Health behavior of Icelandic youth

Associations of screen time and physical activity with mental health and sleep patterns

Soffía Margrét Hrafnkelsdóttir

Dissertation submitted in partial fulfillment of a Ph.D.-degree

HÁSKÓLI ÍSLANDS
MENNTAVÍSINDASVIÐ

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Tengsl skjátíma og hreyfingar við andlega líðan og svefnmynstur

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Ritgerð lögð fram til að uppfylla kröfur um doktorsgráðu

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Ágrip

Bakgrunnur: Unglingsárin eru tími mikilla breytinga og þroska hvað varðar líkamlegt og andlegt atgervi. Á þessum árum eykst tíðni andlegra kvilla og svefntruflana, sem geta haft alvarlegar afleiðingar fyrir unglinga og fylgt þeim inn í fullorðinsárin. Því er afar mikilvægt að skoða þætti sem geta haft áhrif á þessa kvilla með forvarnir í huga. Hreyfing og kyrrseta eru meðal þeirra mótanlegu hegðunarþátta sem taldir eru hafa áhrif á andlega líðan og svefn. Fyrri rannsóknir hafa sýnt að hreyfing minnkar á unglingsárunum og kyrrseta, þar sem skjátími leggur hvað mest til, eykst. Rannsóknir á unglingum þar sem allir þessir þættir, þ.e. andleg líðan, svefn, hreyfing og skjátími, eru mældir samtímis eru fáar og þær sem hafa notað hlutlægar mælingar á svefni eru afar fátíðar.

Markmið: Meginmarkmið þessa doktorsverkefnis var að skoða tengsl skjátíma og hreyfingar við svefn og andlega líðan meðal íslenskra unglinga sem tóku þátt í langtíma hóprannsókn og nota til þess hlutlægar mælingar á svefni.

Efniviður og aðferðir: Rannsóknarþýðið samanstóð af 315 unglingum sem voru í 10. bekk grunnskóla vorið 2015, þar af höfðu 244-247 gild gögn fyrir helstu breytur. Hluti unglinganna (N=168) tók svo þátt í framhaldsrannsókn tveimur árum síðar og höfðu þá 152 einstaklingar gild gögn. Þátttakendur svöruðu rafrænum spurningarlista í skólanum um þætti sem tengdust andlegri líðan (einkennum um þunglyndi, kvíða og líkamleg óþægindi, sjálfstrausti, lífsánægju og líkamsímynd) og lífsstíl (ákafri hreyfingu og skjátíma) auk bakgrunnsbreyta. Auk þess var hreyfing þeirra og svefn mældur með hreyfimælum sem ungmennin báru á úlnlið í 7-10 sólarhringi. Hæð og þyngd þátttakenda var mæld og fituprósenta þeirra ákvörðuð með tvíorku röntgengeisla-gleypnimælingu (dual energy X-ray absorptiometry, DXA). Aðhvarfsgreining, þar sem leiðrétt var fyrir helstu mögulegum gruggunarþáttum, var notuð til að meta tengsl skjánotkunar og hreyfingar við andlega líðan (grein I) og svefn (grein II) við 15 ára aldur og tengsl skjánotkunar og líkamsímyndar við 15 og 17 ára aldur (í þversniði og langsniði, grein III).

Niðurstöður: Meðal skjátími var 5,6 klst/dag við 15 ára aldur, hærri hjá drengjum en stúlkum, en var orðinn jafn hjá kynjunum við 17 ára aldur (6,4 klst/dag). Mjög fáir (<4%) sögðu skjátíma sinn vera innan ráðlagðra marka um hámarkstíma (2 klst/dag). Stúlkur voru meira á internetinu en drengir sem aftur á móti kusu frekar að spila tölvuleiki en stúlkur. Bæði kyn gáfu upp hærri skjátíma um helgar en á virkum dögum. Kynin mældust með svipaða hreyfingu yfir vikuna við 15 ára aldur og bæði kyn hreyfðu sig meira á skóladögum en frídögum. Drengir sögðust hreyfa sig oftar af ákefð en stúlkur, en tæplega 2 af hverjum 3 einstaklingum af báðum kynjum sögðust hreyfa sig af ákefð ≥4x/viku.

Einkenni um þunglyndi, kvíða og líkamleg óþægindi voru algengari hjá stúlkum (15-22%) en drengjum (3-8%) en ekki var kynjamunur á þeim sem greindu frá litlu sjálfsáliti (16%) og óánægju með lífið (20%). Minni skjátími (fyrir neðan miðgildið 5,3 klst/dag) og tíðari áköf hreyfing (≥4x/viku) tengdust minni líkum á að greina frá einkennum um þunglyndi, kvíða, lítið sjálfsálit og óánægju með lífið. Hópurinn sem bæði gaf upp minni skjátíma og tíðari hreyfingu af ákefð var ólíklegastur til að greina frá þessum einkennum um andlega vanlíðan.

Ekki var munur á lengd (6,6 klst/nótt) og gæðum svefns hjá kynjunum, en háttatími og fótaferðartími drengja var seinni en hjá stúlkum. Þátttakendur höfðu mikinn breytileika í svefngildum, staðalfrávik yfir vikuna fyrir lengd, gæði og tímasetningu svefns var umfram 1 klst, og breytileikinn var að meðaltali meiri meðal drengja en stúlkna. Skjátími, sérstaklega leikjaspilun, tengdist meiri breytileika í lengd, tímasetningu og gæðum svefns. Tengslin voru sterkust við breytileika í háttatíma, en einnig fundust tengsl við síðbúinn háttatíma og styttri svefn og hvíld. Kynskipt aðhvarfsgreining sýndi að tengsl milli skjátíma og meiri breytileika í svefni fundust hjá drengjum en ekki stúlkum. Hreyfing tengdist minni breytileika í lengd, tímasetningu og gæðum svefns og voru tengslin sterkust við breytileika í fjölda vaknana. Á óvart kom að hreyfing tengdist einnig minni svefnlengd og því að fara fyrr á fætur.

Meðalskor fyrir líkamsímynd var lægra hjá stúlkum en drengjum við bæði 15 og 17 ára aldur en skorið breyttist ekki milli tímapunkta hjá kynjunum. Tengsl fundust milli skjátíma og verri líkamsímyndar hjá stúlkum en ekki drengjum og voru þau sterkari við 15 ára aldur. Langsniðsgreining sýndi að stúlkur sem voru með skjátíma ofan miðgildis við bæði 15 og 17 ára aldur höfðu 14% lægra skor fyrir líkamsímynd við 17 ára aldur en stúlkur sem höfðu skjátíma neðan miðgildis á báðum tímapunktum.

Ályktanir: Niðurstöður rannsóknarinnar benda til þess að minni skjátími og tíðari áköf hreyfing, bæði í sitt hvoru lagi og þó sérstaklega samverkandi, tengist minni líkum á því að greina frá einkennum um þunglyndi og kvíða, litlu sjálfsáliti og lífsóánægju. Einnig virðast minni skjátími og meiri heildarhreyfing vera tengd minni breytileika í svefni, sérstaklega meðal drengja. Ennfremur gefa niðurstöður bæði í þversniði og langsniði til kynna að skjátími geti stuðlað að líkamsóánægju meðal stúlkna. Kynjamunur í niðurstöðum bendir til þess að skjánotkun geti haft mismunandi áhrif á heilsutengda þætti hjá drengjum og stúlkum. Í heild virðist það hafa góð áhrif á bæði andlega líðan og svefnmynstur unglinga að takmarka skjátíma og stunda reglubundna hreyfingu.

Abstract

Background: Prevalence of mental health problems and sleep disturbances takes a sharp rise during adolescence. The potential harmful consequences of these conditions in adolescence and into adulthood are of great concern and the identification of risk factors and/or protective factors is a very important public health issue. Two modifiable behavioral factors that are thought to affect mental health and sleep are screen time and physical activity. Previous studies have shown that a decrease in physical activity levels and an increase in sedentary time in youth, with screen time being the main contributor, is especially apparent during adolescence. Studies with concurrent measures of mental health, sleep, physical activity, and screen time at this critical stage of development are scarce and those with an objective measure of sleep are exceedingly rare.

Aim: The overall aim of this dissertation was to investigate the relationship of screen time and physical activity with sleep parameters and mental well-being in a cohort of Icelandic adolescents, using objective measures for sleep.

Methods: The study cohort included 315 adolescents attending 10th grade (15 year old) in the spring of 2015, 244-247 of which had valid data for associations of interest. A subset (N=168, thereof 152 with valid data) participated in a follow-up study two years later. By answering a tablet-based questionnaire administered at school, participants self-reported screen time, frequency of vigorous physical activity, mental health status (symptoms of depression, anxiety and somatic discomfort, self-esteem, life satisfaction, and body image), and socio-economic status. Wrist-worn accelerometers were used to objectively measure free-living physical activity and sleep for 7-10 days. Participants´ weight and height were measured and adiposity was determined using dual energy X-ray absorptiometry (DXA). Regression analyses, controlling for potential confounders, were used to assess the relationship of screen time and physical activity with mental health (study I) and sleep (study II) at age 15, and the association between screen time and body image at ages 15 and 17 (cross-sectional and longitudinal, study III).

