Doctoral thesis for the degree of Doctor of Philosophy (PhD) in Medical Science

Physical activity and well-being among adolescents

A public health perspective

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In my letters to my children, I regularly urged them to exercise.

Nelson Mandela, *Long walk to freedom*, 1994

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ABSTRACT

Background: Physical activity among adolescents is diminishing and worldwide about 80% of 13–15-year-old adolescents do not meet the public health guidelines of minimum 60 minutes of daily physical activity of at least moderate intensity. This decline in physical activity has serious consequences as lack of physical activity adversely affects physical and mental health. As physical activity patterns develop during childhood/adolescence and are tracked into adulthood, diminished physical activity during adolescence can negatively influence health and well-being later in life.

Aims: The specific aims of this Thesis were to 1) Examine age-related differences in physical activity and depressive symptoms among 10–19-year-old adolescents; 2) Explore potential effects of a pedometer- and diary-based physical activity intervention on 15–16-year-old adolescents' physical activity and subjective sleep quality; and 3) Investigate the effects of a pedometer- and diary-based physical activity intervention on physical activity among 15–16-year-old adolescents.

Methods: Cross-sectional, semi-longitudinal population-based data from Iceland were used to examine differences in age-related physical activity and depressive symptoms. In a pilot-study, a 2-x-2 factorial design was applied to test the effects of a pedometer- and diary-based intervention. Finally, a randomized controlled trial (RCT) with 4-x-4 factorial design was applied to test the effectiveness of using pedometers, diaries or combination of both in a physical activity intervention.

Results: A decrease occurred in physical activity from the age of 15 with an increase in depressive symptoms during the age from 10 to 19 in Icelandic

adolescents. Gender differences were apparent with girls being less active and having higher levels of depressive symptoms than boys. The intervention in the pilot-study was effective in increasing physical activity among 15–16-year-old adolescents as the intervention group had significantly higher step-count compared to the control group at follow-up. Additionally, subjective sleep quality improved over time in the intervention group. The RCT demonstrated further the effectiveness of the intervention with pedometers alone being equally effective in increasing physical activity as pedometers in combination with diaries.

Conclusion: This Thesis provides important information about when to tailor public health efforts to enhance physical activity and well-being among adolescents. Brief physical activity interventions based on pedometers were effective in increasing daily steps and improving sleep quality among adolescents. This has important public health relevance as the intervention is cost-effective and can easily be disseminated and incorporated into schools' curricula.

Keywords: Adolescents, physical activity, depressive symptoms, sleep quality, intervention, pedometer, school setting, health promotion, public health

SAMMANFATTNING PÅ SVENSKA

Bakgrund: Fysisk aktivet bland barn och ungdomar minskar och över hela världen når 80% av ungdomarna i åldrarna 13-15 år inte upp till de rekommenderade riktlinjerna av minst 60 minuters daglig fysisk aktivitet av minst moderat intensitet. Denna reduktion i fysisk aktivitet har allvarliga konsekvenser eftersom brist på sådan aktivitet har negativa effekter för både fysisk och mental hälsa. Eftersom vanor för fysisk aktivitet grundläggs tidigt under barn- och ungdomsåren och följer oss ända upp i vuxen ålder, kan minskad fysisk aktivitet under ungdomsåren ha en negativ effekt på båda hälsa och välbefinnande senare i livet.

Syfte: Avhandling avser specifikt att undersöka 1) ålders-relaterade skillnader i fysisk aktivitet och depressiva symptom hos ungdomar i åldrarna 10-19 år; 2) möjliga effekter på fysisk aktivitet och subjektiv sömnkvalitet av en intervention med pedometer och dagbok riktad till 15-16 åringar; samt 3) betydelsen av en pedometer- och dagboksbaserad intervention för fysisk aktivitet hos 15-16 åringar.

Metoder: Populationsdata från en semi-longitudinell isländsk tvärsnittsstudie användes för att undersöka skillnader i åldersrelaterad fysisk aktivitet och depressiva symptom. I en pilot-studie användes en 2x2 faktoriell design för att testa effekterna av en intervention med pedometer och dagbok. Vidare användes en randomiserad kontrollerad studie med 4x4 faktoriell design för att testa betydelsen av pedometrar, dagböcker eller en kombination av dessa i samband med en fysisk aktivitets intervention.

Resultat: Avhandlingen visar minskad fysisk aktivitet hos isländska ungdomar från 15-års ålder och en ökning i depressiva symptom i åldrarna 10-19 år. Könsskillnader förekom och flickor var mindre aktiva och hade även högre nivåer av depressiva symptom än pojkar. Interventionen i pilotstudien ökade effektivt den fysiska aktiviteten hos 15-16 åringar. Interventionsgruppen hade signifikant högre antal steg per dag än kontrollgruppen vid uppföljningen. Vidare förbättrades den subjektiva sömnkvaliteten i interventionsgruppen. Den randomiserade kontrollstudien visade även att interventionen var lika effektiv med endast pedometrar än med både pedometrar och dagböcker tillsammans.

Slutsats: Denna avhandling bidrar med viktig information om när i ungdomsåren en insats kan göras för att öka fysisk aktivitet och välbefinnande. En kortvarig intervention för fysisk aktivitet baserad på pedometrar kunde effektivt öka ungdomars dagliga stegantal och deras subjektiva sömnkvalitet. Detta har stor relevans från ett folkhälsovetenskapligt perspektiv eftersom den föreslagna interventionen är kostnadseffektiv och enkelt kan genomföras i skolor genom att t ex inkorporeras i läroplanen.

SAMANTEKT Á ÍSLENSKU

Inngangur: Dregið hefur úr hreyfingu meðal ungmenna og á heimsvísu ná um 80% 13–15 ára ungmenna ekki daglegum viðmiðum um lágmarks hreyfingu af meðalákefð. Skortur á hreyfingu getur haft alvarlegar afleiðingar því hreyfing hefur jákvæð áhrif á líkamlega og andlega heilsu. Á unglingsárum mótast hreyfimynstur einstaklinga sem jafnframt hefur forspárgildi fyrir hreyfingu síðar á lífsleiðinni.

Tilgangur: Markmið þessarar doktorsrannsóknar var að kanna hvernig hreyfing og einkenni þunglyndis þróast á unglingsárum eða frá 10 til 19 ára aldurs. Einnig var markmiðið að rannsaka áhrif hreyfiíhlutunar, með skrefmælum og dagbókum, á hreyfingu og svefngæði 15–16 ára framhaldsskólanema.

Aðferðir: Fyrst var gerð þversniðsrannsókn á um 32 þúsund íslenskum ungmennum þar sem kannaður var munur á hreyfingu og þunglyndiseinkennum eftir aldri. Næst var framkvæmd forrannsókn meðal 80 framhaldsskólanema, með 2x2 þáttagreinandi sniði. Þar voru könnuð áhrif hreyfiíhlutunar á hreyfingu og svefngæði og byggði íhlutunin á skrefmælum og dagbókum. Loks var framkvæmd slembiröðuð meðferðarprófun meðal 240 framhaldsskólanema þar sem kannað var hvort hreyfiíhlutun með skrefmælum og dagbókum yki hreyfingu. Með 4x4 þáttagreinandi sniði var kannað hvort hefði meiri áhif á hreyfingu, skrefmælar eða dagbækur.

Niðurstöður: Niðurstöður doktorsrannsóknarinnar sýna að á unglingsárunum dregur úr hreyfingu, einkum frá 15 ára aldri. Einnig sést aldurs-tengd aukning í einkennum þunglyndis meðal 10 til 19 ára ungmenna. Kynjamunur var greinilegur en stelpur hreyfa sig að jafnaði minna en strákar. Jafnframt koma einkenni þunglyndis frekar fram hjá stelpum en strákum. Íhlutunin sem sett var fram í forrannsókninni hafði marktæk áhrif til góðs bæði á hreyfingu og svefngæði ungmenna. Þegar svefngæði voru skoðuð nánar kom í ljós að það tók þau ungmenni sem juku daglega hreyfingu styttri tíma að sofna á kvöldin. Niðurstöður meðferðarprófunarinnar staðfestu enn frekar jákvæð áhrif íhlutunarinnar á hreyfingu. Í ljós kom að þau ungmenni sem voru með skrefmæla juku marktækt daglega hreyfingu sína. Hinsvegar var ekki munur á skrefmælahópnum og hópnum sem var bæði með skrefmæla og dagbækur. Það er því ljóst að hreyfiíhlutun með skrefmælum var árangursrík því hún jók daglega hreyfingu meðal fyrsta árs framhaldsskólanema.

Ályktanir: Með þessari doktorsrannsókn er sýnt fram á hvernig og hvenær megi framkvæma íhlutanir til að auka hreyfingu og vellíðan meðal ungmenna. Þriggja vikna hreyfiíhlutun með skrefmælum jók daglega hreyfingu og svefngæði meðal fyrsta árs framhaldsskólanema. Þessar niðurstöður eru mikilvægar í lýðheilsufræðilegu samhengi því íhlutun sem þessa má auðveldlega framkvæma í framhaldsskólum án mikils tilkostnaðar. Hér er því um að ræða hagkvæmt og mikilvægt verkefni sem getur haft víðtæk áhrif á vellíðan ungmenna og þar með lýðheilsu landsmanna.

LIST OF PAPERS

This Thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I. **Baldursdottir B,** Valdimarsdottir HB, Krettek A, Gylfason HF, Sigfusdottir ID. Age-related differences in physical activity and depressive symptoms among 10–19-year-old adolescents: A population based study.
Psychology of Sport & Exercise 2016; resubmitted after revision.

II. **Baldursdottir B**, Taehtinen RE, Sigfusdottir ID, Krettek A, Valdimarsdottir HB. Impact of a physical activity intervention on adolescents' subjective sleep quality: A pilot study.
Glob Health Promot. 2016 May 12. pii: 1757975915626112. [Epub ahead of print].

III. **Baldursdottir B**, Valdimarsdottir HB, Elvarsson BTh, Sigfusdottir ID, Krettek A. Increasing physical activity among adolescents: A randomized controlled trial.
Submitted.

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ABBREVIATIONS AND DEFINITIONS

PA	physical activity
MVPA	moderate- to vigorous-intensity physical activity
Org. sports	organized sports
DS	depressive symptoms
SSQ	subjective sleep quality
RCT	randomized controlled trial
ICSRA	Icelandic Centre for Social Research and Analysis
WHO	The World Health Organization
Adolescents	people from age 10 to 19 years according to the WHO definition

1 BACKGROUND

Already Hippocrates and Galen addressed the importance of physical activity for health and well-being and knew that lack of physical activity was detrimental to health even if over-exertion was unwise [1]. Although evidence regarding the positive effects of physical activity on physical and mental health has accumulated since Galen and Hippocrates [2–6], evidence has simultaneously shown a decline in physical activity on the population level, especially during the adolescent years [7–10]. Thus, only about 20% of adolescents worldwide meet the physical activity guidelines [11]. Additionally, mental health problems increase in this age with 10–20% of adolescents facing mental and behavioural problems [12]. This development is of great concern as the foundations for physical activity patterns are laid down in childhood and adolescence and are tracked into adulthood [13–15].

1.1 Adolescent years

Adolescence is defined by the World Health Organization (WHO) as the period between 10 and 19 years and is considered one of the most rapid phases of human development [16]. However, the health of adolescents has not received enough attention which has resulted in less improvements in adolescents' health compared to the health of younger children over the past 50 years [17]. Acknowledging this, WHO has recently put extra focus on adolescents' health [16].

Adolescence is a turbulent and sensitive period with many developmental changes taking place e.g., biological, psychological and sociological. The endocrine, including hormonal, alterations that occur during puberty are responsible for these changes that result for example in changed physical appearance, as well as changed behaviour and feelings [18]. Such changes, in addition to changes in the social and school context, can be frustrating and a burden to adolescents which leads to increased stress levels [19]. This can be especially difficult for those not having enough social support or not being physically active enough as both social support and physical activity can help coping with stress [20,21].

The brain also plays an important role as the developmental changes that are seen in the brain during adolescence are the most dramatic over the human

lifespan [18]. However, the developmental importance and the vulnerability of the adolescent brain, together with indications of greater release of stress hormones in young individuals, may make adolescents more receptive to stress than older individuals [22–24]. Because of the influence of stress on health across the lifespan [23,25,26] and as results show that stress during adolescence strongly associates with depressive disorders in adulthood [27], it is of uttermost importance to find ways for adolescents to better cope with these challenges.

