacher, C., Kedia, G., Brohmer, H., Dinslaken, I., & Corcoran, K. (2018). Key elements of mhealth interventions to successfully increase physical activity: Meta-regression. *JMIR mHealth and uHealth, 6*(11). doi:10.2196/10076

Ekelund, U., Ward, H., Norat, T., Luan, J., May, A., Weiderpass, E., . . . Riboli, E. (2015). Physical activity and all-cause mortality across levels of overall and abdominal adiposity in European men and women : The european prospective investigation into cancer and nutrition study (EPIC). *American Journal of Clinical Nutrition, 101*(3), 613-621. doi: 10.3945/ajcn.114.100065

Ekelund, U., Luan, J., Sherar, L. B., Esliger, D. W., Griew, P., & Cooper, A. (2012). Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA - Journal of the American Medical Association, 307*(7), 704-712. doi:10.1001/jama.2012.156

Ekelund, U., Steene-Johannessen, J., Brown, W. J., Fagerland, M. W., Owen, N., Powell, K. E., . . . Lancet Sedentary Behaviour Working Group. (2016). Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *The Lancet, 388*(10051), 1302-1310. doi:10.1016/S0140-6736(16)30370-1

Ekelund, U., Tomkinson, G., & Armstrong, N. (2011). What proportion of youth are physically active? Measurement issues, levels and recent time trends. *British Journal of Sports Medicine, 45*(11), 859-865. doi:10.1136/bjsports-2011-090190;10.1136/bjsports-2011-090190

Esliger, D. W., Rowlands, A. V., Hurst, T. L., Catt, M., Murray, P., & Eston, R. G. (2011). Validation of the GENEA accelerometer. *Medicine and Science in Sports and Exercise, 43*(6), 1085-93. doi:10.1249/MSS.0b013e31820513be

Esteban-Cornejo, I., Tejero-Gonzalez, C. M., Sallis, J. F., & Veiga, O. L. (2015). Physical activity and cognition in adolescents: A systematic review. *Journal of Science and Medicine in Sport, 18*(5), 534-539. doi:10.1016/j.jsams.2014.07.007

Fanning, J., Mullen, S. P., & Mcauley, E. (2012). Increasing physical activity with mobile devices: A meta-analysis. *Journal of Medical Internet Research, 14*(6). doi:10.2196/jmir.2171

Farrahi, V., Kangas, M., Walmsley, R., Niemelä, M., Kiviniemi, A., Puukka, K., . . . Jämsä, T. (2021). Compositional associations of sleep and activities within the 24-h cycle with cardiometabolic health markers in adults. *Medicine and Science in Sports and Exercise, 53*(2), 324-332. doi: 10.1249/MSS.0000000000002481

Farrahi, V., Niemelä, M., Kangas, M., Korpelainen, R., & Jämsä, T. (2019). Calibration and validation of accelerometer-based activity monitors: A systematic review of machine-learning approaches. *Gait and Posture, 68*, 285-299. doi:10.1016/ j.gaitpost.2018.12.003

Ferney, S. L., & Marshall, A. L. (2006). Website physical activity interventions: Preferences of potential users. *Health Education Research, 21*(4), 560-566. doi:10.1093/her/cyl013

Flores-Mateo, G., Granado-Font, E., Ferré-Grau, C., & Montaña-Carreras, X. (2015). Mobile phone apps to promote weight loss and increase physical activity: A systematic review and meta-analysis. *Journal of Medical Internet Research, 17*(11). doi:10.2196/jmir.4836

Fotheringham, M. J., Owies, D., Leslie, E., & Owen, N. (2000). Interactive health communication in preventive medicine: Internet-based strategies in teaching and research. *American Journal of Preventive Medicine, 19*(2), 113-120. doi:10.1016/S0749-3797(00)00188-4

Freedson, P., Bowles, H. R., Troiano, R., & Haskell, W. (2012). Assessment of physical activity using wearable monitors: Recommendations for monitor calibration and use in the field. *Medicine and Science in Sports and Exercise, 44*(SUPPL. 1), S1-S4. doi:10.1249/MSS.0b013e3182399b7e

Freedson, P. S., Melanson, E., & Sirard, J. (1998). Calibration of the computer science and applications, inc. accelerometer. *Medicine and Science in Sports and Exercise, 30*(5), 777-781. doi:10.1097/00005768-199805000-00021

Freedson, P. S., & Miller, K. (2000). Objective monitoring of physical activity using motion sensors and heart rate. *Research Quarterly for Exercise and Sport, 71*, 21-29. doi:10.1080/02701367.2000.11082782

Füzéki, E., Engeroff, T., & Banzer, W. (2017). Health benefits of light-intensity physical activity: A systematic review of accelerometer data of the National Health and Nutrition Examination Survey (NHANES). *Sports Med., 47*(9), 1769-1793. doi: 10.1007/s40279-017-0724-0

Gal, R., May, A. M., van Overmeeren, E. J., Simons, M., & Monninkhof, E. M. (2018). The effect of physical activity interventions comprising wearables and smartphone applications on physical activity: A systematic review and meta-analysis. *Sports Medicine - Open, 4*(1). doi:10.1186/s40798-018-0157-9

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I., . . . Swain, D. P. (2011). Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Medicine and Science in Sports and Exercise, 43*(7), 1334-1359. doi:10.1249/MSS.0b013e318213fefb

Gaudet, J., Gallant, F., & Bélanger, M. (2017). A bit of fit: Minimalist intervention in adolescents based on a physical activity tracker. *Journal of Medical Internet Research mHealth and uHealth, 5*(7), e92. doi: 10.2196/mhealth.7647

Gibbs, B. B., Hergenroeder, A. L., Katzmarzyk, P. T., Lee, I., & Jakicic, J. M. (2015). Definition, measurement, and health risks associated with sedentary behavior. *Medicine and Science in Sports and Exercise, 47*(6), 1295-1300. doi:10.1249/MSS.0000000000000517

Godino, J. G., Watkinson, C., Corder, K., Marteau, T. M., Sutton, S., Sharp, S. J., . . . van Sluijs, E. M. F. (2013). Impact of personalised feedback about physical activity on change in objectively measured physical activity (the FAB study): A randomised controlled trial. *PLoS ONE, 8*(9). doi:10.1371/journal.pone.0075398