Results: Average total screen time was 5.6 h/day at age 15, higher for boys than girls, but had become equal for the sexes at age 17 (6.4 h/day). Very few participants (<4%) reported screen time within the recommended limit of 2 h/day. Girls reported spending more time on the internet than boys, whereas boys reported more game playing than girls. Both sexes had higher screen time on non-school days than school days. Nearly two thirds of participants reported performing vigorous physical activity ≥4x/week as recommended. Boys and girls had similar objectively measured physical activity across the week, with more activity on school days.

Prevalence of symptoms of depression, anxiety, and somatic complaints was significantly higher among girls (15-22%) than boys (3-8%), whereas reports of low self-esteem (16%) and life dissatisfaction (20%) did not differ by sex. Below median screen time (< 5.3 h/day) and more frequent vigorous physical activity (≥4x/week) were each independently associated with reporting fewer symptoms of depression, anxiety, low self-esteem, and life dissatisfaction, but those reporting both below median screen time and more frequent vigorous physical activity had the lowest risk of reporting these symptoms.

Average values of sleep quality and duration (6.6 h/night) did not differ between the sexes, but boys had later bed and rise times. Participants had highly variable sleep schedules, with weekly intra-individual standard deviations of bed time, rise time, and sleep duration >1 hour, and greater variability for boys than girls. Regression analyses demonstrated that screen time, especially game playing, was associated with greater variability in duration, timing and quality of sleep, most strongly with variation in bed time. Screen time was also associated with later bed time and less rest and sleep durations. Sex-specific associations of screen time with sleep variability parameters were significant for boys only. Physical activity was inversely associated with variability in duration, timing and quality of sleep, most strongly with variation in number of awakenings. Surprisingly, it was also associated with earlier rise time and less sleep duration.

Average body image score was lower for girls at both ages and did not change significantly between age 15 and 17, for either sex. Screen time was negatively associated with body image for girls but not boys and more strongly at age 15. Longitudinal analysis showed that girls with above median screen time at both ages had 14% lower body image score at age 17 than girls with below median screen time at both timepoints.

Conclusions: Our data suggest that less screen time and more frequent vigorous physical activity are both independently and interactively associated with lower risk of reporting symptoms of depression and anxiety, low self-esteem and life dissatisfaction. Similarly, less screen time and more total physical activity are both associated with less variable sleep patterns, especially among boys. Finally, our cross-sectional and longitudinal analyses support the notion that screen use may play a role in the development of body dissatisfaction among girls. The observed sex differences in this dissertation indicate that the sexes may be differently susceptible to the effects of screen use on health outcomes. Overall, these findings highlight the potential health benefits of limiting screen time and being physically active during adolescence.

Acknowledgements

This dissertation is based upon a research project composed of three individual studies. The project was a part of a larger research project, the “Health behavior of Icelandic youth”, which was initiated in 2015 at the Center of Sport and Health Sciences at the University of Iceland. The project has been carried out in collaboration with specialists at the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) in Bethesda, MD, U.S.A.

I would like to thank the many people that have helped and supported me on this journey. My supervisors, professor Sigurbjörn Árni Arngrímsson and associate professor Sigríður Lára Guðmundsdóttir, have given me valuable guidance and advice in my studies. They have been very encouraging, not least during the trying last steps towards the preparation of the final thesis manuscript. I have also received a great support and assistance from Dr. Robert J. Brychta at the NIDDK, a member of the doctoral committee. He has been very helpful with respect to data preparation, statistical analyses and academic writing throughout this project. A colleague of his at NIDDK, Professor Kong Chen, has also given me valuable scientific advice. Professor Erlingur Jóhannsson, the principal investigator of the “Health behavior of Icelandic youth” project, has been encouraging and interested in my studies. I would also like to thank my co-author and fellow doctoral student Vaka Rögnvaldsdóttir for her collaboration on setting up the project´s database and in editing all the output files for sleep measurements from the accelerometers. She has been friendly and delightful to work with as has also been the case with Rúna Sif Stefánsdóttir, our fellow doctoral student. Furthermore, I would like to mention Sunna Gestsdóttir, which I shared an office with during my first and her last year of doctoral study. She was very willing to help and give her assistance whenever needed. Hans Hansson, at the Educational Research Institute has also been helpful in advising on statistical matters. And I thank Þórdís Gísladóttir, at the Center of Health and Sport Sciences, for her friendliness and being such a nice room-mate and travel companion when attending conferences abroad in my doctoral years.

In the spring of 2015, when I became a member of the “Health behavior of Icelandic youth” team, I first joined in the planning of the upcoming data collection and then participated in the collection of data in the six compulsory schools participating in the project. That was a challenging but rewarding period, where my job was to transfer the adolescents from their school to the facilities of Hjartavernd, where their body composition was being measured and blood samples collected, and then back to school afterwards. I had to muster the courage to drive a mini-van with a stick shift, which was definately outside my comfort zone. Two years later, in the follow-up data collection, Vaka and I were responsible for the handling of the accelerometers used for objective measurements of sleep and physical activity. I believe that one gets more connected to the data when participating in collecting it. I also think that it enhanced the team spirit and I would like to thank all the members of the group for the collaboration, e.g. the people enlisted previously in these acknowledgements as well as the master´s students participating in the 2015 data collection: Bjarki Gíslason, Vala Margrét Jóhannsdóttir and Steinar Logi Rúnarsson. The staff at Hjartavernd was also a pleasure to work with as well as very professional. I would furthermore, like to give special thanks to all the adolescents who participated in this study and the principals and staff at the participating schools.

This project would not have been feasible without the financial support from The University of Iceland Research Fund and The Icelandic Center for Research (RANNÍS), and I thank both of these funds for their contributions.

My family has been very supportive and encouraging throughout my doctoral study years. My husband, Þorlákur, has been of great help when I have encountered obstacles or needed a second opinion on academic reasoning and writing. My mother has been very confident in me and proud of my studies. And my son and his challenges in life really inspired me to choose this study subject, and I would like to dedicate this work to him.

Reykjavík, August 2020

Soffía Margrét Hrafnkelsdóttir.

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List of original papers

This dissertation is based on the following three original research papers, identified by Roman numericals in accordance with the studies they represent.

I. Hrafnkelsdottir, S.M., Brychta, R.J., Rognvaldsdottir, V., Gestsdottir, S., Chen, K.Y., Johannsson, E., Guðmundsdottir, S.L., Arngrimsson, S.A. (2018). **Less screen time and more frequent vigorous physical activity is associated with lower risk of reporting negative mental health symptoms among Icelandic adolescents**. *PLoS One*,*13*(4):e0196286.

II. Hrafnkelsdottir, S.M., Brychta, R.J., Rognvaldsdottir, V., Chen, K.Y., Johannsson, E., Guðmundsdottir, S.L., Arngrimsson, S.A. (2020). **Less screen time and more physical activity is associated with more stable sleep patterns among Icelandic adolescents**. *Sleep Health* (in publication).

III. Hrafnkelsdottir, S.M., Brychta, R.J., Rognvaldsdottir, V., Chen, K.Y., Johannsson, E., Guðmundsdottir, S.L., Arngrimsson, S.A. (2020). **Screen time and body image – a longitudinal cohort study in Icelandic adolescents**. Manuscript submitted.

Declaration of contribution

Soffía contributed to the preparation and data collection of the larger research project, Health behviour in the Icelandic youth. She participated significantly in data curation and conceptualization of the three studies comprising the doctoral thesis. Soffía performed the statistical analyses and contributed most to the writing of the three papers. She was the corresponding author for all three papers.

1 Introduction

Sedentary behavior and physical inactivity among children and adolescents is a serious and growing healthcare problem worldwide. With advances in technology, youngsters spend increasing amount of their leisure-time using screen-based media (Rideout, Foehr, & Roberts, 2010). Parallel to this development, physical activity of children and adolescents has decreased considerably in the past years (Dollman, Norton, & Norton, 2005; Dumith, Gigante, Domingues, & Kohl, 2011). Another concern is the decreasing sleep duration in youth that has been observed over the last decades (Keyes, Maslowsky, Hamilton, & Schulenberg, 2015). Collectively, these factors may have detrimental effects on the physical and mental health of children and adolescents and negatively impact their academic attainment (Laurson, Lee, Gentile, Walsh, & Eisenmann, 2014; Salmon, Tremblay, Marshall, & Hume, 2011; Tremblay et al., 2011b; Trinh, Wong, & Faulkner, 2015). In response to this negative development, and in line with recommendations of the World Health Organization (WHO) (World Health Organization, 2004), public health policies of most Western countries emphasize the importance of physical activity among children and adolescents for both short-term and long-term well-being. Guidelines regarding screen time and/or sedentary behavior have also been published in a few countries, including the US, Canada, UK and Australia (Okely et al., 2012). Recommendations for adolescents´ sleep have been issued by the National Sleep Foundation in the U.S., which call for that adolescents not only get an adequate amount of sleep but also maintain a consistent sleep routine (Gruber et al., 2014), as timing and consistency of sleep may affect the restorative properties of sleep and overall health (Becker, Sidol, Van Dyk, Epstein, & Beebe, 2017; Hirshkowitz et al., 2015).