Therefore, although adolescents are often regarded as a healthy group, this period is complicated with many challenges that can both be life-enhancing as well as life-threatening. The risk-seeking behaviour of adolescents together with poor rational decision making could be tentatively explained by a developmental imbalance as there is a disparity in maturation between the limbic system (regulates reward processing, appetite, and pleasure seeking) and the prefrontal cortex region of the brain (the site of executive control functions including decision making, emotional regulation and planning) during early to mid-adolescence [17]. Thus, many adolescents die prematurely because of accidents, suicide, and illnesses that could be preventable or treatable and many more suffer from chronic ill-health and disability with depression being the leading cause [16]. As illnesses and disabilities can hinder adolescents in growing and developing to their full potential as well as having negative influence on their later life, it is important to focus on adolescent health. Therefore, public health initiatives that focus on the adolescent years e.g., physical activity interventions, have the opportunity to improve health both in adolescence and later in life.

1.2 Physical activity

Physical activity can be categorized in relation to e.g., work, transportation, sports, exercise, as well as leisure-time physical activity. A further categorization of leisure-time physical activity is for example sports, conditioning exercises, household tasks and other activities [28,29]. Thus, these categories sometimes overlap which can be confusing. Moreover, although the concepts “physical activity” and “exercise” are often used interchangeably they are not synonymous and a distinction is therefore made between these concepts in this Thesis.

1.2.1 Definition

Physical activity is defined as “any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level” [5,29]. Exercise on the other hand is a subcategory of physical activity

which refers to a planned, structured and repetitive bodily movement with the objective of improving or maintaining health, physical performance, or physical fitness [5,29]. Furthermore, physical fitness is defined as a set of attributes that individuals can obtain by performing physical activity [29] and physical fitness is thus typically defined either in relation to performance or health.

Physical activity can be defined further into three dimensions, e.g., frequency, duration, and intensity and these three dimensions together constitute the amount or the dose of physical activity performed. Moreover, the relationship between the dose of physical activity performed and the fitness or health outcome is considered the dose response relationship [5].

Frequency refers to how often the activity occurs while duration refers to time, i.e., how long the activity lasts. The intensity of physical activity refers to the rate at which the activity is performed or the magnitude of the effort that is required to perform the activity and is therefore important in relation to physical fitness [30]. Thus, moderate-intensity physical activity requires a moderate amount of effort and noticeably accelerates the heart rate, e.g., brisk walking while physical activity of vigorous-intensity requires a large amount of effort and causes rapid breathing and a substantial increase in heart rate, e.g., running [28,30].

Intensity is also defined in relation to the metabolic rate of the body where one metabolic equivalent (MET) is defined as the amount of oxygen consumed while sitting at rest [31]. Further, relative intensity refers to the level of effort required to do an activity while absolute intensity is the amount of energy expended per minute of activity. Accordingly, absolute intensity has been defined into three intervals of metabolic rate <3 METs, 3-5.9 METs, and ≥6 METs which equals to light-, moderate- and vigorous-intensity physical activity, respectively [32]. In relation to public health guidelines for physical activity, the intensity is an important factor.

1.2.2 Guidelines

The first guidelines concerning physical activity were launched in 1975 by the American College of Sports Medicine [33] and later updated in 1980 [34]. These guidelines were more directed towards cardiorespiratory fitness rather than physical activity as such and recommended that people should engage in vigorous-intensity aerobic exercise 3 times/week for 20 min each time [34]. This focus on aerobic exercise dominated the public health messages until the early 1990s [35]. However, as research evidence about the beneficial effects of

moderate-intensity physical activity on health have accumulated, guidelines have changed from focusing primarily on fitness and exercise of vigorous-intensity to emphasize physical activity of moderate-intensity [28,30]. Also, evidence about the dose-response relationship of physical activity now influences the guidelines and emphasizes the importance of moderate active versus sedentary habits [36]. At the same time, evidence of physical inactivity as an independent risk factor for various health outcomes has accumulated [30,37–39].

For children and adolescents, the first physical activity guidelines were published in the United Kingdom in 1998 and were based on studies on children and youth [40]. Before that time, physical activity guidelines for children and adolescents were mostly consistent with the guidelines for adults [40]. The first guidelines for children and adolescents recommended daily physical activity of at least moderate-intensity averaging one hour while the most recent recommendations emphasize the added benefit of more daily physical activity of moderate-to-vigorous intensity or up to several hours per day [41]. The global public health recommendations from the WHO also focus on daily moderate-to-vigorous-intensity physical activity [30] while the older regional guidelines from the European Union only focus on moderate-intensity physical activity of one hour [42]. The national Icelandic guidelines on physical activity for children and adolescents are in accordance with the Nordic regional recommendations [43] as well as the WHO public health recommendations on physical activity [30]. According to these recommendations, children and youth aged 5-18 years should engage in at least 60 minutes/day of moderate- to vigorous-intensity physical activity. The guidelines also recognize the additional health benefits of greater amounts of daily physical activity. Moreover, the WHO guidelines specify that most of the daily physical activity should be aerobic but vigorous-intensity activities, including activities that strengthen muscles and bones, should be incorporated at least three times per week [30]. However, despite numerous health gains of physical activity [3,6,28,44–46], worldwide only about 20% of 13–15-year-olds are meeting the guidelines for daily physical activity [11]. Similarly, in the Nordic countries including Iceland, only between 12 and 23% of 11–15-year-old adolescents are meeting the physical activity guidelines [47]. As physical activity develops during childhood and adolescence and is tracked into adulthood [14,15,48–50] this can have serious consequences for health and well-being also in later life.

1.2.3 Patterns of physical activity

When studying the development of physical activity it is important to differentiate between time-related and age-related trends in physical activity. The unremitting supply of new technologies since the industrial revolution has made it easier for people to perform many work- and household-related tasks with less physical labour needed and less energy expenditure. Additionally, the increasing availability of new devices related to communication and entertainment has resulted in more time spent sedentary. Thus, this development has led to a general decrease over time or time-related decline in physical activity among adults as well as adolescents [11]. However, although an older review of the literature is in agreement with these findings on children [51] still some controversy remains as a more recent review does not support this decline in youth, at least not during the last two decades [52,53].

Interestingly, studies among Amish people show different patterns of physical activity. The lifestyle among this group has remained the same for the last 150 years as they abstain from modern technology and still use labour-intensive farming methods similar to those used before the industrial revolution [54]. Indeed, studies on Amish adults [54] and on Amish and Mennonite children [55–57] show high levels of physical activity compared to people living a contemporary lifestyle. Additionally, there is no age-related decline in physical activity among the Amish people as studies on adults (18–75 years) and youth (6–18 years) show similar amounts of accumulated steps per day or 16.311 and 15.563 steps/day, respectively, averaged over 7 days for both genders [54,56]. Overall, there is no decline in physical activity between 6 and 60 years of age in Amish people [54–56].

The time-related decline in physical activity among contemporary people may have influenced age-related physical activity as the technological revolution may have different impact depending on age. Mounting evidence show age-related decline in physical activity, especially among adolescents [7–10,58–62] which may have a natural, biological basis related to the dopamine system that regulates motivation for locomotion [63]. However, as mentioned above, studies among the Amish people do not support the idea that the age-related decline in physical activity among people living a contemporary lifestyle could be a naturally occurring phenomenon explained by biological alterations in the dopamine system. Thus, the documented health benefits of physical activity [6,28,44,64] are a good reason for finding appropriate methods for

counteracting both the observed age-related and time-related decline of such activity on the population level.

1.3 Well-being and mental health

In 1948, WHO defined health as "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [65]. Accordingly, health has three dimensions i.e., physical, mental and social, which are connected to the concept of well-being. Well-being can therefore be regarded as being a subcategory of health with equal relations to physical, mental and social dimensions. Although concepts of well-being derive from different disciplines, all agree that well-being is more than the absence of disease [66]. Nevertheless, well-being has been more closely related to mental than physical health and the currently accepted definition of mental well-being is feeling good and functioning well [66]. From the standpoint of the science of well-being, the well-being concept is considered as lying at the opposite end of a spectrum to common mental disorders and high well-being is thus equivalent to positive mental health [67]. In this Thesis, well-being is defined as positive mental health. As depressive symptoms and sleep problems may influence well-being and are common among adolescents, they will be a focus of this Thesis. At the same time it is important to realize that focusing only on negative reactions, such as depression, and not for example on life satisfaction and positive emotions makes the picture of well-being incomplete [68].

1.3.1 Depression

According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-V) there are several defined depressive disorders including major depressive disorder (MDD). These disorders have a common feature of the presence of sadness, emptiness, or irritable mood accompanied by somatic and cognitive changes that have significant effect on the individual's capacity to function in life [69]. The diagnostic criterion for MDD is either depressive mood or loss of interest/pleasure or both, for two weeks or more. Also, at least four other symptoms must be associated e.g., disturbed appetite or weight changes, sleeping disturbances, psychomotor agitation, fatigue, feelings of worthlessness, reduced ability to concentrate, or suicidal thoughts [69].

Although, different self-report measures (e.g., The Brief Symptom Inventory, SCL-90) are often used to assess several of these symptoms of depression, they are not intended as clinical diagnostic tools. However, these measures of

depressive symptoms can be used as indications of where on the spectrum of "depressed mood to non-depressed mood" individuals or populations are positioned [70].

Major depression often has its onset in adolescence [71] and at the end of adolescence the lifetime prevalence is up to 25% [72]. Accordingly, increased levels of depression are seen during adolescence [12] with about 4% of 12−17-year-olds and 9% of 18-year-olds experiencing depression, which makes depression one of the most predominant disorders among youth. Additionally, major depression in adolescence has a substantial continuity and associates with morbidity and suicide in adulthood [73].

Evidence show that depressive symptoms in adolescence are associated with increased risk of severe mental illnesses [74] and are strongly predictive of major depression in adulthood [75]. Thus, it is important to put further focus on how depressive symptoms develop during adolescence to be able to tailor interventions aiming at higher well-being.

1.3.2 Sleep quality

As stated above, sleep disturbances can accompany clinical diagnoses of mood disorders such as major depression and thus are one of the depressive symptoms that may impact mental health. The changes in sleep patterns that occur during adolescence, with general reduction of sleep on school days and a delay and lengthening of sleep on weekends, are associated with difficulties falling asleep [76,77]. Not surprisingly, this may result in poor quality of sleep followed by daytime sleepiness as well as impaired school and general functioning [77].

Indeed, poor subjective sleep quality is a common complaint among adolescents [77,78] and a review of the literature suggests that 7-36% of adolescents have problems initiating sleep [77]. Poor subjective sleep quality among adolescents associates with health-related problems such as increased fatigue, anxiety, decreased overall life satisfaction, anger and depression [79], as well as decreased academic performance [80,81]. Thus, it is important to examine feasible ways to enhance sleep quality among adolescents.

1.4 Physical activity and well-being

Physical activity can reduce the harmful effects of stressors, has beneficial effects on brain function [82] and associates with lower stress reactivity in children [83]. In addition, physical activity in adults associates with various health outcomes, including less anxiety and depressive symptoms, elevated mood, improved self-esteem, enhanced physical self-perception, self-efficacy, better cognitive functioning, greater health related quality of life, and efficient stress prevention and reduction [3,82,84,85]. Furthermore, the evidence for both protective and reducing effects of regular physical activity on depression is substantial [5].

Reviews and meta-analyses of studies conducted among adults demonstrate a significant medium to large effect of physical activity on clinical depression [86–89] and also medium effect on depressive symptoms in non-clinical populations [90]. The effects of intensity and duration of the physical activity are unclear but frequency, or becoming physically active instead of sedentary, is the most important factor [88].

There is also increasing evidence for the positive effects of physical activity on adolescents' mental health. Although often small to medium significant effect sizes, physical activity positively influences different mental health outcomes [91] and reduces both clinical depression [64,92,93] and depressive symptoms [92,94] among adolescents.

Additionally, cross-sectional studies suggest that physically active adolescents have more favourable sleep quality than those with more sedentary habits [95,96]. As poor sleep quality is a common complaint among adolescents [77,78] and associates with a variety of health-related problems e.g., depression [79] it is important to study this further. An intervention study, based on vigorous-intensity physical activity (i.e., running) demonstrated positive effects on sleep quality among adolescents [97]. However, interventions based on vigorous-intensity physical activity may not be feasible or realistic in a public health perspective. Therefore, it is interesting to examine if interventions based on physical activity of moderate-intensity e.g., walking, could have positive effects on adolescents' subjective sleep quality as well.

Additionally, although studies among adults [98,99] suggest that physical activity interventions may improve subjective sleep quality, only few physical activity

intervention studies have targeted adolescents' subjective sleep quality. To date, studies have not explored the potential positive effects of pedometer-based physical activity interventions on adolescents' sleep quality.

1.5 Physical activity interventions

Systematic reviews of interventions to promote physical activity among young people show mixed results depending on factors such as study design, settings, study population, and assessment techniques [100,101]. Thus, when conducting an intervention there are many things to consider.