Guthrie, N., Bradlyn, A., Thompson, S. K., Yen, S., Haritatos, J., Dillon, F., & Cole, S. W. (2015). Development of an accelerometer-linked online intervention system to promote physical activity in adolescents. *PLoS ONE, 10*(5). doi:10.1371/journal.pone.0128639

Hallal, P. C., Victora, C. G., Azevedo, M. R., & Wells, J. C. K. (2006). Adolescent physical activity and health: A systematic review. *Sports Medicine, 36*(12), 1019-1030. doi:10.2165/00007256-200636120-00003

Hamel, L. M., Robbins, L. B., & Wilbur, J. (2011). Computer- and web-based interventions to increase preadolescent and adolescent physical activity: A systematic review. *Journal of Advanced Nursing, 67*(2), 251-268. doi:10.1111/j.1365-2648.2010.05493.x

Harries, T., Eslambolchilar, P., Rettie, R., Stride, C., Walton, S., & Van Woerden, H. C. (2016). Effectiveness of a smartphone app in increasing physical activity amongst male adults: A randomised controlled trial. *BMC Public Health, 16*(1). doi:10.1186/s12889-016-3593-9

Hebden, L., Cook, A., van der Ploeg, H.P., King, L., Bauman, A., & Allman-Farinelli, M. (2014). A mobile health intervention for weight management among young adults: A pilot randomised controlled trial. *Journal of Human Nutrition and Dietetics, 27*(4), 322-332. doi:10.1111/jhn.12155

Hildebrand, M., Van Hees, V. T., Hansen, B. H., & Ekelund, U. (2014). Age-group comparability of raw accelerometer output from wrist- and hip-worn monitors. *Medicine and Science in Sports and Exercise, 46*(9), 1816-24. doi:10.1249/MSS.0000000000000289

Hills, A. P., Mokhtar, N., & Byrne, N. M. (2014). Assessment of physical activity and energy expenditure: An overview of objective measures. *Frontiers in Nutrition, 1*(5). doi: 10.3389/fnut.2014.00005

Horton, J. F., Stergiou, P., Fung, T. S., & Katz, L. (2017). Comparison of Polar M600 optical heart rate and ECG heart rate during exercise. *Medicine and Science in Sports and Exercise, 49*(12), 2600-2607. doi:10.1249/MSS.0000000000001388

Hull, H. R., Hesterand, C. N., & Fields, D. A. (2006). The effect of the holiday season on body weight and composition in college students. *Nutrition and Metabolism, 3*:44. doi:10.1186/1743-7075-3-44

Hurling, R., Catt, M., De Boni, M., Fairley, B. W., Hurst, T., Murray, P., . . . Sodhi, J. S. (2007). Using internet and mobile phone technology to deliver an automated physical activity program: Randomized controlled trial. *Journal of Medical Internet Research, 9*(2). doi:10.2196/jmir.9.2.e7

Husu, P., Vähä-Ypyä, H., & Vasankari, T. (2016). Objectively measured sedentary behavior and physical activity of Finnish 7- to 14-year-old children- associations with perceived health status: A cross-sectional study. *BMC Public Health, 16*(1). doi:10.1186/s12889-016-3006-0

Islam, M. M., Poly, T. N., Walther, B. A., & Li, Y. (2020). Use of mobile phone app interventions to promote weight loss: Meta-analysis. *JMIR mHealth and uHealth, 8*(7). doi:10.2196/17039

Jämsä, T., Vainionpää, A., Korpelainen, R., Vihriälä, E., & Leppäluoto, J. (2006). Effect of daily physical activity on proximal femur. *Clinical Biomechanics, 21*(1), 1-7. doi:10.1016/j.clinbiomech.2005.10.003

John, D., Sasaki, J., Staudenmayer, J., Mavilia, M., & Freedson, P. S. (2013). Comparison of raw acceleration from the genea and actigraph™ GT3X+ activity monitors. *Sensors (Switzerland), 13*(11), 14754-14763. doi:10.3390/s131114754

Kahlmeier, S., Wijnhoven, T. M. A., Alpiger, P., Schweizer, C., Breda, J., & Martin, B. W. (2015). National physical activity recommendations: Systematic overview and analysis of the situation in European countries. *BMC Public Health, 15*(1). doi:10.1186/s12889-015-1412-3

Kantomaa, M. T., Tammelin, T. H., Näyhä, S., & Taanila, A. M. (2007). Adolescents' physical activity in relation to family income and parents' education. *Preventive Medicine, 44*(5), 410-415. doi:10.1016/j.ypmed.2007.01.008

Katzmarzyk, P. T. (2010). Physical activity, sedentary behavior, and health: Paradigm paralysis or paradigm shift? *Diabetes, 59*(11), 2717-2725. doi:10.2337/db10-0822

Katzmarzyk, P. T. (2014). Standing and mortality in a prospective cohort of Canadian adults. *Medicine and Science in Sports and Exercise, 46*(5), 940-946. doi:10.1249/MSS.0000000000000198

Kelders, S. M., Sommers-Spijkerman, M., & Goldberg, J. (2018). Investigating the direct impact of a gamified versus nongamified well-being intervention: An exploratory experiment. *Journal of Medical Internet Research, 20*(7), e247. doi:10.2196/jmir.9923

Kelly, L. A., McMillan, D. G. E., Anderson, A., Fippinger, M., Fillerup, G., & Rider, J. (2013). Validity of actigraphs uniaxial and triaxial accelerometers for assessment of physical activity in adults in laboratory conditions. *BMC Medical Physics, 13*(1), 5. doi:10.1186/1756-6649-13-5

King, D., Greaves, F., Exeter, C., & Darzi, A. (2013). 'Gamification': Influencing health behaviours with games. *Journal of the Royal Society of Medicine, 106*(3), 76–78. doi: 10.1177/0141076813480996

Kinnunen, H., Häkkinen, K., Schumann, M., Karavirta, L., Westerterp, K. R., & Kyröläinen, H. (2019). Training-induced changes in daily energy expenditure: Methodological evaluation using wrist-worn accelerometer, heart rate monitor, and doubly labeled water technique. *PLoS ONE, 14*(7). doi:10.1371/journal.pone.0219563