Adolescence is a period marked by significant changes in physical maturity, cognition, emotional attachments, peer relationships, and increased autonomy (Kaufman, 2006). In this sensitive developmental period, individuals start establishing their own lifestyle patterns, forming tendencies and habits towards certain activities and health-related behaviors, which tend to be stable throughout life (Kjonniksen, Torsheim, & Wold, 2008; Telama et al., 2014). Previous studies have shown that a decrease in physical activity levels and an increase in sedentary time in youth is especially apparent during adolescence (Collings et al., 2015; Dumith et al., 2011; Kahn et al., 2008). Furthermore, prevalences of mental health problems and sleep disturbances take a sharp rise during this age period (Patel, 2013a; Urrila, Paunio, Palomaki, & Marttunen, 2015). The potential harmful consequences of these behaviors and conditions are of great concern and the identification of risk factors and/or protective factors is a very important public health issue. Such research is the essence of behavioral epidemiology, a discipline which strives to establish links between behavior and health with the ultimate goal of developing evidence-based interventions to promote health in population settings (Sallis, Owen and Fotheringham, 2000). Various factors have been implicated to affect mental health and sleep, including age, pubertal stage, biological sex, gender, socio-economic status, social support, home and school environment, and lifestyle factors (World Health Organization, 2014). Two modifiable behavioral factors that are thought to affect mental health and sleep are screen time and physical activity (Hale & Guan, 2015; Biddle & Asare, 2011; Suchert, Hanewinkel, & Isensee, 2015; Hoare, Milton, Foster, & Allender, 2016; Lang et al., 2013). Research in this area has, however, typically been limited to cross-sectional analysis (Lang et al., 2016; Hale & Guan, 2015), and in general focused on specific health behaviors and not potential interrelationships between them (Laurson et al., 2014; Trinh et al., 2015). Furthermore, they have mainly relied on subjective measures (Lang et al., 2016; Hale & Guan, 2015).

The main focus of this dissertation is on the relationship of screen time with mental health status, sleep patterns and body image. The relationship of physical activity with mental health and sleep patterns is also explored, as well as the interrelated effects of screen time and physical activity on mental health outcomes. In addition to self-report measures, data collected by actigraphy will be used to shed light on these important public health issues in adolescents.

1.1 Theoretical framework

The term behavioral epidemiology was introduced in the late 1970s to describe the evolving research field focusing on evaluating the effects of behavior on health outcomes, to aid in implementation of health promotion and intervention strategies. Sallis et al. (2000) later presented a detailed conceptualization of this discipline, as a sub-field within the broader area of epidemiology (Sallis, Owen, & Fotheringham, 2000). Particular health behaviors, such as physical activity, sedentary behavior and sleep have typically been investigated as separate sub-domains within the field of behavioral epidemiology. In 2007, Tremblay et al. (Tremblay, Esliger, Tremblay, & Colley, 2007) suggested that a balance is needed between physical acitivity, sleep and physical inactivity for optimal health and in recent years researchers have increasingly started to integrate research on time spent in various health related activities into the unified field of time-use epidemiology. That discipline may be defined as the study of determinants, incidence, distributions, and effects of health-related time-use patterns in populations and of methods for preventing unhealthy time-use patterns as well as achieving the optimal distribution of time-use for population health (Pedišić, Dumuid, & Olds, 2017). A theoretical framework, the Activity Balance Model, has been introduced where compositional data analysis is being proposed as being the preferred method of analysing data for physical activity, sedentary behavior and sleep in an integrated fashion within time-use epidemiology (Pedišić, 2014), typically in a 24-hour time period format (with time spent in these activities being mutually exclusive and making up the total sum of activity over the 24-hour period). Time-use-research has gained momentum in recent years and has laid the foundation for new public health guidelines for youth, encompassing sleep, sedentary behavior and physical activity within the 24-hour time-use continuum, issued in Canada (Tremblay et al., 2016) and New Zealand (New Zealand Ministry of Health, 2017) and under consideration in Australia and Denmark (Pedišic et al., 2017). Figure 1 shows how behavioral and time-use epidemiology subside within the broader field of epidemiology.

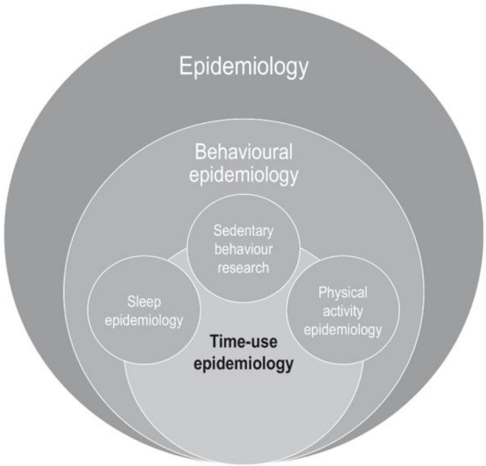

Figure 1. Relationship between time-use epidemiology and previously established epidemiological disciplines (Pedišic et al., 2017).

Social-ecological models are increasingly used to aid in the understanding of health behaviors (Golden & Earp, 2012). These models describe the interactive characteristics of individuals and environments that underlie health outcomes (Brofenbrenner, 1977; McLeroy, Bibeau, Steckler, & Glanz, 1988). The models are multi-level in structure, with factors at the intrapersonal, interpersonal, organizational, community, and public policy levels, and influences on behaviors interact across these different levels (Sallis, Owen, & Fischer, 2008). Sociocultural factors and physical environments may be invisioned to cut across all the levels (Sallis et al., 2008). Figure 2 shows a schematic representation of such a model for the main variables of interest in this dissertation, as well as other factors that may affect the outcomes of the doctoral study, both directly and indirectely.

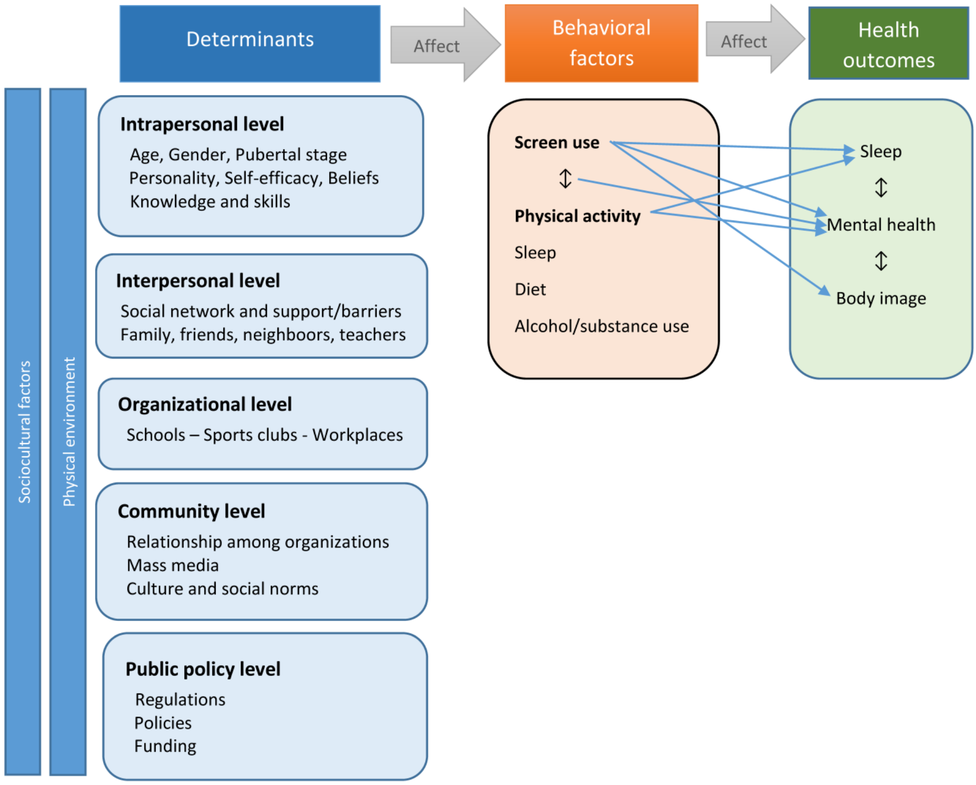

Figure 2. Socio-ecological model showing various determinants of some of the behavioral factors that may affect the health outcomes examined in the dissertation. Behavioral factors explored in the dissertation are bolded, with blue arrows showing the relationships evaluated. Bidirectional black arrows indicate possible interaction between behavioral factors/health outcomes.

Accumulating evidence suggests that unfavorable health behaviors, such as excessive sedentary time, insufficient physical activity and unhealthy dietary choices, established during adolescence and persisting into adulthood, co-occur as risk behavioral clusters in adolescents (Leech, McNaughton, & Timperio, 2014; Pearson et al., 2017). It may, therefore, be more important in terms of public health to look at the relationship of clusters of behaviors with health outcomes, rather than the effects of individual behaviors on health.