1.5.1 School settings

The school as a setting for interventions has generally been successful and a review of 26 school-based programs for promoting physical activity in children and adolescents clearly demonstrates a positive impact on the duration of moderate-to-vigorous physical activity [102]. A more recent review shows positive effects of school-based interventions on both out-of-school as well as on overall physical activity, a very important finding from a public health perspective [103]. A systematic review of follow-up outcomes from school-based physical activity studies reports positive long-term effects in 10 out of 13 studies and indicates that intervention duration (>1 year) and theoretical approach are important for the sustainability [104]. However, interventions with a constant duration of more than one school year may be difficult to implement in school settings. Thus, it is a challenge to conduct a physical activity intervention in upper-secondary schools, taken the complex school context and curricula into account.

1.5.2 Walking for well-being

Because walking is the type of physical activity that most individuals can easily perform without any equipment or cost, it is of great importance for public health, especially when addressing people that are sedentary. Interestingly, when people walk at self-selected speed the speed is at least of moderate-intensity [105]. Indeed, a meta-analysis of randomized, controlled trials shows that brisk walking, defined as being of moderate-intensity [30], is sufficient to have beneficial effects on cardiovascular fitness of previously sedentary individuals [106]. The general stride rate guidelines recommend 100 steps per minute as the approximate speed that equals 3 METs which is defined as the lower end of

moderate-intensity physical activity interval [107] and these recommendations are confirmed in several studies [107–109].

Evidence from studies on children (mean age 11 years) living a traditional lifestyle, comparable to a lifestyle before the industrial revolution, show a greater amount of physical activity and less time spent sedentary during their recreational time compared to peers living a contemporary lifestyle [57]. Further, an analysis of accumulation bouts demonstrates that the physical activity gap between the traditional and the contemporary lifestyle could be compensated by children intermittently accumulating physical activity throughout the day [57]. Thus, it might be adequate to aim for moderate-intensity physical activity e.g., walking, to bridge this gap.

Indeed, although more pronounced among adults [106,110], recent evidence suggest that interventions to increase walking are also effective among children and adolescents, particularly those conducted in the school environment [111]. However, conclusion on the most effective techniques is hindered by the limited number of walking interventions among this age group and the short-term intervention duration. These findings are promising as walking is practical, inexpensive, easy and a natural form of physical activity.

1.5.3 Pedometer-based interventions

Pedometers are a cost-effective and feasible objective measurement option [112] and evidence from reviews and meta-analyses suggests that pedometer-based interventions are effective in promoting physical activity in children, adults and older adults of both genders [113–115]. For example, a systematic review on the usefulness of pedometers shows that pedometer-based interventions among adults increase physical activity by 30% over baseline, are more effective for those with lower activity level at baseline and for those that use a step-diary [113]. However, although less is known about the effectiveness of pedometers to increase physical activity among healthy adolescents [114,115], nevertheless findings from several studies among young people indicate that step diaries and feedback are important components of pedometer interventions and that these are more effective with low active adolescents [115].

Hence, a 10-week pedometer- and diary-based physical activity intervention among 14-year-old adolescents shows increase in daily steps [116]. Similarly, a 5-week study based on pedometers and daily registration of steps among 13-year-old students shows positive influence on physical activity [117]. Also,

pedometers combined with step-diaries increase total physical activity in 15–16-year-old adolescents, especially girls, thereby eliminating the observed differences in physical activity between genders [118]. Furthermore, pedometers in combination with log-books and educational sessions enhance physical activity among low-active 16-year-old girls [119]. Additionally, an intervention study among 16-year-old adolescents demonstrates positive results when pedometers and self-efficacy theory are combined in a school-based physical activity intervention program [120] and pedometers combined with a physical activity logbook increase physical activity in 18-year-old adolescents [121].

According to the above discussed studies on adolescents, diaries with daily registration of steps in combination with pedometers are the most commonly observed intervention components although both feedback and educational sessions are also mentioned. However, all of the above studies use multicomponent interventions and therefore do not demonstrate if pedometers alone are effective in increasing physical activity or if other components are needed, e.g., physical activity diaries.

1.6 Research on Icelandic adolescents

There are indications of decrease in physical activity and increase in depressive symptoms among Icelandic adolescents. For example, a study on 14–15-year-old adolescents in Iceland demonstrates that less than half of them achieve recommended levels of participation in physical activity [122]. Similarly, 66% of 18-year-old Icelandic adolescents do not meet the guidelines of daily physical activity as their daily step count is below 10.000 steps per day [123]. Furthermore, when starting upper-secondary schools, 16-year-old adolescents tend to drop out of organized sport activities [124].

Additionally, 14–15-years-old Icelandic adolescents exhibit time-related increase in depressive symptoms between 1997 and 2006 [125]. Results from studies among Icelandic adolescents also demonstrate that physical activity decreases the likelihood of depressed mood in this age group [21]. A study on sleep habits among Icelanders shows increase in daytime sleepiness and napping with a simultaneous decrease in nocturnal sleep time during adolescence [126]. Interestingly, when sleep habits of Icelandic adolescents are compared with their peers around the world, Icelandic adolescents consistently have delayed bedtimes and shorter nocturnal sleep [77,126].

With the relative share of physical education being only about 10% of the total taught time in the European compulsory school system, including Iceland, and with an even lower share in secondary schools [127] it is important to find ways to enhance physical activity among adolescents. As schools are effective settings for behavioural interventions [102,103] and as 94% of Icelandic adolescents enrol in upper-secondary schools [128], an intervention effort at this stage is critical. Thus, from a public health point of view, a physical activity intervention directed at moderate-intensity activity i.e., primarily walking, may be attractive and doable for the majority of students, independent of gender and social class.

In summary, adolescence is a turbulent period where many physical, psychosocial and environmental changes take place, potentially influencing individual stress levels and well-being. When entering secondary schools, adolescents are adapting to many changes including school workloads, responsibilities, support networks, new environments as well as developmental and hormonal changes. Considering such substantial changes and demands which adolescents are challenged with it is important to focus on this age group and examine the relationship between their level of physical activity and mental well-being, e.g., depressive symptoms and sleep quality. In Iceland, this is especially important in relation to the large attendance proportion of Icelandic adolescents at upper-secondary schools but also because of the relatively high dropout of 22% during the first year of upper-secondary schools [128].

2 AIMS

The overall aim of this Thesis was to examine physical activity and well-being among adolescents' with special emphasis on depressive symptoms and quality of sleep.

The specific aims were to:

1) Examine age-related differences in physical activity and depressive symptoms among 10–19-year-old adolescents (Paper I).

2) Explore potential effects of a pedometer- and diary-based physical activity intervention on 15–16-year-old adolescents' physical activity and subjective sleep quality (Paper II).

3) Investigate the effects of a pedometer- and diary-based physical activity intervention on physical activity among 15–16-year-old adolescents (Paper III).

3 THEORETICAL FRAMEWORK

The Theory of Reasoned Action (TRA) has been successful in furthering our understanding of exercise intentions and physical activity behaviours and has helped to move research on physical activity from being largely atheoretical to theoretical. The Theory of Planned Behaviour (TPB) is a revised edition of TRA and is an attempt to account for behaviour under "incomplete" volitional control which is most likely the case for physical activity where certain resources and skills are required [129]. TPB posits that intensions/actual behaviour is determined by three primary predictors: 1) attitudes, 2) subjective norms, and 3) perceived behavioural control. According to Azjen and others [130,131] these three predictors are determined by beliefs, which are considered the cognitive and affective foundations of these predictors. TPB has been used to understand participation in a wide range of behaviours including physical activity [129]. From the TPB literature it is expected that the intervention will alter/change the main components of the TPB assessed at baseline and that these changes will serve as mediators for the intervention.

As discussed above (section 1.5.3), intervention strategies that are effective among adolescents consist for example of goal-setting in combination with pedometers and physical activity logbooks/diaries as motivational and/or educational tools [115–119,121]. Thus, we use TPB as guidance when designing the physical activity interventions (Paper II and III). More specifically, to influence participants' attitudes towards and evaluations of the behaviour we use an educational approach with information on the beneficial effects of physical activity, emphasizing the importance of moderate-intensity physical activities such as walking. To influence the theory's construct of subjective norms, or the social pressure to perform the behaviour, we introduce the intervention on a school level, addressing whole classes of students. Lastly, to influence the construct of perceived behavioural control, or participants' confidence about his or her ability to perform the behaviour, we use physical activity diaries and pedometers. To potentially increase the motivation for the participating adolescents to be more physically active the diaries include questions and guidance on physical activity habits and adjacent to wearing pedometers participants receive daily step-goals.

Further, as knowledge is limited regarding moderators of physical activity interventions, potential moderators were examine in Papers II and III. Previous

studies show that gender, age, and physical activity levels influence the effectiveness of pedometer-based interventions [114]. Hence, pedometer-based interventions have a stronger effect among girls than boys, younger age groups than older and among those who can be classified as "low-active" compared to "high-active" [113,115,116]. Therefore, this Thesis examines the moderating effects of gender and activity level.

Grounded in public health, with emphasis on gender equality, empowerment and non-stigmatization of specific groups of people, this Thesis focuses on feasible strategies to enhance physical activity among adolescents which also are an under-researched population group.

4 METHODOLOGICAL CONSIDERATIONS

This Thesis consists of three papers, each consisting of one individual study addressing one of the three specific aims. Table 1 provides an overview of the papers, their study design, data analyses etc.

Table 1. *Overview of the thesis's papers with their individual study design, participants, measurements and data analyses.*

Paper	**I**	**II**	**III**
Design	Cross-sectional, semi-longitudinal population-based survey	Intervention, pilot-study 2 x 2 factorial design	Intervention study, randomized controlled trial 4 x 4 factorial design
Participants	10–19-year-old students from primary and secondary schools in Iceland, N=32.456	15–16-year-old students from 4 upper-secondary schools in Reykjavik, N=53	15–16-year-old students from 4 upper-secondary schools in Reykjavik, N=248
Measurements	Physical activity Depressive symptoms	Physical activity (steps/day) Subjective sleep quality	Physical activity (steps/day)
Data Analysis	Frequency and percentage counts Chi-square and regression analysis	Analysis of covariance Repeated measures ANOVA	Augmented form of repeated measures ANOVA Intent-to-treat analysis

4.1 Study design, setting and sample

In this Thesis a cross-sectional study is used to examine the patterns of age-related changes in physical activity and depressive symptoms among 10–19-year-old adolescents. Furthermore, two intervention studies with factorial design were used to examine the feasibility and effectiveness of a physical activity

intervention among 15–16-year-old adolescents. Detailed description of the design, settings and samples is given in the following sections.

4.1.1 Paper I: Cross-sectional study

The data in this study were a part of *Youth in Iceland*, a national program of surveys of adolescents that has been conducted in Iceland since 1997 by the Icelandic Centre for Social Research and Analysis (ICSRA) in collaboration with the Icelandic Ministry of Education, Science, and Culture. These series of cross-sectional surveys monitor a wide range of demographic, behavioural, and health-related variables [132,133].

In Paper I, data from three cross-sectional surveys were analysed: survey A) 10−12-year-old students attending the 5th to 7th grade of the primary Icelandic school system in 2011; survey B) 13−15-year-old students attending the 8th to 10th grade of the primary Icelandic school system in 2012; and survey C) 16−19-year-old students in upper-secondary schools in Iceland in 2013. Thus, Paper I had a cross-sectional, semi-longitudinal study design.

A traditional Icelandic primary school includes ten compulsory grades with 6–15-year-old students, whereas the traditional upper-secondary school is four years with the average age of students being 16 to 19 years. In Iceland, the largest student populations are found in the capital region of Reykjavik (33% of participating schools) and in the surrounding suburban areas (28%), with the remaining populations (39%) in other parts of the country including smaller cities, towns and rural areas [128].

All three surveys were population-based and nationally representative. In survey A, 156 of the 163 primary schools with 5th to 7th grade in Iceland were represented (96%), survey B covered 145 of the 146 primary schools with 8th to 10th grade in Iceland (99%) and survey C encompassed students from upper-secondary schools with all 31 schools represented (100%).

For each of the three surveys, the study sample size (i.e., valid questionnaires), percentage of male and female participants and percentage of participants without gender specification was as follows: For survey A, valid questionnaires were obtained from 10.976 participants, 49.4% of which were boys (N = 5.422), 49.7% girls (N = 5.450) and 0.9% did not specify their gender (N = 104). For survey B, valid questionnaires were obtained from 10.992 participants, 49.1% of which were boys (N = 5.394), 49.4% girls (N = 5.426) and 1.5% did not disclose

their gender (N = 172). For survey C, valid questionnaires were received from 10.892 participants of which 48.3% were boys (N = 5.263), 50.5% were girls (N = 5.501) and 1.2% did not specify their gender (N = 128). The participants in surveys A, B and C represented 86.8%, 86.3%, and 70.2%, respectively, of the total number of students in these age groups in Iceland [128]. Together, Paper I covered 32.860 participants.