Kinnunen, H., Tanskanen, M., Kyröläinen, H., & Westerterp, K. R. (2012). Wrist-worn accelerometers in assessment of energy expenditure during intensive training. *Physiological Measurement, 33*(11), 1841-1854. doi:10.1088/0967-3334/33/11/1841

Knuth, A. G., & Hallal, P. C. (2009). Temporal trends in physical activity: A systematic review. *Journal of Physical Activity and Health, 6*(5), 548-559. doi:10.1123/jpah.6.5.548

Kohl III, H. W., Fulton, J. E., & Caspersen, C. J. (2000). Assessment of physical activity among children and adolescents: A review and synthesis. *Preventive Medicine, 31*(2), S54-S76. doi:10.1006/pmed.1999.0542

Kohl, L. F. M., Crutzen, R., & De Vries, N. K. (2013). Online prevention aimed at lifestyle behaviors: A systematic review of reviews. *Journal of Medical Internet Research, 15*(7). doi:10.2196/jmir.2665

Koorts, H., Salmon, J., Timperio, A., Ball, K., Macfarlane, S., Lai, S. K., . . . Ridgers, N. D. (2020). Translatability of a wearable technology intervention to increase adolescent physical activity: Mixed methods implementation evaluation. *Journal of Medical Internet Research, 22*(8). doi:10.2196/13573

Koster, A., Caserotti, P., Patel, K. V., Matthews, C. E., Berrigan, D., van Domelen, D. R., . . . Harris, T. B. (2012). Association of sedentary time with mortality independent of moderate to vigorous physical activity. *PLoS ONE, 7*(6). doi:10.1371/ journal.pone.0037696

Lau P.W.C., Lau E.Y., Wong D.P., & Ransdell L. (2011). A systematic review of information and communication technology-based interventions for promoting physical activity behavior change in children and adolescents. *Journal of Medical Internet Research, 13*(3). doi:10.2196/jmir.1533

Lee, A. M., Chavez, S., Bian, J., Thompson, L. A., Gurka, M. J., Williamson, V. G., & Modave, F. (2019). Efficacy and effectiveness of mobile health technologies for facilitating physical activity in adolescents: Scoping review. *JMIR mHealth and uHealth, 7*(2). doi:10.2196/11847

Lee, I., Shiroma, E. J., Kamada, M., Bassett, D. R., Matthews, C. E., & Buring, J. E. (2019). Association of step volume and intensity with all-cause mortality in older women. *JAMA Internal Medicine, 179*(8), 1105-1112. doi:10.1001/jamainternmed.2019.0899

Lee, I., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., Katzmarzyk, P. T., . . . Wells, J. C. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: An analysis of burden of disease and life expectancy. *The Lancet, 380*(9838), 219-229. doi:10.1016/S0140-6736(12)61031-9

Lee, J. A., Williams, S. M., Brown, D. D., & Laurson, K. R. (2015). Concurrent validation of the Actigraph gt3x+, Polar Active accelerometer, Omron HJ-720 and Yamax Digiwalker SW-701 pedometer step counts in lab-based and free-living settings. *Journal of Sports Sciences, 33*(10), 991-1000. doi:10.1080/02640414.2014.981848

Lee, P. H., Macfarlane, D. J., & Lam, T. H. (2013). Factors associated with participant compliance in studies using accelerometers. *Gait and Posture, 38*(4), 912-917. doi:10.1016/j.gaitpost.2013.04.018

Lewis, Z. H., Lyons, E. J., Jarvis, J. M., & Baillargeon, J. (2015). Using an electronic activity monitor system as an intervention modality: A systematic review health behavior, health promotion and society. *BMC Public Health, 15*(1). doi:10.1186/s12889-015-1947-3

Lightfoot, J. T., De Geus, E. J. C., Booth, F. W., Bray, M. S., Den Hoed, M., Kaprio, J., . . . Bouchard, C. (2018). Biological/genetic regulation of physical activity level: Consensus from GenBioPAC. *Medicine and Science in Sports and Exercise, 50*(4), 863-873. doi:10.1249/MSS.0000000000001499

Liukkonen, J., Jaakkola, T., Kokko, S., Gråstén, A., Yli-Piipari, S., Koski, P., . . . Tammelin, T. (2014). Results from Finland's 2014 report card on physical activity for children and youth. *Journal of Physical Activity and Health, 11*, S51-S57. doi:10.1123/jpah.2014-0168

Lowe, S. A., & ÓLaighin, G. (2014). Monitoring human health behaviour in one's living environment: A technological review. *Medical Engineering and Physics, 36*(2), 147-168. doi:10.1016/j.medengphy.2013.11.010

Lubans, D. R., Morgan, P. J., & Tudor-Locke, C. (2009). A systematic review of studies using pedometers to promote physical activity among youth. *Preventive Medicine, 48*(4), 307-315. doi:10.1016/j.ypmed.2009.02.014

Lubans, D. R., Smith, J. J., Skinner, G., & Morgan, P. J. (2014). Development and implementation of a smartphone application to promote physical activity and reduce screen-time in adolescent boys. *Frontiers in Public Health, 2*, 42. doi:10.3389/fpubh.2014.00042

LudoCraft Ltd. (2019). Clans of oulu. Retrieved from http://www.ludocraft.com/education/clans-of-oulu/

Luoto, T., Korpelainen, R., Röning, J., Ahola, R., Enwald, H., Hirvonen, N., . . . Heikkinen, H. I. (2014). Gamified persuasion: User experiences of online activation service. *International Journal of Sociotechnology and Knowledge Development, 6*(4), 1-17. doi:10.4018/ijskd.2014100101

Ma, B. D., Ng, S. L., Schwanen, T., Zacharias, J., Zhou, M., Kawachi, I., & Sun, G. (2018). Pokémon GO and physical activity in Asia: Multilevel study. *Journal of Medical Internet Research, 20*(6). doi:10.2196/jmir.9670

Marcotte, R. T., Petrucci, G. J., Cox, M. F., Freedson, P. S., Staudenmayer, J. W., & Sirard, J. R. (2020). Estimating sedentary time from a hip- and wrist-worn accelerometer. *Medicine and Science in Sports and Exercise, 52*(1), 225-232. doi:10.1249/MSS.0000000000002099

Matallaoui, A., Koivisto, J., Hamari, J., & Zarnekow, R. (2017). How effective is “Exergamification”? A systematic review on the effectiveness of gamification features in exergames. Paper presented at the *Proceedings of the 50th Hawaii International Conference on System Sciences,* Waikoloa, Hawaii, United States of America. 3316-3325.