1.2 Physical activity

Physical activity has been defined as the work done by skeletal muscles that increases the energy used by a person from the energy needed at rest (World Health Organization, 2010). Parameters used to describe physical activity are type, duration, frequency and intensity (World Health Organization, 2010). Together these parameters give information about the total volume of the physical activity being performed. Metabolic equivalent (MET) is the unit defined to describe energy use, 1 MET being the energy required at rest or 1 kcal/kg/hour

(World Health Organization, 2010). Sedentary behavior refers to activities that require very low energy expenditure (≤ 1.5 METs) and where sitting, reclining or lying is the dominant posture (Pate, O'Neill, & Lobelo, 2008). Light physical activity is an activity requiring 1.6-2.9 METs (Pate, O'Neill, & Lobelo, 2008). Moderate physical activity has been defined as the activity requiring 3-5.9 METs, e.g. brisk walking, easy cycling, swimming, jogging and weightlifting (World Health Organization, 2010). Vigorous activity is the physical exertion that requires 6 METs or more, such as brisk uphill walking, running and most competitive sports (World Health Organization, 2010).

The importance of the above terminology and its consistent use is reflected in the development of official guidelines regarding physical activity. The first guidelines informing the public of optimal physical activity in order to stay healthy were issued by the American College of Sports Medicine (ACSM) in 1978 (ACSM, 1978). Guidelines regarding physical activity for children and adolescents were proposed by the ACSM ten years later (ACSM, 1988) and updated in the 1990s, based on expert opinions relying on evidence from observational studies using subjective measures of physical activity (Biddle, Sallis, & Cavill, 1998). A minimum of 60 minutes of moderate to vigorous physical activity (MVPA) daily, in addition to strength and flexibility training two times per week were proposed (Biddle et al., 1998). In 2008, the U.S. Department of Health and Human Services issued Physical Activity Guidelines for Americans, which were based on a systematic review of the scientific literature on physical activity and health (U.S. Department of Health and Human Services, 2008). Children and adolescents were advised to do at least 60 min of enjoyable and varied MVPA daily, including a minimum of 3 days with vigorous activity, as well as bone- and muscle-strengthening activity 3 times/week. These guidelines were updated in 2018 to include discussion on sedentary behavior, where individuals are advised to not only move more but also to sit less (U.S. Department of Health and Human Services, 2018). This is important, as it is possible to meet physical activity recommendations and still be highly sedentary (Ferrar, Chang, Li, & Olds, 2013). Health benefits of increased physical activity and reduced sedentary behavior among school-aged children and adolescents now include improved cognition and less depressed mood, in addition to the previously listed benefits to cardiorespiratory and muscular fitness, cardiometabolic health, weight status and bone health. Current Icelandic physical activity guidelines for children and adolescents call for a total of 60 minutes or more of enjoyable and diverse MVPA daily (Directorate of Health, 2008).

Observations of levels of physical activity and adherence to physical activity guidelines have raised concerns about decreasing and insufficient levels of activity. Research has shown that physical activity levels tend to decrease during adolescence (Dumith et al., 2011; Ortega et al., 2013); participation of children and adolescents in physical activity has gradually declined in the last decades (Dollman et al., 2005; Rippe & Hess, 1998) and the number of youngsters who perform very little physical activity has risen significantly

(Ekeland et al., 1999). In Iceland, only 14.5% of 15-year-old boys and 1.5% of 15-year-old girls met the guidelines for physical activity in 2011 (Magnusson, Arngrimsson, Sveinsson, & Johannsson, 2011a). In a study from 2018 on 15-year-old adolescents, 53% of boys and 37% of girls reported participating in sports or other physical activity for at least 6 h/week. Higher percentage of boys (40%) than girls (29%) reported doing vigorous activity for more than 6 days/week (Rognvaldsdottir et al., 2018). These numbers are higher than the ones from 2011, which is likely due to methodological differences, such as in measures of activity (objective in 2011 vs. subjective in 2018) and definitions of MVPA. The sex differences regarding participation in vigorous activity might be the result of boys being more competitive and aggressive than girls, due to higher levels of testosterone in males (Eisenegger, Haushofer, & Fehr, 2011). Social norms and stereotypes may also explain this difference, with males acknowledged to be more athletic than girls (see further in section 1.6) (Klomsten, Skaalvik, & Espnes, 2004).

As stated above, heterogeneity of study results on physical activity levels may reflect challenges in measurements. Most of the information on physical activity in the past has been gathered using subjective measures such as questionnaires. The reliability and validity of subjective methods have been questioned (Chinapaw, Mokkink, van Poppel, van Mechelen, & Terwee, 2010) and in recent years accelerometers have increasingly been used to measure physical activity in an objective manner (Chinapaw et al., 2012). The newest accelerometers measure physical activity in a triaxial format, using validated filtering algorithms to obtain information about the amount and intensity of the activity (Butte, Ekelund, & Westerterp, 2012; Rowlands et al., 2014; Yang & Hsu, 2010). Physical activity may also be evaluated by direct observation, giving detailed information but being very labour intensive for researchers (McKenzie, Marshall, Sallis, & Conway, 2000). More recently, wearable cameras have been used to capture behaviors and the contexts in which they occur, but carry some ethical and technical challenges (Everson, Mackintosh, McNarry, Todd, & Stratton, 2019). Subjective and objective methods have their strengths and limitations. Subjective methods can give information about the type of activity and are easier and less costly to use for screening purposes of larger samples than objective methods, although recall and reporting biases may be a problem. Objective methods, using accelerometers, are more reliable and easier to validate but have the disadvantage that they cannot distinguish between different types of activity and may even be unable to detect non-weight-bearing physical activity, such as cycling and swimming (Butte et al., 2012). Measurements by accelerometers also vary depending on the region of the body they are attached to (Zinkhan et al., 2014). In light of the above, it might be most beneficial to use a combination of objective measures and questionnaires to get information on both the amount and type of activities being performed (Pearson, Braithwaite, Biddle, van Sluijs, & Atkin, 2014).

1.3 Screen time

During leisure time, typical sedentary behaviors among youth include screen-based activities such as spending time on social media and the internet, watching television and playing passive video games (Rideout, 2015). Screen time has been found to increase during adolescence (Pate, Mitchell, Byun, & Dowda, 2011) and tracks moderately from childhood to adulthood (Biddle, Pearson, Ross, & Braithwaite, 2010). Screen-based media use has increased rapidly in recent years with advances in technology, notably the introduction of hand-held devices such as tablets and smartphones (Rideout, 2015). Official guidelines for screen time were first issued in 2001, by the American Academy of Pediatrics (AAP), calling for no more than 2 h/day of recreational screen time for school-aged children and adolescents (American Academy of Pediatrics, 2001). These recommendations were based on expert opinion and clinical experience rather than a systematic review of the evidence. Similar recommendations were subsequently issued by Canada (Canadian Society for Exercise Physiology, 2011; Tremblay et al., 2011a) and Australia (Australian Government Department of Health, 2004). In the UK, children and young people have been advised to minimize the amount of time spent being sedentary (sitting) for extended periods (UK Department of Health, 2010). In 2016, the AAP revised their guidelines, aborting the 2 h/day limit and recommending instead that parents and caregivers develop a family media plan that takes into account the health, education and entertainment needs of each child as well as the whole family (American Academy of Pediatrics, 2016). In Iceland, similar guidelines to the revised AAP recommendations were issued in 2018 by authorities in the fields of health care, child welfare and safe internet use (SAFT, 2018), updating the previous recommendations that recreational screen time of school-aged children and adolescents should not exceed 2 h/day (Directorate of Health, 2008). In the UK, the Royal College of Paediatrics and Child Health very recently issued the first guidelines on screen time in the country, which emphasize establishing a family media plan rather than setting time limits on screen use (Royal College of Paediatrics and Child Health, 2019).

Despite official guidelines, numerous recent studies have reported increased duration of screen-time behavior in children and adolescents exceeding the recommended screen time limits. A large cross-national study examining trends in adolescent screen-time behaviors from 2002 to 2010 in 30 countries across Europe, North-America and Israel, reported that the average total screen time of 15 year-old adolescents increased in this time period by 2-3 h/day (Bucksch et al., 2016). In 2010, the average daily screen time across the week was around 6 h for girls and 7 h for boys, and it was around 2 h higher on non-school days than school days for both sexes (Bucksch et al., 2016). Likewise, among American youth, the average screen media use was found to be 6.7 h/day for 13-18 year-olds in 2015, with only 23% spending 2h/day or less on screen activities (Rideout, 2015). Similar values have been reported for Canadian and Australian adolescents (Day, 2014; Active Healthy Kids Canada, 2012; Colley et al., 2011; Houghton et al., 2015; Kremer et al., 2014). In Iceland, 58% of boys and 43% of girls in grades 6, 8 and 10 (11-, 13- and 15-year-olds) reported in 2006 their total screen time to be 4 h or more each day (Bjarnason, Jonsson, Olafsson, Hjalmsdottir, & Olafsson, 2006) and in 2014, the majority of 15 year old boys reported spending more than 2h/day in their spare time on school days watching TV, using a computer for email, internet or homework and playing games on a computer or a games console. Values were similar for girls, except for much lower percentage reporting game playing (World Health Organization, 2016c). These numbers were lower than the ones reported for Denmark, Sweden and Norway in 2014, but similar or slightly higher than those reported for Finland (World Health Organization, 2016c). In all categories of screen use, the percentage for Iceland was somewhat lower than the average one across 49 countries (World Health Organization, 2016c).