4.1.2 Paper II: Intervention, pilot-study

In Paper II, the feasibility and effectiveness of conducting an intervention in an upper-secondary school setting was tested. When exploring potential schools for this study, by interviewing the schools' masters and investigating the schools' curricula, it became evident that only five schools were both suited and willing to participate in such a pilot study. All eligible schools were located in the Capital region in Iceland i.e., Reykjavik and its surrounding communities. Results from Paper I demonstrated the most prominent changes in physical activity and depressive symptoms occur between the ages of 15 and 16, which corresponds to the transition period from compulsory to upper-secondary school in the Icelandic school system. There is a high attendance in upper-secondary schools in Iceland, especially in the first year [128]. However, there are less physical education classes in secondary compared to compulsory schools [127]. Thus, we determined that it was most appropriate to conduct the pilot-study in upper-secondary schools and therefore the participants were first-year students, aged 15–16 years.

Four out of five eligible schools were randomly selected and then, one first-year class from each of the four schools was randomly selected for the study. Out of 108, a total of 84 students agreed to participate (13, 19, 25 and 27 participants in the four schools) whereof 63% were girls. The four schools were randomized into two study groups; either an intervention group with pedometers and physical activity diaries (PD, 38 participants) or a control group without pedometers and diaries (C, 46 participants). Thus, a 2 (group) by 2 (time) factorial design was used for this study.

During this pilot study it became clear that in one of the four schools it was too complicated to approach the students at times needed, most likely due to the school's structure and teachers' attitudes. This resulted in fewer participants from this school than originally planned, as only 13 students accepted to participate in the pilot-study. Additionally, there was a higher drop-out rate in

this school (31%) compared to the other three schools during the intervention (26, 11 and 0%, respectively).

4.1.3 Paper III: Intervention study, RCT

Building on the experience from the pilot study (Paper II) we developed, planned and implemented a randomized controlled trial (RCT) intervention in September 2012. As explained above, there were only four eligible schools remaining for the RCT intervention. Although we had considered extending the duration of the intervention, the experience from the pilot study showed that different circumstances, vacation times and exam schedules between the schools would make extended intervention duration difficult to manage. Furthermore, as an intervention period of three weeks in the pilot study had significantly increased physical activity in the PD group (see Paper II) we decided to continue with this set-up in the RCT intervention as well.

However, as the pilot study only included one intervention group which had both pedometers and physical activity diaries, it was not clear if both were needed. Therefore, a RCT study was conducted with a 4 (group) by 4 (time) factorial design. Additionally to the two groups in the pilot study (pedometer & diary (PD) and control (C)) we added a group with pedometers only (P) and a group with diaries only (D). Based on previous research and power analyses on mental well-being outcomes from unpublished results from the cross-sectional ICSRA surveys, a sample size of 240 students (60 in each study group) was found necessary to detect a statistical difference in the outcome variables (with 80% power and assuming 5% significance). Thus, to obtain a minimum of 60 participants in each study group, we randomly selected three first-year classes from each of the four upper-secondary schools chosen to participate in the RCT intervention. This led to, in total, a recruitment of 251 participants whereof 63% were girls. To minimize contamination between study groups, one group was randomized to each school.

4.2 Procedure

4.2.1 Paper I: Cross-sectional study

Anonymous questionnaires were distributed to three different cohorts of students at three separate time points. Teachers at each school supervised questionnaire completion onsite under oversight of ICSRA. Survey A was conducted in February 2011, survey B in February 2012 and survey C in

October 2013. For each survey, data were collected on the same day in all schools and all students who attended school that day were asked to participate.

4.2.2 Paper II: Intervention, pilot-study

This study was conducted in four upper-secondary schools in October and November 2011. Approval was obtained from the participating schools thereafter the study was introduced to a first-year class that had been randomly selected form each school. During this initial presentation, students were given information (orally and on paper) about the study including aims, measures, time frame etc. Students were also told that they would receive two movie tickets as compensation for their participation at baseline and follow-up.

Starting on Monday the second week of October, after receiving signed informed consent from participants and their parents, baseline measurements were conducted at each respective school. First, participants answered a questionnaire regarding demographic characteristics, physical activity and sleep habits for about 30-40 minutes, sitting at separate tables in their classroom. Each questionnaire was marked with an individual research number and participants were asked not to write their names or ID on the questionnaire and after answering, to put the questionnaire in the provided, unmarked envelope. Second, sealed pedometers labelled with the individual research number were handed to participants. Third, participants received a visual demonstration and written instructions of how to wear and handle the pedometer. Fourth, participants were instructed to maintain normal physical activity habits and wear the pedometer from awakening to bedtime for three consecutive weekdays. By the end of this three days baseline period, participants returned their sealed pedometers to the school's main office.

Prior to the intervention period, starting on Monday the following week, the schools were randomized to either an intervention group (with pedometers and diaries; PD group) or a control group (C group). At the beginning of the intervention period, participants in the intervention group (PD) were given a short educational session (15 minutes) including information on the positive effects of physical activity for health, with special emphasis on the importance of the brain in this context. Physical activity in the range of 10.000-12.000 steps/day has been suggested to be equivalent to the recommended guidelines of 60 minutes of MVPA [134–136]. Therefore, students were motivated to be physically active and instructed to gradually aim for 8.000-10.000 steps daily during the intervention period. Further, we explained that it is not necessary to

attend specific sport- or gym-sessions to achieve this goal and stressed the importance of regular, moderate-intensity physical activity, e.g., walking. Examples were given of ways that could help accumulating daily steps, such as to use class-breaks to stand up and walk during school hours, take the stairs instead of elevators, walk to a friend instead of sending a message, walk to school instead of getting a ride, and go for brisk walking tours when possible. It was also stressed that activity bouts of for example 10 minutes would count in this context.

After the educational session, for further motivation, participants in the PD group received physical activity diaries and unsealed pedometers to wear on weekdays during the intervention period. The physical activity diary was an A-4 sized compendium with instructions about the handling of the pedometers and advice about easy ways to incorporate extra steps into daily habits. Additionally, the diary contained designated areas for registration of daily steps. For motivational purposes as well as to remind participants to wear their pedometers, bulk text-messages were sent to the PD group every morning. Additionally every evening bulk text-messages were sent to participants in the PD group reminding them to fill out their physical activity diaries and to submit their step-count via text-message to the research team.

A follow-up assessment was conducted in the week following the intervention period, or in the second week of November. The follow-up procedures were identical to the baseline procedures. Participants in the control group completed baseline and follow-up assessments but did not keep track of their physical activity in any form nor did they receive text-messages during the intervention period.

4.2.3 Paper III: Intervention study, RCT

The RCT intervention study was conducted from September 2012 to January 2013. After obtaining approval from the participating upper-secondary schools and randomly selecting three first-year classes from each school the study was introduced to eligible participants in the selected classes. This introduction was identical to the one provided to participants prior to the pilot-study (Paper II), see section 4.2.2.

The baseline assessment was conducted during the second week of September (10–14 September, 2012) and was identical to the baseline assessment in Paper II (see section 4.2.2) with the exception now that the participants were asked to

wear pedometers for four consecutive weekdays compared to three days in the pilot-study.

After completion of the baseline assessments, schools were randomized to four study groups; a group with pedometers (P), a group with physical activity diaries (D), a group with both pedometers and diaries (PD) and a control group without pedometers and diaries (C).

The intervention period started on Monday the following week immediately after the baseline measurements and continued for three weeks (17 September to 5 October, 2012). The research team met with the two pedometer groups (P and PD) separately and gave an educational session comparable to the one that was given to the intervention group (PD) in the pilot-study (Paper II). However in the RCT study (Paper III), the daily step-goal was set higher than in the pilot-study as participants in the P and PD groups were now told to aim for 10.000–12.000 steps daily. This amount of daily steps is the range that has been suggested to be equivalent to the physical activity guidelines for adolescents of at least 60 minutes of MVPA daily [134–136]. Additionally, as the third intervention group in the RCT study did not wear pedometers (the D group with physical activity diaries only) that group did not receive a step-goal, but otherwise received the same motivational messages.

After the educational session, the two groups with pedometers (P and PD) were given their labelled and now unsealed pedometers and the two groups with physical activity diaries (PD and D) additionally received their diaries. The physical activity diary included questions about daily physical activity, e.g., "How much physical activity did you do today?". Additionally, all groups received a non-physical activity diary including questions on sleep and emotional feelings. This was done to control for potential motivational effects of the text-messages on the three intervention groups (P, PD and D). Thus, during workdays every morning at 7 am and every evening at 9 pm all study participants received text-messages. The morning text-message was sent to remind participants to wear pedometers and/or to fill out relevant fields in their diaries. Similarly, the evening text-message was sent as a reminder to submit a text-message with daily step-count to the research team and/or to fill out relevant fields in the diaries.

Three follow-up assessments were conducted; follow-up-1 immediately after the intervention (8–12 October, 2012), follow-up-2 was scheduled four weeks after completion of the intervention (5–9 November, 2012), and follow-up-3 was

executed four months after the intervention (21–25 January, 2013). All procedures at all follow-up assessments were identical to the baseline procedures. Thus, at every follow-up, all participants answered questionnaires and wore sealed pedometers for four consecutive weekdays.

4.3 Measurements

Below, considerations about the pros and cons of different methods to measure physical activity are given. There are many aspects to consider, e.g., cost, feasibility, validity, reliability, participant compliance, etc. When employing population-based surveys, a reliable but short subjective measurement tool is the endeavour. On the other hand, considering the drawback of self-report measures, the use of accurate objective methods with low burden for both participants and researchers become relevant. Later in this section, considerations are given on the measurements used to assess depressive symptoms and quality of sleep.

4.3.1 Measuring physical activity

Many measurement methods have been used to assess physical activity both subjectively and objectively, but to date no single method has become the gold standard [137,138]. This is not surprising considering how broad and diverse the concept of physical activity is, constituted by different categories and activities with differing intensity, frequency and duration. Additionally, the population that will be measured (e.g., size and age) should be considered as well as the purpose, context and design of the study. Subjective methods include self-reports, e.g., questions, questionnaires, interviews and diaries, while objective methods include direct observation, heart rate, pedometers, and accelerators [137]. When choosing between measurement options for physical activity, consideration of reliability and validity is important as well as taking participants' physical burden into account. However, of greatest importance is the research question that is posed in each study, as it will guide the choice of assessment method [139].

When choosing an assessment method for physical activity in children and adolescents compared to adults, participants' burden and the study context are even more important factors. Thus, the researcher must thoroughly consider all aspects and find the optimum balance between feasibility and validity when choosing a measurement method for the study [139].

In the cross-sectional study (Paper I) we used the two following questions to assess physical activity: "How often do you participate in sports and/or fitness training to the extent that make you breath considerably or sweat?" and "How often do you participate in sports and/or fitness training (practice or compete) with a sports club or a team?". The choice of using two questions instead of a questionnaire to measure physical activity in Paper I was made with the considerations as discussed below.

A comprehensive review on physical activity questionnaires for youth found no questionnaire to possess both acceptable reliability and construct validity [138]. Also, standardized self-report measures of physical activity are generally considered too time consuming and complex to use when surveying multiple health behaviours among adolescents. Additionally, the question "How often do you participate in sports and/or fitness training to the extent that make you breath considerably or sweat?" or almost an identical, single-item question has been used to assess MVPA in several studies [47,140] with the single-item question used in the Health Behaviour in School-aged Children (HBSC) survey being ranked as the top 5 in expert evaluation of instruments to measure physical activity in young people [141]. Finally, this single-item has comparable validity and reliability to one of the most reliable instruments measuring physical activity among adolescents, the Oxford Physical Activity Questionnaire (OPAQ) [142]. Because of the above arguments and as the selected questions have been extensively used in the *Youth in Iceland* surveys to measure physical activity, we decided to use the same questions to measure physical activity in the cross-sectional study (Paper I). However, it should be noted that the measure of MVPA we used in our study was not specifically designed to capture moderate- and vigorous-intensity physical activity. Although we belief that the wording of the question is broad enough to encompass both moderate and vigorous activity levels this has not been tested.

We used an objective measurement tool, Yamax CW-701 pedometer, to determine physical activity (steps/day) in the two intervention studies (Papers II and III). Yamax pedometers are one of the most accurate and reliable pedometer models available and are frequently used in physical activity research [143–147]. Furthermore, pedometers have high validity as they correlate strongly with accelerometers, specifically uniaxial accelerometers (r=0.86) [145]. However, although pedometers unlike accelerometers can neither measure frequency nor intensity of physical activity, pedometers are more practical, cost-effective and have lower analysis burden compared to accelerometers [135,148].

Additionally a recent study on children and adolescents using pedometers and accelerometers shows that daily step-counts from pedometers correlate highly (r=0.81) with daily minutes of MVPA from accelerometers ($p < 0.0001$) [135].