Matthews, C. E., Chen, K. Y., Freedson, P. S., Buchowski, M. S., Beech, B. M., Pate, R. R., & Troiano, R. P. (2008). Amount of time spent in sedentary behaviors in the United States, 2003-2004. *American Journal of Epidemiology, 167*(7), 875-881. doi:10.1093/aje/kwm390

Matthews, C. E., George, S. M., Moore, S. C., Bowles, H. R., Blair, A., Park, Y., . . . Schatzkin, A. (2012). Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. *American Journal of Clinical Nutrition, 95*(2), 437-445. doi:10.3945/ajcn.111.019620

Matthews, C. E., Hagströmer, M., Pober, D. M., & Bowles, H. R. (2012). Best practices for using physical activity monitors in population-based research. *Medicine and Science in Sports and Exercise, 44*(SUPPL. 1), S68-S76. doi:10.1249/MSS.0b013e3182399e5b

Matthews, C. E., Keadle, S. K., Berrigan, D., Staudenmayer, J., Saint-Maurice, P. F., Troiano, R. P., & Freedson, P. S. (2018). Influence of accelerometer calibration approach on moderate-vigorous physical activity estimates for adults. *Medicine and Science in Sports and Exercise, 50*(11), 2285-2291. doi:10.1249/ MSS.0000000000001691

Matthews, C. E., Moore, S. C., Sampson, J., Blair, A., Xiao, Q., Keadle, S. K., . . . Park, Y. (2015). Mortality benefits for replacing sitting time with different physical activities. *Medicine and Science in Sports and Exercise, 47*(9), 1833-1840. doi:10.1249/MSS.0000000000000621

Mattocks, C., Ness, A., Leary, S., Tilling, K., Blair, S. N., Shield, J., . . . Riddoch, C. (2008). Use of accelerometers in a large field-based study of children: Protocols, design issues, and effects on precision. *Journal of Physical Activity and Health, 5*(SUPPL. 1), S98-S111. doi: 10.1123/jpah.5.s1.s98

Merchant, A. T., Dehghan, M., & Akhtar-Danesh, N. (2007). Seasonal variation in leisure-time physical activity among Canadians. *Canadian Journal of Public Health, 98*(3), 203-208. doi:10.1007/BF03403713

Middelweerd, A., Mollee, J., McA Klein, M., Manzoor, A., Brug, J., & Te Velde, S. J. (2020). The use and effects of an app-based physical activity intervention “Active2Gether” in young adults: Quasi-experimental trial. *Journal of Medical Internet Research Formative Research, 4*(1), e12538. doi:10.2196/12538

Migueles, J. H., Cadenas-Sanchez, C., Ekelund, U., Delisle Nyström, C., Mora-Gonzalez, J., Löf, M., . . . Ortega, F. B. (2017). Accelerometer data collection and processing criteria to assess physical activity and other outcomes: A systematic review and practical considerations. *Sports Medicine, 47*(9), 1821-1845. doi:10.1007/s40279-017-0716-0

Migueles, J. H., Cadenas-Sanchez, C., Rowlands, A. V., Henriksson, P., Shiroma, E. J., Acosta, F. M., . . . Ortega, F. B. (2019). Comparability of accelerometer signal aggregation metrics across placements and dominant wrist cut points for the assessment of physical activity in adults. *Scientific Reports, 9*(1). doi:10.1038/s41598-019-54267-y

Migueles, J. H., Cadenas-Sanchez, C., Tudor-Locke, C., Löf, M., Esteban-Cornejo, I., Molina-Garcia, P., . . . Ortega, F. B. (2019). Comparability of published cut-points for the assessment of physical activity: Implications for data harmonization. *Scandinavian Journal of Medicine and Science in Sports, 29*(4), 566-574. doi:10.1111/sms.13356

Ministry of Social Affairs and Health, Helsinki, Finland. (2013). *ON THE MOVE national strategy for physical activity promoting health and wellbeing 2020.* Helsinki, Finland: Retrieved from https://julkaisut.valtioneuvosto.fi/handle/10024/69943

Mo, D., Xiang, M., Luo, M., Dong, Y., Fang, Y., Zhang, S., . . . Liang, H. (2019). Using gamification and social incentives to increase physical activity and related social cognition among undergraduate students in Shanghai, China. *International Journal of Environmental Research and Public Health, 16*(5). doi:10.3390/ijerph16050858

Mutrie, N., Doolin, O., Fitzsimons, C. F., Grant, P. M., Granat, M., Grealy, M., . . . Skelton, D. A. (2012). Increasing older adults' walking through primary care: Results of a pilot randomized controlled trial. *Family Practice, 29*(6), 633-642. doi:10.1093/fampra/cms038

Norton, K., Norton, L., & Sadgrove, D. (2010). Position statement on physical activity and exercise intensity terminology. *Journal of Science and Medicine in Sport, 13*(5), 496-502. doi:10.1016/j.jsams.2009.09.008

Pate, R. R., Mitchell, J. A., Byun, W., & Dowda, M. (2011). Sedentary behaviour in youth. *British Journal of Sports Medicine, 45*(11), 906-913. doi:10.1136/bjsports-2011-090192

Patrick, K., Norman, G. J., Davila, E. P., Calfas, K. J., Raab, F., Gottschalk, M., . . . Covin, J. R. (2013). Outcomes of a 12-month technology-based intervention to promote weight loss in adolescents at risk for type 2 diabetes. *Journal of Diabetes Science and Technology, 7*(3), 759-770. doi:10.1177/193229681300700322

Paul, D. R., Kramer, M., Moshfegh, A. J., Baer, D. J., & Rumpler, W. V. (2007). Comparison of two different physical activity monitors. *BMC Medical Research Methodology, 7:*26. doi:10.1186/1471-2288-7-26

Peltola, K., Hannula, M., Held, T., Kinnunen, H., Nissilä, S., Laukkanen, R., & Marti, B. (2000). Validity of polar fitness test based on heart rate variability in assessing VO2max in trained individuals. Paper presented at the *5th Annual Congress of the European College of Sport Science,* Jyväskylä, Finland. 565.