Sex disparities have been observed for both time (Bucksch et al., 2016) and type (Rideout, 2015; Active Healthy Kids Canada, 2012; Bucksch et al., 2014) of screen behavior. In a cross-national study examining trends in adolescent screen-time behaviors from 2002 to 2010 the average total screen time of 15-year-old boys was 1.1 h and 1.3 h higher on school days and non-school days, respectively, than that of same age girls (World Health Organization, 2016c). Similarly, according to a Canadian survey, boys spent almost one hour more in front of screens than girls, which was mostly due to more game playing by boys (Active Healthy Kids Canada, 2012). Boys seem to favor computer gaming, whereas girls are more likely to use the internet for communication purposes via social media, web-browsing or e-mailing (Active Healthy Kids Canada, 2012; Bucksch et al., 2014). Higher levels of the sex hormone testosterone in boys and estrogen in girls, in addition to the effects of social norms and stereotypes (see section 1.6), might explain these behavioral differences between the sexes. Boys may be more competitive and prefer the action and aggression in gaming whereas girls may be more interested in social bonding (Kay, 2008; Terlecki, 2011). Therefore, it is important to view screen time not only as a single construct but also break it down into specific types of activity, preferably in a sex-specific manner, when exploring the effects of screen time on health outcomes (Bucksch et al., 2014; Straker, Smith, Hands, Olds, & Abbott, 2013).

Various studies have suggested that the home environment, and in particular the presence of a TV and PC in a child's bedroom, influences children's screen-based activities (Brindova et al., 2014). Having access to media devices in the bedroom has become more common in recent years, with majority of adolescents having a TV or computer in their bedroom (Rideout, 2015; Pavelka et al., 2016). This has been found to correlate with the time spent watching TV and playing video games, as well as increased total screen time (Granich, Rosenberg, Knuiman, & Timperio, 2010; Atkin, Corder, & van Sluijs, 2013; Brindova, Pavelka, et al., 2014). Furthermore, access to media devices in the bedroom has been found to interfere with sleep (Hale et al., 2018; Gruber et al., 2014; Barr-Anderson, Van Den Berg, Neumark-Sztainer, & Story, 2008). Another key factor in the home environment that seems to influence the amount of time youngsters spend in screen-based activities is whether parents set rules to limit the screen use of their children (He, Harris, Piché, & Beynon, 2009; Te Velde et al., 2011; Vandewater, Park, Huang, & Wartella, 2005). However, the majority of children report that their parents seldom/never set limits on their screen use (Pavelka et al., 2016; De Decker, De Craemer, De Bourdeaudhuij, Wijndaele, & Duvinage, 2013; Rebholz, Chinapaw, Van Stralen, Bere, & Bringolf, 2014). Removing media devices from the bedroom may be a good intervention strategy to reduce the screen time of youngsters (Tandon et al., 2012).

As with physical activity, measures of screen time suffer from methodological challenges. Screen time has typically been assessed by self-report via questionnaires, which may result in recall and reporting biases. Employing time use diaries and/or using discrete time periods to report on may help minimizing such biases, but it also increases subject burden which may reduce compliance (Taylor, Ferguson, Peng, Schoeneich, & Picard, 2019). Questionnaires may include separate questions for time spent on individual screen-based activities (games, TV/DVD watching, web/browsing/social-media/email, and other screen usage), which are then combined to yield total screen time. While this approach can potentially provide more detailed information on individual screen activities, this may result in an over-estimation of total screen time, as multi-tasking on different screens, such as watching TV and using a smart-phone at the same time, is quite prevalent in youth (Rideout, 2015). Using wearable cameras to record activity will likely be employed more in future studies, but this methodology is still in its infancy and, as previously stated, presents some technical and ethical concerns (Everson et al., 2019). Thus, for now, subjective measures of screen use are preferred by most researchers due to low cost and minimum burden on study participants.

1.4 Mental health and body image

The WHO states in its Constitution from 1948: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (World Health Organization, 1948). An important implication of this definition is that mental health is more than just the absence of mental disorders or disabilities and WHO defines mental health as “a state of well-being in which an individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and is able to make a contribution to his or her community” (World Health Organization, 2001). In this dissertation, the following outcome measures of mental health are explored: symptoms of depression, anxiety and somatization, self-esteem, life satisfaction and body image.

1.4.1 Depression, anxiety and somatization

The prevalence of mental disorders, including depression and anxiety, has been increasing over the past decades (von Soest & Wichstrom, 2014). Between 1990 and 2013, the number of people suffering from depression and/or anxiety increased by nearly 50%, from 416 million to 615 million (World Health Organization, 2016a). Mental disorders account for 30% of the global non-fatal disease burden and close to 10% of the world´s population is affected (World Health Organization, 2016a). Depression alone accounts for 4.3% of the global burden of disease and is among the largest single causes of disability worldwide (11% of all years lived with disability globally), particularly for women (World Health Organization, 2013). The prevalence of depressive disorder increases dramatically after puberty, with a notable sex difference that persists through the lifespan; women are between 1.5 and 2 times more likely to be diagnosed than men (Patel, 2013a). Half of all detected mental illnesses begin by the age of 14 and three-quarters by the mid-20s, but most cases are believed to be undetected and untreated (World Health Organization, 2014). Worldwide, 10-20% of children and adolescents experience mental disorders, including depression and anxiety (Patel, 2013b; World Health Organization, 2016b). Depression is the leading cause of illness and disability among adolescents and suicide ranks third as a cause of death in this age group (World Health Organization, 2014). Prevalence of major depression in adolescents is estimated to be 5-8%, higher for girls than boys, and twice as many girls may have experienced subthreshold depression than boys (Urrila et al., 2015). Prevalence of anxiety in youth is estimated at 9%-20%, higher for girls, and up to 50% of youth may have experienced subclinical anxiety symptoms (Costello, Egger, & Angold, 2005; Maras et al., 2015). The prevalence of mental health problems among Icelandic youth is estimated at 12–15% and 2–5% are believed to experience serious mental and behavioral problems (Magnússon, 2004). A study on the secular trends in symptoms of depression and anxiety among Icelandic adolescents in the period 1997-2006 showed an increase of symptoms of anxiety among both boys and girls and an increase of depressive symptoms among girls (Sigfusdottir, Asgeirsdottir, Sigurdsson, & Gudjonsson, 2008). During this period, the proportion of adolescents who visited psychiatrists, psychologists and social workers increased as well (Sigfusdottir et al., 2008). An article on time trends between 2006 and 2016 showed that proportion of adolescents reporting high symptoms of anxiety and depressed mood increased during this period for both sexes (Thorisdottir, Asgeirsdottir, Sigurvinsdottir, Allegrante, & Sigfusdottir, 2017). This is in line with findings from the other Nordic countries (Due et al., 2014; Ahnquist, 2014; Santalahti, 2014).

In addition to depression and anxiety, somatic complaints are also common among children and adolescents. The prevalence has been estimated to be 2-10% and girls are more likely to be affected (Vila et al., 2009). These complaints of physical symptoms, such as headache, stomach pain, back or neck pain, sleep disturbances and fatigue, are often medically unexplained and tend to be associated with emotional problems (Kinnunen, Laukkanen, & Kylma, 2010; Vila et al., 2009). These facts constitute the basis for the concept of somatization, when psychological distress is believed to be expressed as physical symptoms (Kinnunen et al., 2010; Vila et al., 2009). Somatic symptoms can impair daily activities and development in adolescence (Kinnunen et al., 2010). They tend to persist from childhood to adulthood (Steinhausen & Winkler Metzke, 2007) and may affect mental health later in life (Kinnunen et al., 2010).