Further, although reactivity (change in behaviour when participants know they are being monitored) is considered a threat to measurement accuracy, results from studies on children and adults have been inconsistent and the few studies that have examined reactivity among adolescents have not found such evidence [149–151]. However, a recent study found pedometer monitoring protocols to influence reactivity. Thus, when adolescents wore pedometers that were sealed for one week compared to daily or unsealed pedometers, no reactivity was seen in the group with weekly-sealed pedometers whereas reactivity was evident in both the group wearing daily-sealed and unsealed pedometers. Furthermore, the step-counts in the weekly-sealed pedometer group had the strongest association (r=0.82) with accelerometer outcome (counts-per-minute) [149].

Although tampering with or shaking of pedometers to increase step-counts has been considered a problem in pedometer research, such evidence is scarce [149]. However, in a study on 12-year-old adolescents wearing pedometers, between 58–69% admitted shaking [152]. Similarly, 49% of participants in a study report tampering, although tampering was less pronounced and not seen as a threat to measurement accuracy in a group with weekly-sealed pedometers [149].

Based on the above considerations, we used sealed pedometers at baseline and follow-ups as it is important to minimize the reactivity when trying to measure the habitual physical activity. On the other hand, to maximise the motivational effect of the pedometers during the intervention period we used unsealed pedometers as studies show that pedometers are motivational in themselves [116,153].

4.3.2 Depressive symptoms

In the cross-sectional study (Paper I) we assessed depressive symptoms with nine items derived from the Symptom Check List (SCL-90) of Derogatis and co-workers [154] and these items have been used to measure depressive symptoms in several published papers [133,155,156]. When answering, participants were asked to self-report how often during the last week the following statements applied to them: “I was sad or had little interest in doing things”, “I had little appetite”, “I felt lonely”, “I cried easily or wanted to cry”, “I had sleeping problems”, “I felt sad or blue”, “I was not excited in doing

things", "I was slow or had little energy", and "The future seemed hopeless". Possible responses are; 0 = "almost never", 1 = "seldom", 2 = "sometimes" to 3 = "often" which are combined into a scale ranging from 0 to 27, a continuous variable with higher scores representing higher levels of depressive symptoms. Cronbach's α was calculated as 0.86, 0.91 and 0.91 from survey A, B and C, respectively (Paper I).

4.3.3 Sleep quality

Subjective sleep quality was assessed with four individual items that have been prevalently used earlier; sleep onset latency, nightly awakenings, sleep quality in general and sleep sufficiency [81,157,158] with items deriving from the Pittsburgh Sleep Quality Index [157] and the School Sleep Habits Survey [159]. Participants were asked to indicate how each of the four items applied to them over the past three weeks. The first item, "How long did it usually take you to fall asleep?" was answered on a five point scale ranging from "it only took me a few minutes" to "it took me more than three hours or I did not fall asleep". The second item, "On average, how often did you usually wake up during the night?" was answered on a four point scale ranging from "never" to "more than three times". A fifth answer key was also provided where participants could answer "I do not know" and this was scored as a missing value. The third item, "How would you evaluate your sleep quality in general" was scored on a three point scale; "good", "average" or "poor". The fourth item, "How often did you receive sufficient sleep?" was scored on a five point scale ranging from "always" to "never". All four items were summarized to provide a global score with a minimum possible score of four and maximum of 17, where higher scores represented better sleep quality. Cronbach's α for the SSQ-scale at baseline was 0.57 and at follow-up 0.65. Thus, although the internal reliability of the SSQ-scale was not high at baseline a reliability of 0.65 at follow-up is acceptable [81]. Additionally, with respect to the feasibility of a brief instrument, this measure of sleep quality was used in the pilot-study (Paper II).

4.4 Data analysis

4.4.1 Paper I: Cross-sectional study

To examine the pattern of both physical activity and depressive symptoms, we used data from individuals at every age in all three surveys. We conducted frequency counts and calculated percentages for questions regarding participants' physical activity within gender and age. Tests of the differences

between two proportions were conducted to examine physical activity levels by gender within age. To compare mean levels of depressive symptoms between genders we conducted independent sample t-tests.

To explore the relationship between depressive symptoms and physical activity, we performed multiple linear regression analysis using levels of depressive symptoms as the dependent variable and gender, age and physical activity as independent variables on a combined sample of the three surveys. In order to meet the assumption of independence, all 13-year-old and 16-year-old students were deleted from the regression analysis as most 13-year-olds in 2012 (survey B) were 12-year-old in 2011 (survey A), and most 16-year-olds in 2013 (survey C) were 15-year-old in 2012 (survey B). The deletions did neither affect the direction nor the significance of the coefficients.

We used Markov Chain Monte Carlo multiple imputation method to examine the impact of missing data on the results. Five data sets were generated and missing values imputed by regressing the variable with missing data on a set of predictor variables. Statistical analyses were performed with SPSS version 22. For missing data, the multiple imputation command in SPSS was used assuming random pattern of missing data. The level of significance was set at $p < 0.001$.

4.4.2 Paper II: Intervention, pilot-study

Mean step-counts were calculated for both baseline and follow-up. Although four days are recommended [139] and commonly used in research among adolescents to determine steps per day [53,160–162], two days are considered sufficient in population surveillance with respect to reliability and validity [150]. Results from pedometer studies indicate differences in the amount of steps taken during weekdays compared to weekends with a lower physical activity among adolescents during weekends [58,163]. In our study, weekends were not included and therefore a lower variance in steps between days was expected [164]. Also, our aim was to determine if the intervention would be effective in increasing adolescents' physical activity on weekdays rather than assessing their mean yearly habitual physical activity. Thus, we decided to use four weekdays to measure daily step-count.

According to Tudor-Locke and colleagues [165], individuals' daily basal energy expenditure or "basal-activity" can be considered equivalent to <2.500 pedometer-determined steps/day. Based on the above considerations, participants that did not provide a minimum of two days of valid step data

and/or their daily step data was <2.500 steps/day at baseline were excluded from the data analyses.

For sleep quality measures, items were reversed and higher scores represented better sleep quality. Furthermore, we excluded participants with missing values on one or more of the four individual sleep items from subjective sleep quality analyses.

Statistical analyses were performed with IBM statistic, SPSS version 20. Group differences in descriptive and main study variables (i.e., step count, sleep quality) at baseline were assessed by Fischer's exact test, Pearson's chi-square and independent samples t-test. Factorial analysis of variance (FANOVA) was used to assess the potential differential influence of subject attrition between the treatment groups. Analysis of covariance (ANCOVA) was used to analyse step count and repeated measures analysis of variance (ANOVA) was used to analyse sleep quality. The level of significance was set at $p < 0.05$.

4.4.3 Paper III: Intervention study, RCT

We used the same criteria as accounted for in Paper I both to calculate mean step-counts at baseline and follow-ups and to include minimum number days of valid step data in the statistical analysis.

To account for the clustering effect of schools when analysing the average number of daily steps in the RCT study, we used the below detailed augmented form of the repeated measures ANOVA:

$$S_{gtc(i)} = I_g + \Psi_t + \Omega_{gt} + \sum_i k\beta_{ki} + \kappa_c + \rho_{c(i)} + \epsilon_{gtc(i)}$$

where I_g denotes the effect of intervention group g and Ψ_t the effect of time t. The term Ω_{gt} denotes the two way interaction between intervention group and time. The effects of covariates are considered by the β_{ki} term for covariate k, the term $\rho_{c(i)} \sim N(0, \sigma_R^2)$ represents the correlation between measurements of a subject i within class c and the term $\epsilon_{civt} \sim N(0, \sigma^2)$ is the observation error. Model covariates we considered were demographic effects that differed between intervention groups at baseline and those that were significant were included in a full model and thereafter eliminated in a stepwise manner based on the Akaike Information Criterion (AIC) [166]. We tested intervention effects and interaction with the three follow-up time points for significance using a likelihood ratio test. To calculate the confidence intervals for the mean step-

count levels at different time points, we used least square means [167] and comparisons between these levels were made with Tukey's method.

We handled missing values, due to issues such as equipment malfunction or participant unavailability, by applying an intent-to-treat analysis (ITT). In an ITT analysis, measurements from all participants in the original intervention groups are used when available. We performed all statistical analyses with R (version 3.2.2, see [168] for further details) using the approaches for model fitting described by Bates and colleagues [169].

For analysis of statistical power, we considered results from a meta-analysis of 32 studies published during 2001-2007 on the effects of pedometer-based PA interventions [114]. The number of participants varied from 8 to 330 with a mean of 80 participants per study. The overall effect-size was 0.68 (95% CI; 0.55, 0.81) which translates to an average increase of 2.000 steps in the intervention group for all studies. This indicates that pedometers are a useful motivational tool to increase PA participation. Thus, with a sample size of 240 individuals, an effect size of 0.68 and assuming 5% significance, the power to detect a significant difference between two time points would therefore be 97%.

4.5 Ethical considerations

In the cross-sectional study (Paper I), data collection including participant involvement was based on informed passive parental consent, guided by a methodological protocol developed by ICSRA and in compliance with Icelandic law on the protection of human subjects. No identifying information was obtained. A detailed description of all data collection protocols has been published elsewhere [170].

The National Bioethics Committee in Iceland approved the two intervention studies described in Papers II and III (reference 11-099-V3). Additionally, we provided information about the studies to the Icelandic Data Protection Authority. Participants, as well as their parents, were informed about the study before it was initiated. Both participant and parental approvals were obtained for each participant prior to the intervention through written informed consent.

To facilitate recruitment, adherence and minimize loss of data, all participants in the intervention studies were offered two movie tickets as compensation for their participation in baseline and follow-up measurements. Additionally,

participants in the pedometer groups received two more movie tickets as compensation for wearing and returning the pedometers at the end of the intervention period. Furthermore, the groups with pedometers received credits on their mobile phones, covering the expenses associated with their daily text messages when reporting step-counts. Similar procedures have been used in studies among adolescents [119,164].

5 RESULTS

This section presents the key results of the Thesis, based on the three individual papers. For a more detailed description, please refer to the individual papers at the end of this Thesis.

5.1 Paper I

5.1.1 Decrease in physical activity

Results on adolescents' participation in physical activity measured as participation in both MVPA and organized sports show a general decline in physical activity from the age around 15. A closer look at participants' levels of MVPA (*Figure 1*) show that the percentage of low-active students, or those that almost never engage in MVPA, decreased from 26% at age 10 to 9% at age 14, thereafter it increased again to 15% at the age of 19.

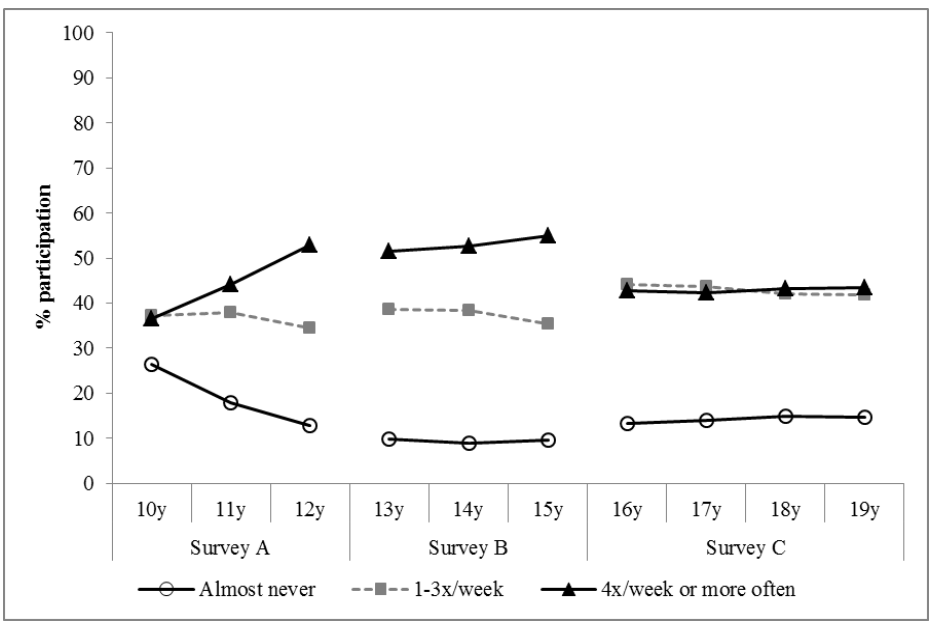

Figure 1. *Participation of Icelandic adolescents in MVPA (moderate-to-vigorous physical activity), by age (y=years) and within surveys A, B and C (year 2011, 2012 and 2013, respectively).*

On the other hand, the percentage of high-active students, or those that participated ≥4 times per week in MVPA, increased from 37% at age 10 to 55% at the age of 15 wherefrom it dropped to 42% at age 17 and increased again to 44% at the age of 19.