Piercy, K. L., Troiano, R. P., Ballard, R. M., Carlson, S. A., Fulton, J. E., Galuska, D. A., . . . Olson, R. D. (2018). The physical activity guidelines for Americans. *JAMA-Journal of the American Medical Association, 320*(19), 2020-2028. doi:10.1001/jama.2018.14854

Pivarnik, J. M., Reeves, M. J., & Rafferty, A. P. (2003). Seasonal variation in adult leisure-time physical activity. *Medicine and Science in Sports and Exercise, 35*(6), 1004-1008. doi:10.1249/01.MSS.0000069747.55950.B1

Plasqui, G., Bonomi, A. G., & Westerterp, K. R. (2013). Daily physical activity assessment with accelerometers: New insights and validation studies. *Obesity Reviews, 14*(6), 451-462. doi:10.1111/obr.12021

Poitras, V. J., Gray, C. E., Borghese, M. M., Carson, V., Chaput, J. -., Janssen, I., . . . Tremblay, M. S. (2016). Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Applied Physiology, Nutrition and Metabolism, 41*(6), S197-S239. doi:10.1139/apnm-2015-0663

Pratt, M., Sarmiento, O. L., Montes, F., Ogilvie, D., Marcus, B. H., Perez, L. G., . . . Wells, J. C. (2012). The implications of megatrends in information and communication technology and transportation for changes in global physical activity. *The Lancet, 380*(9838), 282-293. doi:10.1016/S0140-6736(12)60736-3

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity, 5*(1), 56. doi:10.1186/1479-5868-5-56

Prochaska, J. O., & DiClemente, C. C. (1983). Stages and processes of self-change of smoking: Toward an integrative model of change. *Journal of Consulting and Clinical Psychology, 51*(3), 390-395. doi:10.1037/0022-006X.51.3.390

Pyky, R., Jauho, A-M., Ahola, R., Ikäheimo, T. M., Koivumaa-Honkanen, H., Mäntysaari, M., . . . Korpelainen, R. (2015). Profiles of sedentary and non-sedentary young men - A population-based MOPO study. *BMC Public Health, 15*(1). doi:10.1186/s12889-015-2495-6

Pyky, R., Koivumaa-Honkanen, H., Leinonen, A-M., Ahola, R., Hirvonen, N., Enwald, H., . . . Korpelainen, R. (2017). Effect of tailored, gamified, mobile physical activity intervention on life satisfaction and self-rated health in young adolescent men: A population-based, randomized controlled trial (MOPO study). *Computers in Human Behavior, 72*, 13-22. doi:10.1016/j.chb.2017.02.032

Ridgers, N. D., McNarry, M. A., & Mackintosh, K. A. (2016). Feasibility and effectiveness of using wearable activity trackers in youth: A systematic review. *Journal of Medical Internet Research mHealth and uHealth, 4*(4), e129. doi:10.2196/mhealth.6540

Rose, T., Barker, M., Maria Jacob, C., Morrison, L., Lawrence, W., Strömmer, S., . . . Baird, J. (2017). A systematic review of digital interventions for improving the diet and physical activity behaviors of adolescents. *Journal of Adolescent Health, 61*(6), 669-677. doi:10.1016/j.jadohealth.2017.05.024

Rosenberger, M. E., Haskell, W. L., Albinali, F., Mota, S., Nawyn, J., & Intille, S. (2013). Estimating activity and sedentary behavior from an accelerometer on the hip or wrist. *Medicine and Science in Sports and Exercise, 45*(5), 964-975. doi:10.1249/MSS.0b013e31827f0d9c

Ross, R., & McGuire, K. A. (2011). Incidental physical activity is positively associated with cardiorespiratory fitness. *Medicine and Science in Sports and Exercise, 43*(11), 2189-2194. doi:10.1249/MSS.0b013e31821e4ff2

Rowlands, A. V., Fraysse, F., Catt, M., Stiles, V. H., Stanley, R. M., Eston, R. G., & Olds, T. S. (2015). Comparability of measured acceleration from accelerometry-based activity monitors. *Medicine and Science in Sports and Exercise, 47*(1), 201-10. doi:10.1249/MSS.0000000000000394

Rowlands, A. V., Rennie, K., Kozarski, R., Stanley, R. M., Eston, R. G., Parfitt, G. C., & Olds, T. S. (2014). Children's physical activity assessed with wrist- and hip-worn accelerometers. *Medicine and Science in Sports and Exercise, 46*(12), 2308-2316. doi:10.1249/MSS.0000000000000365

Ryan, J., Edney, S., & Maher, C. (2017). Engagement, compliance and retention with a gamified online social networking physical activity intervention. *Translational Behavioral Medicine, 7*(4), 702-708. doi:10.1007/s13142-017-0499-8

Santos, R., Mota, J., Okely, A. D., Pratt, M., Moreira, C., Coelho-e-Silva, M. J., . . . Sardinha, L. B. (2013). The independent associations of sedentary behaviour and physical activity on cardiorespiratory fitness. *British Journal of Sports Medicine, 48*(20):1508-12. doi:10.1136/bjsports-2012-091610

Santtila, M., Pihlainen, K., Koski, H., Vasankari, T., & Kyröläinen, H. (2018). Physical fitness in young men between 1975 and 2015 with a focus on the years 2005-2015. *Medicine and Science in Sports and Exercise, 50*(2), 292-298. doi:10.1249/MSS.0000000000001436

Sardi, L., Idri, A., & Fernández-Alemán, J. L. (2017). A systematic review of gamification in e-health. *Journal of Biomedical Informatics, 71*, 31-48. doi:10.1016/j.jbi.2017.05.011

Schmidt-Kraepelin, M., Warsinsky, S., Thiebes, S., & Sunyaev, A. (2020). The role of gamification in health behavior change: A review of theory-driven studies. Paper presented at the *Proceedings of the 53rd Hawaii International Conference on System Sciences,* Maui, Hawaii. 1256.