Every classification in the area of mental health has its limitations, as no gold standard exists. The categorial classification of the "Diagnostic and Statistical Manual of Mental Diseases" (DSM), established for adults by the American Psychiatric Association, is the reference classification for mental illness and the one used in the majority of international research (American Psychiatric Association, 2013). The international classification of diseases (ICD-11) from the World Health Organization is a similar classification system, and like the DSM it is not specific to children (World Health Organization, 2019). Various measures have been used for evaluating the prevalence of mental disorders in general population samples. Typically, such measures are on the form of a self-administered questionnaire, which is a more feasible evaluation tool in population based studies than a clinical evaluation. One such measure is the Symptoms Checklist-90 (SCL-90) (Derogatis, Lipman, Rickels, Uhlenhuth, & Covi, 1974), a widely applied self-assessment instrument for a broad range of mental disorders (Prinz et al., 2013). It evolved from the Hopkins Symptom checklist (HSCL) (Derogatis et al., 1974). SCL-90 is used as a screening tool in patient settings, but also as a diagnostic proxy for depression and anxiety in public health surveys (Lundin, Hallgren, & Forsell, 2015). It consists of nine symptom dimensions, each comprised of 3-13 items, including depression (13 items), anxiety (10 items) and somatic complaints (12 items). Each item is scored on a five-point Likert scale and total score calculated for each symptom dimension. A threshold value, based on the midpoint of possible scores, is used to place individuals into healthy vs. symptomatic categories. Numerous short versions of the SCL-90 have been developed, for the sake of convenience in population surveys. A validation study of the SCL-90 subscales of depression and anxiety, conducted in Sweden using a sample from the general population (n=8613, age 20-64 years), found that both subscales performed excellently in detecting their respective DSM-IV disorders (using semi-structured psychiatric interviews as criterion standard). It was, therefore, concluded that these subscales are suitable instruments for assessing depression and anxiety disorders in public health surveys (Lundin et al., 2015). Various short versions of the SCL-90 have also been shown to have comparable validity to that of the original longer version and can be recommended as more economic variants and clinically meaningful instruments for screening of various psychopathological symptoms (Prinz et al., 2013). In Iceland, subscales of the SCL-90 have been used to screen for symptoms of the corresponding illnesses in epidemiological research on adolescents (Gestsdottir et al., 2015; Sigfusdottir et al., 2008).

Depression and anxiety are strong predictors of negative health and psychosocial outcomes, including academic difficulties, behavioral problems, low self-esteem, substance abuse, and suicide (Maras et al., 2015). Moreover, youth experiencing anxiety and depression are at significantly increased risk of being affected by these conditions in adulthood (Maras et al., 2015), which may potentially limit their future educational and financial prospects. It is, therefore, of great public health importance to find and understand potential determinants of mental health, particularly modifiable behavioral factors.

1.4.2 Self-esteem

Self-esteem is the positive outcome of a person´s self-evaluation of his/her overall worthiness as an individual (Baumeister, 1998; Rosenberg, Schooler, Schoenbach, & Rosenberg, 1995). Self-acceptance or self-respect is believed to be the most important feature of self-esteem (Rosenberg et al., 1995). Self-esteem may indicate how satisfied with life and themselves individuals are and how they experience and manage challenges and changes in their life (Kling, Hyde, Showers, & Buswell, 1999). Mental well-being is highly affected by self-esteem among adolescents (Boden, Fergusson, & Horwood, 2008) and low self-esteem has been linked to increased depression and anxiety (Patel, Flisher, Hetrick, & McGorry, 2007). Self-esteem is also positively associated with body image, which can be thought of as a person´s physical self-esteem (Siegel, Yancey, Aneshensel & Schuler, 1999).

1.4.3 Life satisfaction

Life satisfaction is a person´s perceived overall quality of life with regard to factors such as health, living standard and social support and is considered essential to overall well-being (George, 2002). It is often used synonymously with subjective well-being, quality of life or happiness (Daig, Herschbach, Lehmann, Knoll, & Decker, 2009). Poor life satisfaction is strongly associated with mortality in adults (Lacruz, Emeny, Baumert, & Ladwig, 2011), and psychosocial and behavioral problems (Suldo & Huebner, 2006) and violence (Valois, Zullig, Huebner, & Drane, 2001) in adolescents. Research indicates that the association between age and life satisfaction is U-shaped, i.e. that adolescents seem to be less satisfied with life than either younger or older individuals (Blanchflower & Oswald, 2008).

1.4.4 Body Image

Body image can be defined as a person's perceptions, thoughts, and feelings about his/her body (Grogan, 2008). Body image or physical self-esteem is considered to be an important factor affecting global self-esteem (Fox, 1998; Rosenberg et al., 1995; Shavelson, Hubner, & Stanton, 1976). Body dissatisfaction occurs when feelings towards one´s body are negative and disparate from one's concept of the ideal body (Grogan, 2008). Adolescents may be especially vulnerable due to the major physical and psychological changes they undergo during puberty (Smolak & Thompson, 2009), and their extensive use of social media (Rodgers & Melioli, 2016). High prevalence of body dissatisfaction was found across 24 regions in Europe, the United States, and Canada among 11- to 15-year-old adolescents in an international survey (Al Sabbah et al., 2009). The prevalence was higher among girls (up to 62% vs. up to 40% for boys), and those older and overweight (Al Sabbah et al., 2009). In a longitudinal study of Canadian adolescents, 57% of girls desired a thinner body at age 14, with the prevalence increasing to 66% at age 18. Among adolescent boys the prevalence was 44.0% at baseline, and remained unchanged 4 years later (Dion et al., 2015). According to an Icelandic study examining body image trends from 1997-2010 among 14-15-year-old adolescents, girls reported more negative body image than boys at all timepoints. Positive change was, however, observed across this period, more so for girls (Asgeirsdottir, Ingolfsdottir, & Sigfusdottir, 2012). Another study on Icelandic 15-year-olds similarly found girls to have significantly lower average body image score than boys (Gestsdottir et al., 2015). It should be mentioned that measures used for evaluating body image vary greatly, making comparison between studies difficult.

Negative feelings towards one´s body may promote unhealthy weight-control behaviors and eating disorders (López-Guimerà, Levine, Sánchez-Carracedo, & Fauquet, 2010) and have also been linked to depression (Stice & Whitenton, 2002; Paxton, Eisenberg, & Neumark-Sztainer, 2006), lower self-esteem (Tiggemann, 2005; van den Berg, Mond, Eisenberg, Ackard, & Neumark-Sztainer, 2010), and suicide ideation and attempts (Brausch & Muehlenkamp, 2007; Crow, Eisenberg, Story, & Neumark-Sztainer, 2008; Rodriguez-Cano, Beato-Fernandez, & Llario, 2006). Understanding and mitigating risk factors for body dissatisfaction is therefore very important, especially among females.

1.5 Sleep

Sleep is defined as a spontaneous and reversible state of rest characterised by inhibition of voluntary muscles and sensory activity, and by reduced consciousness, responsiveness to stimuli, and interactions with the environment (Carskadon & Dement, 2011). It is an activity at the lowest end of the intensity spectrum, with a relative energy expenditure of 0.95 METs (Ainsworth et al., 2011). Human beings spend on average one third of their life sleeping and sleep plays an important role in preserving energy, restoring the nervous system, and facilitating development in the human body (Porkka-Heiskanen, Zitting, & Wigren, 2013). Thus, adequate sleep is essential for the maturation, growth and optimal health of children and adolescents, and for daily functioning throughout life (Bin, Marshall, & Glozier, 2012; Gregory, 2008; Matricciani, Olds, & Petkov, 2012; Nixon et al., 2008).

Sleep duration and the timing of sleep are two important aspects of sleep which are regulated by two different physiological processes (Gruber et al., 2014). One is a homeostatic process that regulates sleep onset by creating so-called sleep pressure as the wake time lengthens and by dissipating this pressure as sleep is initiated and sustained. The other is a circadian process that regulates sleep onset and awakening by realigning the internal circadian clock with the light-dark cycle using input from the environment. Light is thus the major environmental factor governing the setting of time. Sleep quantity, timing and quality are determined by the interaction of these two processes. Both are sensitive to levels of sex hormones, such as estrogen and testosterone, and are thus affected by puberty (Hagenauer & Lee, 2012).

Studies on the quality of sleep and secular trends in sleep of children and adolescents suggest that sleep duration in this group is declining, indicating that children overall are not getting enough sleep (Bin et al., 2012; Keyes et al., 2015; Matricciani et al., 2012; Van Cauter, Spiegel, Tasali, & Leproult, 2008). The 2011 Sleep in America Poll (National Sleep Foundation, 2011) reported that around 60% of adolescents in the U.S. sleep less than the recommended 8-10 hours (Hirshkowitz et al., 2015) on school nights and 77% are having sleep problems, with waking up feeling un-refreshed (59%) and having difficulty falling asleep (42%) most commonly reported. A complaint of excessive daytime sleepiness is also very common among adolescents (Gradisar, Gardner, & Dohnt, 2011; National Sleep Foundation, 2006; Tynjala, Kannas, & Levalahti, 1997).