For medium-active students, or those that engage 1−3 times per week in MVPA, the overall picture was more stable with percentages from 34 to 38% between the ages of 10 to 15 when the percentage increased to 44% at age 16 and then decreased again to 42% at the age of 19 (*Figure 1*).

The results on participation in organized sports show a diminished participation from the age of 14 (*Figure 2*). Thus, the percentage of students that almost never participated in organized sports, ranged from 37% at the age of 10 to 68% at the age of 19. The percentage that practiced organized sports 1−3 times per week declined from 33% at age 11 to 14% at age 19. The number that practiced organized sports ≥4 times per week increased from 30% at age 10 to 42% at age 13 thereafter the number decreased to 19% at the age of 19.

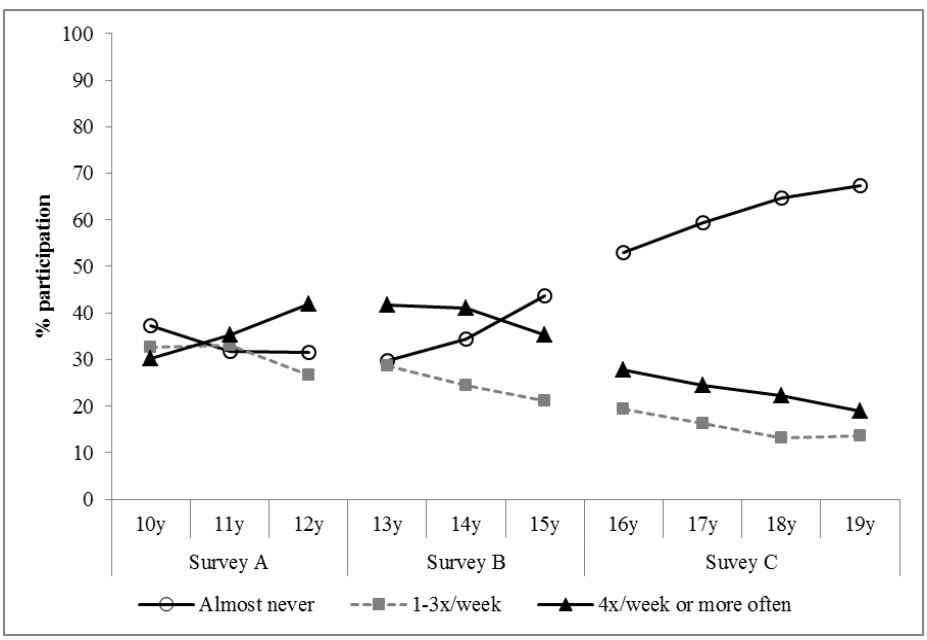

Figure 2. *Participation of Icelandic adolescents in organized sports, by age (y = years) and within surveys A, B and C (year 2011, 2012 and 2013, respectively).*

We found gender-related differences in participation in MVPA. Compared to boys at all ages, more girls partook 1−3 times per week in MVPA while the opposite was true for participation in MVPA ≥4 times per week where more boys were represented at all ages. This difference was significant in all age groups ($p < 0.001$) except from 13-year-old and 14-year-old students where the difference, although in the same direction, was not significant ($p > 0.001$). Thus in general, more girls were medium-active compared to boys and more boys were high-active compared to girls. The landscape for low-active boys and girls, or those that almost never participated in MVPA, was similar and the percentage of participants did not differ by gender ($p > 0.001$).

Gender differences were also evident in organized sports participation. In general, girls participated less in organized sports than boys. Thus, at every age from 10 to 19, more girls than boys indicated that they almost never engaged in organized sports ($p < 0.001$). In the student group that practiced organized sports ≥4 times per week, girls were less represented ($p < 0.001$). However, for those students that practiced organized sports 1−3 times per week there was no difference between genders ($p > 0.001$).

5.1.2 Increase in symptoms of depression

We found that at every age, except at ages 10 ($p = 0.149$; $d = .05$) and 11 ($p = 0.004$; $d = .10$), girls reported significantly higher levels of depressive symptoms than boys ($p < 0.001$), see *Figure 3*. Cohen's *d* ranged from 0.25 at age 12 to 0.57 at age 17. The gap in depressive symptoms between boys and girls was narrowest at age 10 and widest at age 17, where the mean level of depressive symptoms was 3.88 points higher for girls than for boys.

When effects of all predictors were held constant, e.g., gender, age, participation in organized sports and MVPA, a regression analyses with depressive symptoms as the dependent variable showed that with increasing age the level of depressive symptoms increased. On average, girls scored higher than boys on level of depressive symptoms, with the difference between girls and boys increasing with age as indicated by a significant interaction between gender and age ($p <0.001$). Direct, negative significant effects were found for all four physical activity variables in the model, indicating that when physical activity increased, depressive symptoms decreased. Girls benefitted more from participating in organized sports than boys, as indicated by the significant interaction between gender and organized sports ($p <0.001$). However, the effects of participating in MVPA were similar for both girls and boys ($p <0.513$).

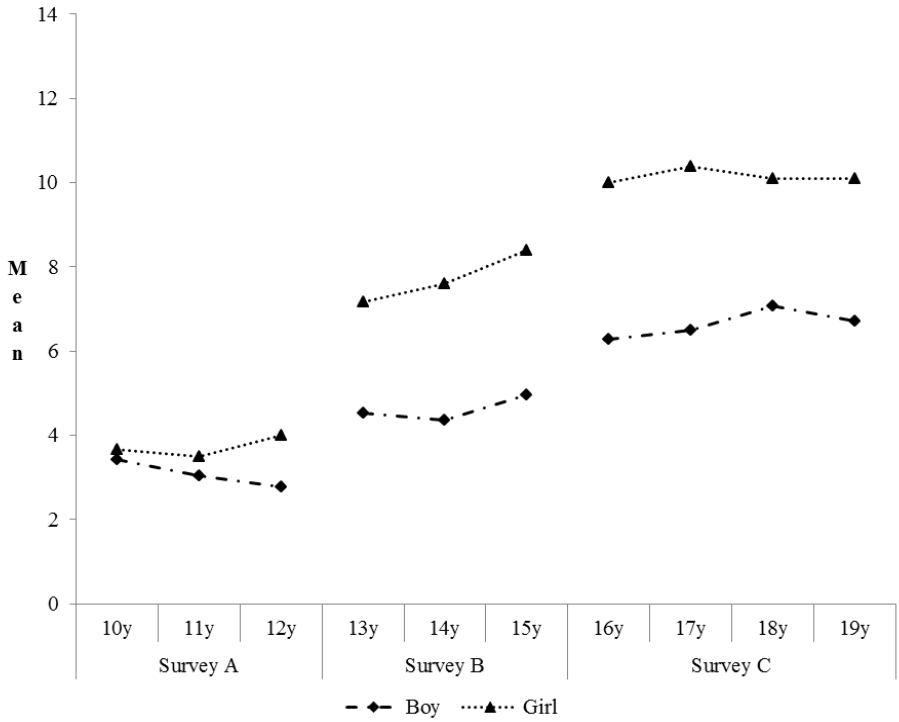

Figure 3. *Mean levels of depressive symptoms among Icelandic adolescents, by gender within age (y=years) and within surveys A, B and C (year 2011, 2012 and 2013, respectively).*

5.2 Paper II

5.2.1 Increased physical activity

Due to a baseline difference in mean step-count between the control (M = 8658.57, SD = 2335.35) and the intervention group (M = 7128.29, SD = 2281.61), $t(51) = 2.41$, $p = 0.02$ we used ANCOVA for the analysis of group differences in daily steps at follow-up. Here, the intervention group had higher mean step-count (M = 8384.13, SD = 2904.05) than the control group (M = 7666.48, SD = 2854.03), $F(1, 50) = 5.16$, $p = 0.03$, partial $\eta^2 = 0.093$.

5.2.2 Enhanced subjective sleep quality

At baseline there was no difference in subjective sleep quality between the control (M = 14.58, SD = 2.53) and the intervention group (M = 13.86, SD = 2.27), with $t(51) = 1.09$, $p = 0.66$. Therefore, subjective sleep quality was examined with two (Group: intervention and control) by two (Time: baseline and follow-up) repeated ANOVA. The main effect of time was not significant, $F(1, 43) = 0.69$, $p = 0.41$, partial $\eta^2 = 0.016$ but there was a significant time by group interaction effect, $F(1, 43) = 5.81$, $p = 0.02$, with partial $\eta^2 = 0.119$. Simple effect analyses of the within subject factors demonstrated a significant increase in subjective sleep quality in the intervention group (M = 14.48, SD = 1.91), $F(1, 18) = 4.59$, $p = 0.05$, partial $\eta^2 = 0.203$, while there was no change over time in the control group (M = 14.12, SD = 2.60), $F(1, 25) = 1.47$, $p = 0.24$, partial $\eta^2 = 0.055$. A more detailed examination of the individual sleep items indicated a trend towards a baseline difference between the groups in subjective sleep onset latency ($p = 0.08$). To control for potential baseline differences, we conducted an ANCOVA analysis for each of the four individual sleep items of the SSQ-scale We found significantly higher mean score in subjective sleep onset latency for the intervention group compared to the control group at follow-up, $F(1, 44) = 4.90$, $p = 0.03$, partial $\eta^2 = 0.100$. The remaining sleep items did not reach statistical significance between the groups.

5.3 Paper III

5.3.1 Pedometers increased physical activity

The results from the repeated measure ANOVA showed a significant interaction between intervention groups and time, ($\chi^2(9) = 111.925$, $p < 0.01$). As shown in *Figure 4*, the intervention groups differed in mean daily steps at follow-up-1 but not at follow-up-2 or follow-up-3.

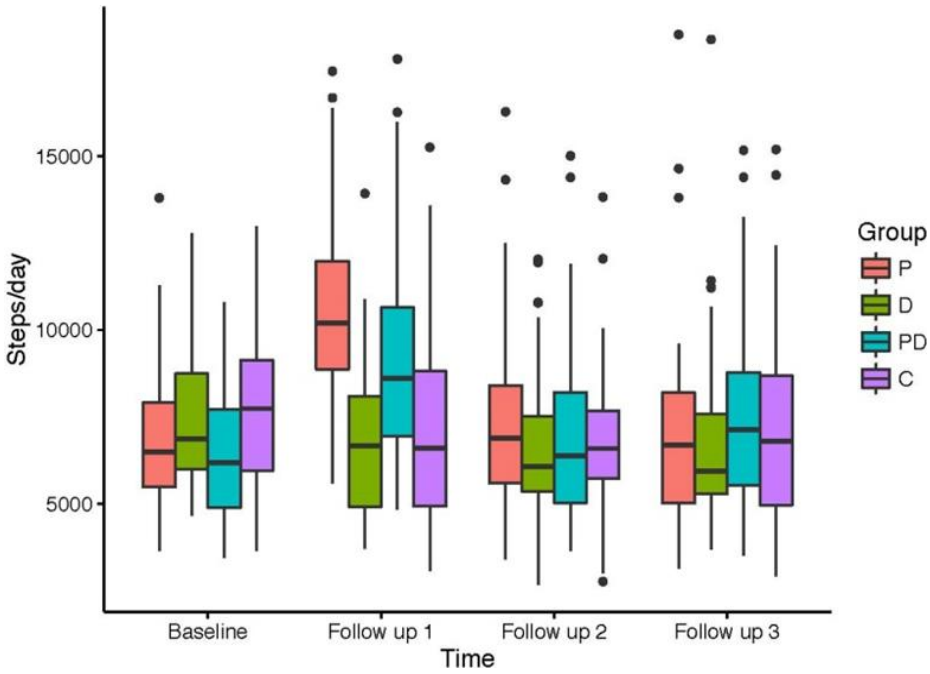

Figure 4. *Mean number of daily steps in all groups, by time where P=group with pedometers, D=group with diaries, PD=group with pedometers and diaries, and C=control group.*

From baseline to follow-up-1 there was an increase of 3.546 (p<0.01) and 2.509 (p<0.01) in mean daily step-count in the group with pedometers (P) and the group with pedometers and physical activity diaries (PD), respectively. During the same time period, we found a decrease of 766 (p=0.23) and 792 (p=0.16) in mean daily step-count in the group with physical activity diaries (D) and the control group (C), respectively. Furthermore, in the groups with pedometers (P and PD) the mean daily step-count at follow-up-1 was 10.467 and 9.651 steps for the P and PD groups, respectively, which was close to the goal of 10.000 steps per day.