Schoeller, D. A. (1988). Measurement of energy expenditure in free-living humans by using doubly labeled water. *Journal of Nutrition, 118*(11), 1278-1289. doi:10.1093/jn/118.11.1278

Schoeppe, S., Alley, S., Van Lippevelde, W., Bray, N. A., Williams, S. L., Duncan, M. J., & Vandelanotte, C. (2016). Efficacy of interventions that use apps to improve diet, physical activity and sedentary behaviour: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity, 13*(1). doi:10.1186/s12966-016-0454-y

Schoeppe, S., Vandelanotte, C., Bere, E., Lien, N., Verloigne, M., Kovács, É, . . . Van Lippevelde, W. (2017). The influence of parental modelling on children’s physical activity and screen time: Does it differ by gender? *European Journal of Public Health, 27*(1), 152-157. doi:10.1093/eurpub/ckw182

Scott, J. J., Rowlands, A. V., Cliff, D. P., Morgan, P. J., Plotnikoff, R. C., & Lubans, D. R. (2017). Comparability and feasibility of wrist- and hip-worn accelerometers in free-living adolescents. *Journal of Science and Medicine in Sport, 20*(12), 1101-1106. doi:10.1016/j.jsams.2017.04.017

Shephard, R. J. (2003). Limits to the measurement of habitual physical activity by questionnaires. *British Journal of Sports Medicine, 37*(3), 197-206. doi: 10.1136/bjsm.37.3.197

Sieverdes, J. C., Ray, B. M., Sui, X., Lee, D., Hand, G. A., Baruth, M., & Blair, S. N. (2012). Association between leisure time physical activity and depressive symptoms in men. *Medicine and Science in Sports and Exercise, 44*(2), 260-265. doi:10.1249/MSS.0b013e31822e00a6

Sigmundová, D., El Ansari, W., Sigmund, E., & Frömel, K. (2011). Secular trends: A ten-year comparison of the amount and type of physical activity and inactivity of random samples of adolescents in the Czech Republic. *BMC Public Health, 11*, 731. doi:10.1186/1471-2458-11-731

Sirard, J. R., & Slater, M. E. (2009). Compliance with wearing physical activity accelerometers in high school students. *Journal of Physical Activity and Health, 6*(SUPPL. 1), S148-S155. doi:10.1123/jpah.6.s1.s148

Skender, S., Ose, J., Chang-Claude, J., Paskow, M., Brühmann, B., Siegel, E. M., . . . Ulrich, C. M. (2016). Accelerometry and physical activity questionnaires - A systematic review. *BMC Public Health, 16*(1). doi:10.1186/s12889-016-3172-0

Slootmaker, S. M., Chinapaw, M. J. M., Seidell, J. C., van Mechelen, W., & Schuit, A. J. (2010). Accelerometers and internet for physical activity promotion in youth? feasibility and effectiveness of a minimal intervention [ISRCTN93896459]. *Preventive Medicine, 51*(1), 31-36. doi:10.1016/j.ypmed.2010.03.015

Stamatakis, E., Ekelund, U., Ding, D., Hamer, M., Bauman, A. E., & Lee, I. (2019). Is the time right for quantitative public health guidelines on sitting? A narrative review of sedentary behaviour research paradigms and findings. *British Journal of Sports Medicine, 53*(6), 377-382. doi:10.1136/bjsports-2018-099131

Statistics Finland. (2018). Official Statistics of Finland. The use of information and communication technologies by individuals. Retrieved from https://www.stat.fi/til/sutivi/2018/sutivi_2018_2018-12-04_tie_001_en.html

Strath, S. J., Bassett Jr., D. R., & Swartz, A. M. (2003). Comparison of MTI accelerometer cut-points for predicting time spent in physical activity. *International Journal of Sports Medicine, 24*(4), 298-303. doi:10.1055/s-2003-39504

Strath, S. J., Kaminsky, L. A., Ainsworth, B. E., Ekelund, U., Freedson, P. S., Gary, R. A., . . . Swartz, A. M. (2013). Guide to the assessment of physical activity: Clinical and research applications: A scientific statement from the American Heart Association. *Circulation, 128*(20), 2259-2279. doi:10.1161/01.cir.0000435708.67487.da

Tabak, M., Dekker-Van Weering, M., Van Dijk, H., & Vollenbroek-Hutten, M. (2015). Promoting daily physical activity by means of mobile gaming: A review of the state of the art. *Games for Health Journal, 4*(6), 460-469. doi:10.1089/g4h.2015.0010

Tammelin, T., Näyhä, S., Laitinen, J., Rintamäki, H., & Järvelin, M. (2003). Physical activity and social status in adolescence as predictors of physical inactivity in adulthood. *Preventive Medicine, 37*(4), 375-381. doi:10.1016/S0091-7435(03)00162-2

Telama, R., & Yang, X. (2000). Decline of physical activity from youth to young adulthood in Finland. *Medicine and Science in Sports and Exercise, 32*(9), 1617-1622. doi: 10.1097/00005768-200009000-00015

Telama, R., Yang, X., Viikari, J., Välimäki, I., Wanne, O., & Raitakari, O. (2005). Physical activity from childhood to adulthood: A 21-year tracking study. *American Journal of Preventive Medicine, 28*(3), 267-273. doi:10.1016/j.amepre.2004.12.003

Tercyak, K. P., Abraham, A. A., Graham, A. L., Wilson, L. D., & Walker, L. R. (2009). Association of multiple behavioral risk factors with adolescents' willingness to engage in eHealth promotion. *Journal of Pediatric Psychology, 34*(5), 457-469. doi:10.1093/jpepsy/jsn085

Thompson, A. M., McHugh, T., Blanchard, C. M., Campagna, P. D., Durant, M. A., Rehman, L. A., . . . Wadsworth, L. A. (2009). Physical activity of children and youth in Nova Scotia from 2001/02 and 2005/06. *Preventive Medicine, 49*(5), 407-409. doi:10.1016/j.ypmed.2009.09.009