Sleep timing is another important parameter of sleep, which is affected by genetics, developmental stage and environmental factors. Individual sleep pattern preferences differ; some persons are most alert during the early part of the day and prefer to wake up early in the morning but others are most alert in the late evening hours and prefer to go to bed late in the evening (Werner, Le Bourgeois, Geiger, & Jenni, 2009). These are termed to be different chronotypes: morning-types vs. evening-types, which have a strong heritability factor (Klei et al., 1998). People are on average early chronotypes in childhood, turn very quickly towards eveningness during puberty, and slowly turn back to morningness again from the age of 17–20 years (Randler & Engelke, 2019). In adolescence, there is a developmental decrease in total sleep time and circadian shift towards later hours which may result in prolonged sleep onset and delayed bedtime (Lang et al., 2016; Urrila et al., 2015). Along with constraints, such as early school or work hours and other social schedules, this may lead to a sleep deprivation, especially on school days. To compensate, adolescents typically sleep longer on non-school days, i.e. there is a tendency towards a weekend shift in sleep duration (Chaput et al., 2015; Rognvaldsdottir et al., 2017). Furthermore, research indicates that intra-individual variability in sleep is common amongst adolescents, resulting in unstable sleep patterns across the week (Becker et al., 2017). Although the causes of adolescent sleep variability are likely complex and multifaceted, potential contributors include biological changes due to puberty and brain maturation, increased academic, extracurricular, and social demands, and reduced parental supervision (Becker, Langberg, & Byars, 2015).Insufficient sleep duration is known to have adverse effects on the health and well-being of youngsters (Garaulet et al., 2011; Lo, Ong, Leong, Gooley, & Chee, 2016; Becker et al., 2017). It has been associated with various negative health-related factors in children and adolescents, including increased rates of overweight and obesity (Gradisar et al., 2011; Matricciani et al., 2012) and unhealthy lifestyle behaviors such as smoking and alcohol use (Wong, Brower, Fitzgerald, & Zucker, 2004). However, sleep quality and timing, and consistency of sleep patterns may also affect the restorative properties of sleep and overall health (Becker et al., 2017; Hirshkowitz et al., 2015). Research on the effects of sleep variability on health has been limited, but emerging literature indicates that it may be just as important as the mean values of sleep parameters (Becker et al., 2017; Fuligni & Hardway, 2006). Disturbances in the sleeping patterns of children and adolescents seem to adversely affect their physical and mental well-being. Sleep disturbances have been associated with poor physical performance (Gerber, Brand, Holsboer-Trachsler, & Puhse, 2010; Ortega et al., 2010; Roberts, Roberts, & Duong, 2008), as well as various psychosocial and physical health deficits (Bin et al., 2012; Matricciani et al, 2012), including less concentration (Wolfson & Carskadon, 1998), poor working memory (Kopasz et al., 2010; Steenari et al., 2003), hyperactivity (Becker et al., 2017; Langberg et al., 2019), worse academic performance (Blunden & Chervin, 2008; Cooper, Kohler, & Blunden, 2012), and impaired motor skills (Kuriyama, Stickgold, & Walker, 2004; Wilhelm, Metzkow-Meszaros, Knapp, & Born, 2012). Inconsistent sleep patterns have also been found to correlate with unhealthy diet, increased body weight, and less favorable body composition (Becker et al., 2017). Thus, it is recommended that adolescents not only get an adequate amount of sleep, but also maintain a consistent sleep routine (Gruber et al., 2014).

As sleep plays such a vital role in adolescent health and development, it is of great importance to further the knowledge on adolescent sleep, especially on the understudied parameters of sleep variability and quality. Adolescent sleep patterns have typically been evaluated with self-report, using questionnaires and sleep diaries. Questionnaires have been widely used for population samples, due to their convenience and cost effectiveness, but recall bias may be a problem and lack of standardization of measures makes comparison between studies difficult. Sleep diaries kept over a period of 1-2 weeks may provide a detailed information on sleep parameters with minimum recall bias, but compliance and accuracy in reporting is a challenge with adolescent samples (Lang et al., 2016). Inaccurate information on parameters such as bedtime and sleep quality may result in overestimated sleep duration (Lang et al., 2016; Arora, Broglia, Pushpakumar, Lodhi, & Taheri, 2013; Short, Gradisar, Lack, Wright, & Carskadon, 2012) and imprecise assessment of sleep quality, such as under-report of the number of awakenings during the sleep period (Short et al., 2012). Therefore, more studies are needed where sleep parameters are evaluated objectively in the natural sleep environment, which may provide more accurate measures (Bin et al., 2012; Nixon et al., 2008). One such objective method, wrist actigraphy, is a convenient way to evaluate free-living sleep in population samples (Martin & Hakim, 2011; Lang et al., 2016). A watch-like accelerometer is used to collect information about sleep patterns 24 h/day over extended periods, typically 1-2 weeks, in the adolescent´s natural sleep environment. This method has been validated against laboratory-based polysomnography in adolescence and shown to have higher accuracy than self-report for sleep duration (Zinkhan et al., 2014) and awakenings (Martin & Hakim, 2011). Wrist actigraphy is, therefore, a preferred method to evaluate sleep quality, timing and variability, and will likely be used more extensively in future sleep research.

1.6 Screen time, physical activity and health outcomes

Screen time and physical activity may be independent risk factors for health problems. Screen time may impact health via sedentary behavior effects (Tremblay et al., 2011b), sleep disturbances (Hale & Guan, 2015), and psychosocial and psychological effects (Suchert et al., 2015). Being physically active has been linked to various health benefits, including improved mental health (Biddle, 2016; Cooney et al., 2013; Jayakody, Gunadasa, & Hosker, 2014; Perraton, Kumar, & Machotka, 2010) and psychological functioning (Kalak et al., 2012), and better sleep (Lang et al., 2016, Gerber et al., 2014; Kalak et al., 2012; Kline, 2014; Lang et al., 2013; Lang et al., 2016; Youngstedt & Kline, 2006).

1.6.1 Screen time, physical activity and mental health

A systematic review of the relationship between sedentary behavior and various health indicators in children and youth aged 5-17 years (Tremblay et al., 2011b) found the majority of included studies reporting an inverse relationship between screen time (TV-viewing being the most common form) and various metabolic markers, as well as self-esteem, depressive symptoms, perceptions of self-worth, and academic achievement. There was evidence for a dose-response relationship as each additional hour of screen time seemed to increase the risk for worse metabolic profile, lower self-esteem and decreased academic achievement. Apart from the sedentary effects, screen time may have psychosocial and psychological effects on the individual. Media use via the internet provides adolescents with diverse opportunities for comparing themselves with others, not only in terms of physical appearance but also with respect to other skills, experiences or talents. Discrepancies between these publicized ideals and the self could cause social pressure and mental health problems (Suchert et al., 2015). Screen time might also exert influences on mental problems via influences on sleep (Montagni, Guichard, & Kurth, 2016).

Evidence from population-based cohort studies and randomized controlled trials suggests that physical activity may reduce depressive symptoms in adults (Jayakody et al., 2014; Biddle, 2016; Cooney et al., 2013; Perraton et al., 2010). There is also growing evidence that physical activity may have beneficial effects on mental health in adolescents (Biddle & Asare, 2011; Rothon et al., 2010). Research on adolescents is, however, more limited than in adults, with longitudinal studies particularly lacking (Rothon et al., 2010). Regular physical activity may promote mental health via physiological, biochemical and psychological mechanisms (Rothon et al., 2010). It may have beneficial effects on body composition (Reddon, Meyre, & Cairney, 2017; Hoare, Skouteris, Fuller-Tyszkiewicz, Millar, & Allender, 2014) and levels of mood-regulating neurotransmitters in the brain (Heijnen, Hommel, Kibele, & Colzato, 2015), and improve self-esteem, self-efficacy, cognitive and psychological function and decrease distress (Biddle & Asare, 2001; Rothon et al., 2010). Physical activity may also promote mental health by increasing social interaction and social support (De Moor, Boomsma, Stubbe, Willemsen, & de Geus, 2008; Rothon et al., 2010; Stein, Fisher, Berkey, & Colditz, 2007).

Although an understudied area of research, a growing body of evidence suggests that physical activity and screen time are independently associated with mental health among adolescents (Iannotti et al., 2009; Trinh et al., 2015). In a study by Trinh et al. (2015), screen time was independently associated with poorer mental health and academic outcomes and the effects were greater than the independent associations of physical activity with these outcomes. These factors may also operate synergistically to increase risk, high levels of screen time and low physical activity levels have been found to interact and lead to increased mental health problems (Cao et al., 2011; Feng, Zhang, Du, Ye, & He, 2014; Hamer, Stamatakis, & Mishra, 2009; Kremer et al., 2014; Wu, Tao, Zhang, Zhang, & Tao, 2015). This is of major public health concern, as physical inactivity and screen-based sedentary behaviors are highly prevalent among young people and are likely to remain so into later life (Kjonniksen et al., 2008).

1.6.2 Screen time, physical activity and sleep

Greater adolescent screen time has been linked to shorter sleep duration, delayed bed time and poorer sleep quality (Hale & Guan, 2015; LeBourgeois et al., 2017; Hale et al., 2018), and greater variability in sleep duration and bed time (Fuligni & Hardway, 2006; Hayes et al., 2017). The relationship between physical activity and sleep in adolescents is more complex, but greater physical activity is generally found to have beneficial effects on sleep (Lang et al., 2016).