Examination of group differences at follow-up-1 (*Table 2*) showed that the group with pedometers (P) differed significantly in daily steps compared to the

group with physical activity diaries (D) and the control group or $t(15.9) = 5.288$, $p < 0.01$ and $t(16.5) = 5.213$, $p < 0.01$, respectively. Similarly, the daily steps in the group with both pedometers and physical activity diaries (PD) differed significantly from the group with physical activity diaries (D) and the control group or $t(24.0) = 3.632$, $p < 0.01$ and $t(25.9) = 3.465$, $p < 0.01$, respectively.

Table 2. *Estimated differences in daily steps between intervention groups at follow-up-1*

Group contrasts*	Estimated step difference	SE	df	T ratio	*p*-value	Cohen's *d*
P - D	3838.3	725.8	15.9	5.288	< 0.01	1.33
P - PD	815.3	758.8	17.9	1.074	0.709	0.25
P - C	3578.1	686.4	16.5	5.213	< 0.01	1.28
PD - D	3023.0	832.3	24.0	3.632	< 0.01	0.74
PD - C	2762.9	797.3	25.9	3.465	< 0.01	0.68
D - C	-260.1	701.5	18.2	-0.371	0.982	0.09

* Group contrasts = the estimated difference in daily steps at follow-up-1 between any two groups. P = group with pedometers, D = group with diaries, PD = group with pedometers and diaries, C = control group.

To examine if the intervention had differential effects depending on participants' activity levels at baseline we divided participants into five activity levels according to Tudor-Locke et al. [136] i.e., levels of daily steps as 1) <5.000 (sedentary), 2) 5.000–7.499 (low active), 3) 7.500–9.999 (somewhat active), 4) ≥10.000–12.499 (active), and 5) ≥12.500 (highly active). We additionally divided participants dependent on if they were meeting the lower end of the set daily step-goal of 10.000–12.000 or not, with the 10.000 steps as a cut-off estimate. However, the interaction for both five levels and two levels were insignificant when entered into our model ($\chi^2(33) = 36.35$, $p = 0.315$ and $\chi^2(9) = 11.85$, $p = 0.222$, respectively).

To test the hypothesis that the intervention was more beneficial for girls than boys, we entered the interaction between gender and time into our statistical model. There was a significant three-way interaction between group, gender and time ($p<0.01$). However, there were no differences between genders in the three intervention groups P, D or PD at follow-up-1. However, boys compared to

girls in the control group had higher step-counts both at follow-up-1 and follow-up-3 ($t(662.2) = 2.651$, $p < 0.01$) and $t(750.6) = 3.345$, $p < 0.01$, respectively). Similarly, boys in the D group had higher step-counts than girls at follow-up-2 and -3 ($t(610.6) = 2.934$, $p < 0.01$ and $t(653.3) = 2.029$, $p = 0.043$, respectively). In the group with both pedometers and physical activity diaries (PD), girls had significantly greater number of steps than boys ($t(621) = -2.138$, $p = 0.033$) at follow-up-3.

5.3.2 Participants' compliance

The drop-out rate from baseline to follow-up-1 was low with an overall compliance of 86.6%. More specifically, at follow-up-1 the compliance was 83.6, 80.3, 91.9 and 90.6% for group P, D, PD and C, respectively. At follow-up-2, the compliance was less in all groups with 67.2, 68.9, 83.9 and 81.3% compliance in groups P, D, PD and C, respectively. Finally at follow-up-3, the compliance had declined further to 54.1, 52.5, 79.0 and 51.6% in the same order of groups.

5.4 Summary of main results from Papers I-III

The results from Paper I demonstrated a decrease in physical activity with more than half of Icelandic adolescents in upper-secondary schools not meeting the guidelines for recommended daily physical activity. At the same time depressive symptoms increased, particularly among girls. Our large cohort, with over 32.000 adolescents and wide age-range, allowed us to demonstrate that the most prominent differences in physical activity and depressive symptoms occurred between the ages of 15 and 16 or around the transition time from compulsory school to upper-secondary school in the Icelandic school system. We also observed gender differences for both physical activity and depressive symptoms with girls having lower physical activity and higher depressive symptoms. This is the first time that gender- and age-related differences as well as the associations between physical activity and depressive symptoms are assessed on a nation-wide level with identical instruments in the whole adolescence period from the age of 10 to 19 years. Therefore, our results add to the broader scope of information than has been previously presented in the literature. These findings provide important information about when to tailor public health efforts to reduce the burden of depressive symptoms among adolescents, for example by employing physical activity interventions.

The results from Paper II were promising as immediately following the 3-weeks intervention, the group with pedometers and physical activity diaries had significantly higher mean step-count compared to the control group. Additionally, the intervention was also effective regarding participants quality of sleep as the intervention group showed a significant increase in subjective sleep quality while there was no change over time in the control group. Further analysis of the individual items of the sleep quality scale demonstrated sleep onset latency being significantly higher in the intervention group compared to the control group. This means that participants in the intervention group fell asleep faster than their peers in the control group. Thus, the pilot-study (Paper II) was effective both in increasing physical activity and sleep quality among 15–16-year-old adolescents. One of the limitations of this study was that both pedometers and physical activity diaries were used and, therefore, it could not be determined if both were needed to increase physical activity.

The results from Paper III further confirmed the effectiveness of pedometer-based interventions in increasing physical activity. More specifically, only the intervention group with pedometers (P) and the group with both pedometers and physical activity diaries (PD) increased their daily steps from baseline to follow-up-1 by approximately 3.500 and 2.500 steps, respectively. However, there were no differences between the two pedometer groups. To our knowledge, this is the first study to demonstrate that pedometers by themselves can promote physical activity among adolescents and additional components such as physical activity diaries are not required. The intervention increased physical activity over the three weeks intervention period and pedometers alone were as effective in increasing physical activity as pedometers plus physical activity diaries. However, during the same period in both the physical activity diary group (D) and in the control group (C) there was a non-significant decrease in daily steps by 770 and 790 steps, respectively.

As prior pedometer-based intervention studies have shown that both gender and physical activity levels at baseline moderate the effects of the interventions, we examined if these factors had moderating effects in our RCT intervention. This was however not the case for the examined activity levels in our study. Furthermore, at follow-up-1 we found no gender differences in the intervention groups (P, PD or D). The compliance of participants in the RCT was higher than in the pilot-study with an overall compliance of 86.6% at follow-up-1 in the RCT compared to 63.1% in the pilot-study. At follow-up-2 and follow-up-3 in the RCT, the overall compliance rate was 75.3 and 59.3%, respectively.

6 DISCUSSION

In this Thesis, the age-related differences in physical activity and depressive symptoms among 10–19-year-old adolescents were examined in a cross-sectional, semi-longitudinal Icelandic population-based survey. Additionally, a pedometer- and diary-based physical activity intervention was successfully developed and implemented in upper-secondary schools and its effects on physical activity and subjective sleep quality in 15–16-year-old adolescents determined. Overall our findings showed that physical activity declines and depression increases during the adolescent years (Paper I) and that pedometer intervention is effective in improving sleep and in increasing physical activity among adolescents (Papers II and III). The findings have the potential of having major public health relevance as the intervention can easily be disseminated and incorporated into upper-secondary school's curriculum.

6.1 Physical activity

The results from Paper I, regarding age-related decline in physical activity among Icelandic adolescents, show an overall decrease in adolescents' physical activity from the age of 15 with more than half of adolescents in upper-secondary schools not meeting the guidelines for recommended daily physical activity. Thus, our results show that 10–19-year-old adolescents in Iceland exhibit increase in non-compliance with physical activity guidelines with increasing age; around 50% of 13–15-year-old and 60% of 16–18-year-old adolescents were not meeting the physical activity guidelines. This demonstrates a similar pattern as previously reported on non-compliance with over 50% of 14–15-year-old adolescents in Iceland [155] and for example around 50% of 6–18-year-olds in Spain not meeting the physical activity guidelines [61]. Even less compliance has been reported or 23–12% among 11–15-year-old adolescents worldwide [11,47], as low as 9–7% among 11–17-year-olds in Germany [60] and 9–8% among 12–19-year-olds in USA [171]. Although subjective measures of physical activity tend to overestimate physical activity [52] and different measurement tools make the comparison difficult, these comparable figures from Germany and USA derive from subjective and objective measurements, respectively. Similarly, the low worldwide estimates as well as the higher Spanish and Icelandic compliance estimates derive from similar subjective measurements of physical activity. Nevertheless, even though subjectively derived and therefore potentially overestimated, estimates of 40–50% of 10–19-year-old

adolescents meeting the physical activity guidelines as reported in Paper I are unacceptable. Moreover, results from the new Health Behaviour in School-aged Children (HBSC) Study show that only around 23% of 11–15-year-old Icelandic adolescents in 2013/14 report at least 60 minutes of MVPA daily and thus meet the public health guidelines on physical activity [172]. Although this is a higher compliance than seen in the HBSC survey from 2009/10 with around 16% of this group of Icelandic adolescents meeting the guidelines [47], there is clearly need for actions to enhance physical activity in adolescence.

The age-related decline in physical activity demonstrated in Paper I was most pronounced in the age between 15 and 16, or around the transition from compulsory to upper-secondary schools in the Icelandic educational system. Although, our results support previous international studies [7–10,58,59,171] on age-related decline in physical activity the age-related pattern in our study is somewhat different. Thus, our results showing peak levels of MVPA and participation in organized sports at the age of 15 and 13, respectively, are inconsistent with studies showing the decline in objectively determined physical activity apparent from the age of 10 [59,173]. Different measurement tools make comparisons between studies difficult and there may be differences in the educational systems (e.g., the definition of primary and secondary schools varies) that influence the time when the decline in physical activity starts or is most apparent. For example, recommended minimal annual time taught for physical education differs between countries and is less in Iceland compared to Finland, Norway and Sweden [127].

As previously discussed in the Background (section 1.2) evidence from the literature also support time-related decline in physical activity [11,51]. However, some controversy remains as research from the last decades does not support this time-related decline [52,53] and therefore the ever increasing and negative influence of technology on physical activity since the beginning of the industrial revolution may be diminishing. Even so, because of the low compliance with physical activity guidelines and the beneficial effects of physical activity on health, it is important to design and/or test interventions that enhance participation in physical activity among adolescents.

The observed association between physical activity and symptoms of depression, showing lower levels of depressive symptoms with higher participation is both MVPA and organized sports is an important finding. The even stronger association for organized sports compared to MVPA

demonstrates the importance of organized sports for adolescents overall physical activity, especially girls. This is in line with previous findings [174,175] and supplies further arguments for finding strategies to enhance girls' participation in organized sports as well as minimizing their drop-out demonstrated from age 14 in our data.

6.2 Depressive symptoms and quality of sleep

Overall, our results on depressive symptoms (Paper I) reflect those for physical activity though in opposite direction. However, even though previous findings report a similar increase in symptoms of depression in adolescence [12,73] our findings demonstrate age-related differences in depressive symptoms throughout the adolescent years from 10 to 19. Thus, we were able to demonstrate a prominent increase in symptoms of depression between the ages of 15 and 16. Interestingly, this increase is concurrent with the most conspicuous decline in physical activity in this population-based sample (Paper I).

Sleep is important for adolescents' well-being [79–81] and poor sleep quality is a common complaint [77,78] with up to 36% of adolescents having problems with falling asleep [77]. This makes our findings showing beneficial effects of a brief pedometer- and diary-based physical activity intervention on adolescents' subjective sleep quality especially interesting (Paper II). Moreover, one item of the subjective sleep quality scale, i.e., sleep onset latency, improved significantly in the intervention group compared to the control group. This means that in our 3-weeks intervention, participants using pedometers and physical activity diaries fell asleep faster than their peers in the control group. This is even more important considering the delayed bedtimes and shorter nocturnal sleep reported for Icelandic adolescents compared to their peers around the world [77,126].

6.3 Interventions

Because we determined the most apparent changes in both physical activity and depressive symptoms occurred between the ages of 15 and 16, or in the transition period from compulsory to upper-secondary schools (Paper I), we found it of uttermost importance to examine the feasibility of intervening in this age period. In addition, as already described above (section 4.1.2), due to the high attendance rate (94%) together with lower levels of physical education in

upper-secondary schools compared to compulsory schools in Iceland [127], we decided it was important to test the feasibility and effectiveness of a physical activity intervention among 15–16-year-old first-year students in upper-secondary schools.

6.3.1 Intervention components

As explained above (section 3) we used the core constructs of TPB to guide our intervention design by influencing: 1) attitudes with a motivating educational approach, 2) subjective norms by addressing adolescents in social groups (i.e., school-classes), and 3) behavioural control by using physical activity diaries and pedometers in combination with goal-setting. Indeed, intervention strategies based on motivation and goal-setting using pedometers and physical activity diaries have been effective in increasing physical activity among adolescents [115–119,121]. Thus, with the aim of designing an easy to deliver and practical intervention, universally directed at first-year students in upper-secondary schools we chose to test the feasibility and effectiveness of conducting a pedometer- and diary-based intervention. Indeed, studies on cost-effectiveness of physical activity interventions acknowledge pedometer-based interventions to be one of the most cost-effective approaches [176,177] and even likely to be cost-saving [176]. Further, recognizing walking as a natural form of physical activity and the behaviour that most people can do without additional equipment or guidance, we encouraged participants to use every opportunity to add more steps into their daily routines.