Tremblay, M. S., Aubert, S., Barnes, J. D., Saunders, T. J., Carson, V., Latimer-Cheung, A. E., . . . on behalf of SBRN Terminology Consensus Project Participants. (2017). Sedentary behavior research network (SBRN) – terminology consensus project process and outcome. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 75. doi:10.1186/s12966-017-0525-8

Tremblay, M. S., Colley, R. C., Saunders, T. J., Healy, G. N., & Owen, N. (2010). Physiological and health implications of a sedentary lifestyle. *Applied Physiology, Nutrition and Metabolism, 35*(6), 725-740. doi:10.1139/H10-079

Tremblay, M. S., LeBlanc, A. G., Kho, M. E., Saunders, T. J., Larouche, R., Colley, R. C., . . . Gorber, S. C. (2011). Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 98. doi:10.1186/1479-5868-8-98

Troiano, R. P., Berrigan, D., Dodd, K. W., Mâsse, L. C., Tilert, T., & Mcdowell, M. (2008). Physical activity in the United States measured by accelerometer. *Medicine and Science in Sports and Exercise, 40*(1), 181-188. doi:10.1249/mss.0b013e31815a51b3

Troiano, R. P., McClain, J. J., Brychta, R. J., & Chen, K. Y. (2014). Evolution of accelerometer methods for physical activity research. *British Journal of Sports Medicine, 48*(13), 1019-23. doi:10.1136/bjsports-2014-093546

Trost, S. G., Mciver, K. L., & Pate, R. R. (2005). Conducting accelerometer-based activity assessments in field-based research. *Medicine and Science in Sports and Exercise, 37*(11 SUPPL.), S531-S543. doi:10.1249/01.mss.0000185657.86065.98

Trost, S. G., Pate, R. R., Freedson, P. S., Sallis, J. F., & Taylor, W. C. (2000). Using objective physical activity measures with youth: How many days of monitoring are needed? *Medicine and Science in Sports and Exercise, 32*(2), 426-431. doi:10.1097/00005768-200002000-00025

Trost, S. G., Wong, W., Pfeiffer, K. A., & Zheng, Y. (2012). Artificial neural networks to predict activity type and energy expenditure in youth. *Medicine and Science in Sports and Exercise, 44*(9), 1801-1809. doi:10.1249/MSS.0b013e318258ac11

Trost, S. G., Zheng, Y., & Wong, W. (2014). Machine learning for activity recognition: Hip versus wrist data. *Physiological Measurement, 35*(11), 2183-2189. doi:10.1088/0967-3334/35/11/2183

Tucker, P., & Gilliland, J. (2007). The effect of season and weather on physical activity: A systematic review. *Public Health, 121*(12), 909-922. doi:10.1016/j.puhe.2007.04.009

Tudor-Locke, C., Bassett, D. R., Shipe, M. F., & McClain, J. J. (2011). Pedometry methods for assessing free-living adults. *Journal of Physical Activity & Health, 8*(3), 445-453. doi:10.1123/jpah.8.3.445

Vähä-Ypyä, H., Vasankari, T., Husu, P., Mänttäri, A., Vuorimaa, T., Suni, J., & Sievänen, H. (2015). Validation of cut-points for evaluating the intensity of physical activity with accelerometry-based mean amplitude deviation (MAD). *PloS One, 10*(8). doi:10.1371/journal.pone.0134813

Vähä-Ypyä, H., Vasankari, T., Husu, P., Suni, J., & Sievänen, H. (2015). A universal, accurate intensity-based classification of different physical activities using raw data of accelerometer. *Clinical Physiology and Functional Imaging, 35*(1), 64-70. doi:10.1111/cpf.12127; 10.1111/cpf.12127

Väinämö, K., Nissilä, S., Mäkikallio, T., Tulppo, M., & Röning, J. (1996). Artificial neural networks for aerobic fitness approximation. Paper presented at the *Proceedings of the 1996 IEEE International Conference on Neural Networks, ICNN. Part 1 (of 4),* Washington, DC, USA. 1939-1944.

Van Der Ploeg, H. P., Chey, T., Korda, R. J., Banks, E., & Bauman, A. (2012). Sitting time and all-cause mortality risk in 222 497 Australian adults. *Archives of Internal Medicine, 172*(6), 494-500. doi:10.1001/archinternmed.2011.2174

Van Hecke, L., Loyen, A., Verloigne, M., van der Ploeg, H. P., Lakerveld, J., Brug, J., . . . Deforche, B. (2016). Variation in population levels of physical activity in European children and adolescents according to cross-European studies: A systematic literature review within DEDIPAC. *International Journal of Behavioral Nutrition and Physical Activity, 13*(1). doi:10.1186/s12966-016-0396-4

Van Hoye, K., Boen, F., & Lefevre, J. (2015). The impact of different degrees of feedback on physical activity levels: A 4-week intervention study. *International Journal of Environmental Research and Public Health, 12*(6), 6561-6581. doi:10.3390/ijerph120606561

Vandelanotte, C., Spathonis, K. M., Eakin, E. G., & Owen, N. (2007). Website-delivered physical activity interventions. A review of the literature. *American Journal of Preventive Medicine, 33*(1), 54-64. doi:10.1016/j.amepre.2007.02.041

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: The evidence. *The Canadian Medical Association journal, 174*(6), 801-809. doi:10.1503/cmaj.051351

Ward, D. S., Evenson, K. R., Vaughn, A., Rodgers, A. B., & Troiano, R. P. (2005). Accelerometer use in physical activity: Best practices and research recommendations. *Medicine and Science in Sports and Exercise, 37*(11 SUPPL.), S582-S588. doi:10.1249/01.mss.0000185292.71933.91

Watson, K. B., Carlson, S. A., Carroll, D. D., & Fulton, J. E. (2014). Comparison of accelerometer cut points to estimate physical activity in US adults. *Journal of Sports Sciences, 32*(7), 660-669. doi:10.1080/02640414.2013.847278

Welk, G. J., Blair, S. N., Wood, K., Jones, S., & Thompson, R. W. (2000). A comparative evaluation of three accelerometry-based physical activity monitors. *Medicine and Science in Sports and Exercise, 32*(9 SUPPL.), 489-497. doi:10.1097/00005768-200009001-00008

Welk, G. J., McClain, J., & Ainsworth, B. E. (2012). Protocols for evaluating equivalency of accelerometry-based activity monitors. *Medicine and Science in Sports and Exercise, 44*(SUPPL. 1), S39-S49. doi:10.1249/MSS.0b013e3182399d8f

Wen, C. P., Wai, J. P. M., Tsai, M. K., Yang, Y. C., Cheng, T. Y. D., Lee, M., . . . Wu, X. (2011). Minimum amount of physical activity for reduced mortality and extended life expectancy: A prospective cohort study. *The Lancet, 378*(9798), 1244-1253. doi:10.1016/S0140-6736(11)60749-6

World Health Organization (Ed.). (2010). *Global recommendations on physical activity for health*. Geneva, Switzerland: WHO Press.