6.3.2 Effectiveness of pedometer-interventions

The results from our pilot-study where we tested a 3-week physical activity intervention based on pedometers and physical activity diaries were promising (Paper II). The intervention was effective in both increasing daily physical activity and in improving subjective sleep quality. The increase in daily steps of 1.200 is similar to earlier reported increase of approximately 1.000 steps/day [116] but studies have also described higher increases in steps or between 2.000 and 4.000 steps/day [117,119]. Our findings, thus, further strengthen the evidence for the effectiveness of pedometer- and diary-based interventions among adolescents. However, as the pilot-study intervention was based on both pedometers and physical activity diaries it was not clear if both elements were needed to effectively increase physical activity.

Building on the experience from the pilot-study we conducted a 3-week RCT intervention study with four study groups; P, D, PD and C (Paper III). The results showed that only PD and P groups increased daily steps at follow-up-1 with an increase of approximately 2.500 and 3.500 steps/day in the PD and P groups, respectively. The two pedometer groups did not differ demonstrating that pedometers are effective in increasing physical activity among adolescents and additional components such as physical activity diaries are not required. Previous pedometer-based studies among adolescents have used multicomponent interventions and therefore not been able to tease apart the effects of pedometers and diaries on physical activity. Hence, our results are the first to demonstrate that pedometer themselves, without the addition of diaries, can increase physical activity among adolescents.

6.3.3 Activity levels prior to intervention

In Paper III, we also examined if participants' physical activity levels at baseline were moderating the effects of the intervention as participants' activity levels have previously been found to be moderators [113,115]. According to Tudor-Locke and colleagues [136] participants were divided into five activity levels sedentary, low active, somewhat active, active, and highly active. We also divided participants into two activity levels based on the cut-off estimate of 10.000 daily steps according to the lower end of the step-goal set when implementing the intervention. However, we did not find any moderating effects of these activity levels. This is inconsistent with prior findings which show that pedometer-based interventions are more effective for low active individuals [113,115], but different definitions of low activity between studies make comparisons difficult. Thus, although pedometer-determined physical activity cut-off points for healthy adults are fairly established and sex-specific step index has been introduced for children (between 6-12 years), too little step data is available to suggest such step index for adolescents [165]. Therefore, more studies among the adolescent population are needed for a general consensus on how many steps per day that are sufficient for adolescents to be considered as either active or inactive.

6.3.4 Use of strategies and theories

Although theory-based behaviour interventions among adults are more effective than atheroretic ones, less is known about theory-driven interventions for adolescents [112,178]. Further, studies with adolescents that have used health behaviour theories to guide development of interventions seldom actually test if

the effectiveness of the interventions were mediated by changing the processes thought to be responsible for the behaviour change [116,119,179–182]. Of the studies that assess theory-based processes, self-efficacy has most commonly been used and found to mediate the effectiveness of physical activity interventions [180–182]. However, only three pedometer-based studies among adolescents have used health behaviour theories in connection with their behaviour strategies but none found any mediating effects on changes in daily steps [179,183,184]. A potential reason for theory-based interventions not being commonly used or even effective among children and adolescents could be that behavioural theories and models were originally designed for adult populations at risk. Thus, while adults may be motivated to be physically active to enhance their health and reduce the risk of an unhealthy lifestyle, adolescents may not find this important as they might not perceive themselves to be at risk for any diseases. As discussed above (section 1.1) such "immortal mentality" could be explained by the developmental imbalance in adolescence which also may result in poor rational decision making and risk-seeking behaviour [17]. Additionally, it is possible that the applied instruments are not appropriately measuring the behavioural constructs and thus may lack validity and reliability [185].

6.3.5 Duration and sustainability of interventions

We used four assessments points in the RCT intervention study, baseline and three follow-up assessments (Paper III). Follow-up-1 was conducted immediately after the 3-weeks intervention, while follow-up-2 and follow-up-3 were done four weeks and four months after the intervention, respectively. Our results showed that the effect of the intervention, i.e., the increase in physical activity in the pedometer groups at follow-up-1, was short-term as at follow-up-2 and -3 there were no differences in physical activity between study groups. Our failure to observe long term effects of our intervention could be because pedometer-interventions stop working once the pedometer is taken away or because our intervention period was too short to create a long term behaviour change.

Although a systematic review of school-based physical activity interventions described positive effects of intervention of longer duration, i.e., >1 year [104] a meta-analysis of pedometer-based interventions [114] found little difference in mean effect sizes between interventions lasting 8-15 weeks compared to interventions of shorter than 8 weeks duration (0.65 vs. 0.68). However, most pedometer-based studies have been of short duration with short term follow-ups and therefore their sustainability is unclear [153]. Thus, to date evidence on

the sustainability of the effects of pedometer-based interventions on behavioural change are scarce and studies with longer term follow-up are needed [112].

As interventions of more than one year duration may be difficult to implement in upper-school settings, interventions of brief duration may be more attractive in this context. Indeed, the experience from our pilot-study revealed that because of different circumstances in the participating schools, e.g., school happenings, exams and vacations being administered at different times during the school semester, an extension of the intervention duration would have been challenging. Thus, the positive effects of our 3-weeks pedometer-based interventions (Papers II and III) are indeed promising. They clearly demonstrate that such brief interventions are feasible and effective in the upper-secondary schools context and although the effects after intervention completion do not last steps could be taken to increase the possibility of long term behaviour change. For example, such brief interventions could be implemented once per semester as part of physical education classes. Further, new devices (e.g., smart phones, Fitbit) that capture physical activity and send reinforcing or encouraging messages may be more attractive and effective than pedometers for this age group. Although it is important to use validated measurement tools (e.g., Yamax pedometers) for research purposes it may be more feasible and even more effective in real life situations to use e.g., smart phones, which almost every adolescent possesses today.

6.4 Public health perspective

The public health perspective of this Thesis in grounded in the WHO definition of health from 1948: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" [65] together with the principle of the Ottawa Charter for Health Promotion which defines health promotion as "the process of enabling people to increase control over, and to improve, their health" [186]. While the Ottawa Charter can be looked upon as the cornerstone of public health and health promotion, as can equality and empowerment be thought of as the core values of health promotion and public health.

The goal of this Thesis was to provide adolescents with tools and information that would enable them to take control of their own health. More specifically, based on the serious development of diminishing physical activity and increasing problems of mental health among adolescents, the aspiration behind this Thesis

was to reach this under-researched population as adolescents have been. Acknowledging the importance of health and well-being for this vulnerable period of life, we provided information and education to adolescents about the importance of physical activity for health and well-being. Further, we focused on feasible strategies whereby adolescents could develop their own personal skills to incorporate physical activity, with emphasis on moderate-intensity, into their daily life.

Thus, this Thesis covers an urgent topic and the results are timely and contribute importantly to health promotion and public health. Indeed, on May 11, 2016 the Lancet announced that they, together with four leading academic institutions, have formed a commission on adolescent health and wellbeing [187]. The Lancet commission recognizes that adolescents' health has been neglected, the main reason for this being that the determinants of adolescent health are largely beyond the scope of the current healthcare system [187]. With mental disorders as depressive, conduct and anxiety disorders being among the top ten causes of years lost due to disability (YLDs) [188], it is time for all to act jointly for the well-being of adolescents. The importance of focusing interventions on adolescents is acknowledged by the potential of such interventions to be effective and cost-effective for disease-burden in later life [188].

As addressed in the Background section, the unremitting supply and influence of technology on our physical and social environment has made our lifestyle more sedentary. Therefore it can be a challenge for individuals to be and stay physically active in our contemporary society. However, as discussed above (sections 1.2.3 and 1.5.2) evidence from studies on people living a traditional lifestyle similar as before the industrial revolution, show no age-related decline in physical activity. Therefore, and because of the documented health benefits of physical activity, it is important to find appropriate methods for counteracting the decline in physical activity on the population level.

The importance of physical activity for the individual, the family, the school/workplace, the society, and the world is infinite. An intervention with emphasis on increasing moderate-intensity physical activity and adolescents' awareness about physical activity as part of their daily lifestyle has great public health relevance. A pedometer-based intervention is a relatively inexpensive and practical way of increasing physical activity and thus potentially positively influencing mental health, well-being and quality of life among adolescents.

Moreover, an effective and feasible physical activity intervention can easily be disseminated and incorporated into upper-secondary schools curricula. By focusing on adolescents, with the aim of enabling them to make healthier choices, the influence of a physical activity intervention will scatter through society. Additionally, as pedometer-based interventions are one of the most cost-effective interventions [176,177], the public health benefits of such interventions are great. As walking is a natural form of physical activity and the behaviour that most individuals can perform it is of great public health importance to encourage people to use every opportunity to add steps into their daily routines. A pedometer is a simple and inexpensive tool which can be used on the population level to enhance such behaviour. The results from this Thesis can be used in developing health promotion policies for adolescents worldwide.

7 CONCLUSIONS

This Thesis demonstrates that physical activity decreases and depressive symptoms increase in adolescence and that pedometer-based interventions are effective in increasing physical activity among this age group.

The most prominent differences in both physical activity and depressive symptoms occur among Icelandic adolescents between ages 15 and 16 or around the transition from compulsory to upper-secondary school in the Icelandic educational system. This is the first time that gender- and age-related differences as well as associations between physical activity and depressive symptoms are assessed on a nation-wide level with identical instruments during the whole adolescent period. This Thesis therefore provides important information about when to tailor and implement public health efforts to enhance physical activity and well-being among adolescents.

Furthermore, immediately following the 3-weeks physical activity intervention adolescents with pedometers took significantly more daily steps compared to their peers in the control group. Additionally, the intervention developed in this Thesis was effective in enhancing subjective sleep quality among adolescents. Further examination of sleep quality showed that sleep onset latency was improved which means that adolescents that were more physically active fell asleep faster than their less active peers. This is an important finding as sleep-related complaints are common in adolescence.

This Thesis also showed that pedometers alone are effective in increasing daily steps and that there is no need to include physical activity diaries into pedometer-based interventions. Thus, the results clearly demonstrate that brief physical activity interventions based on pedometers are effective in increasing daily steps and improving sleep quality among adolescents. This has important public health relevance as the intervention is cost-effective and can easily be disseminated and incorporated into schools' curricula.

The aspiration behind this Thesis was to reach adolescents, an under-researched population, because of the serious development of diminishing physical activity and increasing problems of mental health in this group during such a vulnerable period of their lives.

The findings from this Thesis provide important information on when to tailor and implement public health interventions for adolescents and, additionally, propose feasible strategies which can enable adolescents to make healthier choices and develop their own personal skills to incorporate physical activity into their daily life. The results from this Thesis can thus be used in developing health promotion policies for adolescents.

8 FUTURE PERSPECTIVES

Intervention studies designed for adolescents are increasingly guided by health behaviour based theories. However, there is a lack of research testing whether the effects of interventions are indeed due to the influences on the processes proposed by the theories to cause a behaviour change. It is critical for future research to untangle the underlying mechanisms whereby interventions are effective in increasing physical activity as that will provide important information for refining and improving interventions for adolescents. It is particularly important to understand the mechanisms that maintain changes in physical activity as most intervention studies focusing on adolescents, including this Thesis, have shown that the interventions are effective in the short run but not in the long run.

Future studies should also focus on for whom the intervention is most effective. Some prior studies have found differential effects of participants physical activity levels at baseline with interventions being more effective for those having lower activity levels. However, we found no moderating effects of the tested activity levels in our studies. Therefore, future research should address if different activity levels are moderating factors among adolescents. Other moderators need to be identified as it will help tailor the interventions to the need of adolescents.

Additionally, studies should be directed towards finding a general consensus on how many steps per day that are sufficient for adolescents to be considered active or inactive or even more specified e.g., inactive, low active, somewhat active, active, and highly active. A step-related index identifying several activity cut-off points in relation to health would indeed be useful for researchers and practitioners as well as the general public. For valid and reliable estimates that can be compared within and between countries it is important to develop and implement standardized measurements for physical activity and mental health. Without such measurement tools, we will not be capable to identify and address those most in need.

The unremitting supply and influence of technology on our physical and social environment has made our lifestyle more sedentary. However, new devices to measure and motivate physical activity are promising and it is important to involve adolescents in future research on how best to make use of this new and

ever evolving technology. It is vital to find appropriate methods for counteracting the decline in physical activity on the population level and we believe there are positive and challenging opportunities ahead of us. With reference to the severe trend of diminishing physical activity and rising incidences of mental health problems among the adolescent population this is indeed an urgent topic.

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