Wu, S., Cohen, D., Shi, Y., Pearson, M., & Sturm, R. (2011). Economic analysis of physical activity interventions. *American Journal of Preventive Medicine, 40*(2), 149-158. doi:10.1016/j.amepre.2010.10.029

Wylie-Rosett, J., Swencionis, C., Ginsberg, M., Cimino, C., Wassertheil-Smoller, S., Caban, A., . . . Lewis, J. (2001). Computerized weight loss intervention optimizes staff time: The clinical and cost results of a controlled clinical trial conducted in a managed care setting. *Journal of the American Dietetic Association, 101*(10), 1155-1162. doi: 10.1016/s0002-8223(01)00284-x

Yang, C., & Hsu, Y. (2010). A review of accelerometry-based wearable motion detectors for physical activity monitoring. *Sensors, 10*(8), 7772-7788. doi:10.3390/s100807772

Zenko, Z., Willis, E. A., & White, D. A. (2019). Proportion of adults meeting the 2018 physical activity guidelines for Americans according to accelerometers. *Frontiers in Public Health, 7*, 135. doi:10.3389/fpubh.2019.00135

Zuckerman, O., & Gal-Oz, A. (2014). Deconstructing gamification: Evaluating the effectiveness of continuous measurement, virtual rewards, and social comparison for promoting physical activity. *Personal and Ubiquitous Computing, 18*(7), 1705-1719. doi:10.1007/s00779-014-0783-2

Original articles

I Leinonen, A-M., Ahola, R., Kulmala, J., Hakonen, H., Vähä-Ypyä, H., Herzig, K-H., Auvinen, J., Keinänen-Kiukaanniemi, S., Sievänen, H., Tammelin, T., Korpelainen, R., & Jämsä, T. (2017). Measuring physical activity in free-living conditions – Comparison of three accelerometry-based methods. Frontiers in Physiology, 7:681. doi: 10.3389/fphys.2016.00681

II Jauho, A-M., Pyky, R., Ahola, R., Kangas, M., Virtanen, P., Korpelainen, R., & Jämsä, T. (2015). Effect of wrist-worn activity monitor feedback on physical activity behavior: A randomized controlled trial in Finnish young men. Preventive Medicine Reports, 2: 628–634. doi:10.1016/j.pmedr.2015.07.005

III Leinonen, A-M., Pyky, R., Ahola, R., Kangas, M., Siirtola, P., Luoto, T., Enwald, H., Ikäheimo, TM., Röning, J., Keinänen-Kiukaanniemi, S., Mäntysaari, M., Korpelainen, R., & Jämsä, T. (2017). Feasibility of gamified mobile service aimed at physical activation in young men: a population-based randomized controlled MOPO study. Journal of Medical Internet Research mHealth and uHealth, 5(10):e146. doi:10.2196/mhealth.6675

Original publications are not included in the electronic version of the thesis.

1592. Juntunen, Mikael (2020) Technical and algorithmic approaches for medical photon counting computed tomography in the example of coronary artery calcium quantification

1593. Ilo, Arjaleena (2020) Infrared thermography in vascular disorders : screening and follow-up

1594. Daddali, Ravindra (2020) Molecular mechanisms regulating the onset of labor : comparative proteomics and miRNAomics of human spontaneous and elective labors

1595. Niemi-Nikkola, Ville (2021) Spinal fractures and spinal cord injuries : incidence, epidemiological characteristics and survival

1596. Nurkkala, Marjukka (2021) Häiriintynyt syömiskäyttäytyminen, paino ja fyysinen aktiivisuus : nuoret miehet ja ylipainoiset työikäiset

1597. Eteläinen, Sanna (2021) Gestational diabetes : screening, diagnosis and consequences

1598. Roininen, Nelli (2021) New prognostic markers and prognosis in various breast cancer subtypes

1599. Hyrkäs-Palmu, Henna (2021) Cold weather-related sensitivity among asthmatics and determinants affecting it

1600. Haukilahti, Anette (2021) Sudden cardiac death, cardiac mortality, and morbidity in women : electrocardiographic risk markers

1601. Lukkari, Sari (2021) Association between perinatal and childhood risk factors with mental disorders in adolescence

1602. Karjula, Salla (2021) Long-term consequences of polycystic ovary syndrome on mental health and health-related quality of life

1603. Kinnunen, Lotta (2021) The association of parental somatic illness with offspring's mental health

1604. Jaurila, Henna (2021) Tissue repair and metabolic dysfunction in sepsis

1605. Kiviahde, Heikki (2021) Occlusal characteristics in Northern Finland Birth Cohort (NFBC) 1966 subjects : a longitudinal study

1606. Fouda, Shaimaa (2021) Studies on tooth loss, mandibular morphology and dental prostheses: clinical, radiological and *in vitro* examinations

Book orders:
Virtual book store
http://verkkokauppa.juvenesprint.fi

UNIVERSITY OF OULU P.O. Box 8000 FI-90014 UNIVERSITY OF OULU FINLAND

ACTA UNIVERSITATIS OULUENSIS

UNIVERSITY OF OULU

ISBN 978-952-62-2886-0 (Paperback)
ISBN 978-952-62-2887-7 (PDF)
ISSN 0355-3221 (Print)
ISSN 1796-2234 (Online)