In a recent review (Hale & Guan, 2015), screen time was found to be adversely associated with sleep outcomes (shortened duration and delayed timing) in 90% of included studies, but as most of them were cross-sectional, causality was not confirmed and mechanisms remain unclear (Hale & Guan, 2015). Previous research, based on self-report, has found that adolescents with more screen/computer use experience greater nightly variation in sleep duration (Fuligni & Hardway, 2006), and greater weekend shift in bed time (Hayes et al., 2017). The following mechanisms, to explain sleep disruption by screen usage, have been suggested (all resulting in delayed onset of sleep): 1) sleep may directly been displaced by screen time, 2) light emitted from electronic devices may disrupt circadian rhythms by depressing melatonin production, and 3) screen-based media use may lead to increased mental, emotional and physiologic arousal (Owens, 2014). Reduced physical activity as a result of increased sedentary behavior is also a plausible pathway for the adverse effects of screen time on sleep (Lang et al., 2016).

Physical activity, especially vigorous activity, may promote better sleep in adolescents (Gerber et al., 2014; Kalak et al., 2012; Kline, 2014; Lang et al., 2013; Lang et al., 2016; Dworak et al., 2008, Youngstedt & Kline, 2006). However, the majority of the studies have been cross-sectional in design, few studies have used objective measures for sleep, and both sleep and physical activity have often been assessed using instruments with limited or unknown reliability and validity (Lang et al., 2016). The following mechanisms for the effects of physical activity on sleep have been proposed: 1) physical activity produces physiological changes, including enhanced body temperature control and melatonin production, resulting in more favorable sleep regulation and improved sleep quality (Chennaoui, Arnal, Sauvet, & Leger, 2015; Dworak et al., 2008), 2) physical activity may affect sleep quality by improving mental health (Strohle, 2009), and 3) individuals engaging in physical activity tend to practice several other healthy behaviors, such as having good dietary habits (Halson, 2014) and using less caffeine (Drake, Roehrs, Shambroom, & Roth, 2013).

As previously mentioned, employing time use diaries and/or using discrete time periods to report on screen use and physical activity may help to minimize recall and reporting biases, but it also increases subject burden which may reduce compliance (Taylor, Ferguson, Peng, Schoeneich, & Picard, 2019). It may though be worthwhile, especially in research on the relations of screen time/physical activity with sleep, as it is valuable to know the timing of these activities within the day and to have the measure of exposure (screen use/physical activity) precede the measurement of the outcome (sleep) to combat reverse causality.

1.6.3 Screen time and body image

Negative effects of television use and print media on body image are well documented (López-Guimerà et al., 2010; Holland & Tiggemann, 2016). The impact of newer media sources is less known, but emerging evidence suggests that internet usage, especially social media use and networking, may have adverse effects on perceptions of one´s physical appearance (Holland & Tiggemann, 2016; Dumas & Desroches, 2019). This is of special concern for adolescents, as their internet usage has increased exponentially in recent years, largely through smartphones (Saul & Rodgers, 2018).

Screen time may affect health and well-being via psychosocial and psychological effects (Suchert et al., 2015). Social media, television and other screen-based material provides adolescents with diverse opportunities to compare their physical appearance to that of others, elevating the potential for body dissatisfaction (Suchert et al., 2015). Girls may be more vulnerable than boys since media extensively promotes an unrealistic thin-beauty ideal for women that is unattainable for most females (Calado, Lameiras, Sepulveda, Rodriguez, & Carrera, 2011; Suchert et al., 2015; Swami et al., 2010). Screen time is also typically sedentary and higher levels of sedentary behavior are associated with greater adiposity (Ekelund, Hildebrand, & Collings, 2014; Suchert, Hanewinkel, & Isensee, 2016; Tremblay et al., 2011b) and lower fitness (Tremblay et al., 2011b), both of which may result in body image dissatisfaction (Gao et al., 2016). In addition, consumption of energy-dense snacks and drinks are often associated with screen time (Pearson & Biddle, 2011; Hobbs, Pearson, Foster, & Biddle, 2015) which may result in overweight and obesity (Zhang, Wu, Zhou, Lu, & Mao, 2015), which in turn may lead to body dissatisfaction (Gao et al., 2016).

1.6.4 Sleep and mental health

There is a high co-morbidity between mental health problems and sleep disturbances (Alfano & Gamble, 2009; Barclay & Gregory, 2013; Gregory & Sadeh, 2012; Koffel & Watson, 2009; Urrila et al., 2015). Prospective studies suggest that sleep predicts anxiety symptoms in early adolescence (McMakin & Alfano, 2015) and there is good evidence of concurrent and longitudinal associations between sleep difficulties and anxiety in both community and clinical samples of children and adolescents (Willis & Gregory, 2015). Methodologic inconsistencies need though be considered, such as variation in conceptualization of sleep problems, measurement of sleep, and the classification of anxiety (Willis & Gregory, 2015). In the past, sleep disturbances were regarded as exclusively secondary symptoms to depression, but now sleep and depression are rather viewed as being in an interactive, bidirectional relationship with each other (Roberts & Duong, 2013; Urrila et al., 2015). Prospective epidemiological studies in adults suggest that sleep disturbances increase the risk for depressive disorders and that poor sleep precedes depression (Paunio et al., 2009). Longitudinal studies in adolescents show similar findings (Kaneita et al., 2009; Roane & Taylor, 2008; Roberts & Duong, 2014). The precise neurobiological mechanisms by which sleep alterations and depression and anxiety are linked during adolescence are not fully understood. Aberrations in brain maturation, expressed at different levels of organization, for example gene expression, neurotransmitter and hormone metabolism, and activity of neuronal networks have been suggested (Urrila et al, 2015; Willis & Gregory, 2015). The circadian systems may change in adolescent depression beyond that observed during healthy adolescent development, i.e. beyond the typical circadian shift towards eveningness (Urrila et al, 2015). In summary, mental health problems have been found to be strongly correlated to sleep disturbances, and the relationship between these factors are likely bi-directional.

1.7 Sex and gender differences

The Institute of Medicine defines sex as “the classification of living things, generally as male or female according to their reproductive organs and functions assigned by chromosomal complement” (Wizemann & Pardue, 2001). Gender is defined as “a person’s self-representation as male or female, or how that person is responded to by social institutions based on the individual’s gender presentation. Gender is shaped by environment and experience” (Wizemann & Pardue, 2001). In other words, sex differences refer to biological differences of males and females, whereas gender differences (masculinity vs. femininity) are shaped by cultural norms and the interaction of the individual with the environment. According to social learning theory, imitation, reward, and punishment for incorrect behavior are central factors in the development of gender roles, which begins very early in childhood (Bandura, 1989). Typically, adults interact in more masculine manner with boys and more feminine way with girls (Carson, Burks, & Parke, 1992).

It is well-established that there are differences in the incidence, prevalence, prognosis, risk factors and treatment outcomes for mental disorders in men and women, with women having a higher lifetime prevalence of mood and anxiety disorders than men (Riecher-Rössler, 2010). Although the causes of these differences are not fully understood, they are often conceptualised as being due to biological sex differences, but gender inequity and gender roles may also be important determinants (Seedat et al., 2009). Despite this, investigation of sex and gender differences in the causes of mental disorders has been limited and minority of studies stratify or adjust analyses for sex (Riecher-Rössler, 2017; Howard, Ehrlich, Gamlen, & Oram, 2017). A stronger gendered perspective in mental health research is needed and statistical analyses should be disaggregated by sex (Howard et al., 2017). It is also worth mentioning that the instruments used for evaluating mental health status among adolescents may work differently for boys and girls. For example, a differential item functioning (DIF) across gender was observed in a study on adolescent data examining the psychometric properties of the HSCL-10 instrument (Kleppang & Hagquist, 2016). Five of the ten items of this instrument showed evidence of DIF for gender, which may distort comparisons between boys and girls.

Potential risk factors for depression in women include the influence of sex hormones, women´s blunted hypothalamic-pituitary-adrenal axis response to stress, lower self-esteem among females and higher tendency for body shame and rumination, higher rates of interpersonal stressors, experienced violence and sexual abuse, and lack of gender equality and discrimination (Kuehner, 2017). Regarding anxiety, the fluctuating levels of the sex hormones oestradiol and progesterone in females may play a role, as this may modify neurotransmitters and neurosteroids, as well as influence cognition and behavioral processes (Li, Bronwyn, & Graham, 2017). Psychosocial factors, such as gender-based violence against women (Oram, Khalifeh, & Howard, 2017) and gender role traditionality (Seedat et al., 2009), may also be potential determinants of increased prevalence of post-traumatic stress, anxiety, and depressive disorders among females.

During the adolescent years, rapid biological changes with growth spurt and sexual maturation take place, with earlier timing in girls than boys. These changes are linked to psychological mechanisms such as self-concept, which become increasingly correlated with external indicators of competence as children grow older (Shavelson, Hubner, & Stanton, 1976). Earlier pubertal maturation with increases in body fat among girls, has been linked to body dissatisfaction (Brooks-Gunn, Graber, & Ohring, 2002; Lintunen, Rahkila, Silvennoinen, & Österback, 1984). In contrast, early-developing boys have been found to have a significantly higher physical self-concept than their late-maturing male peers, as they experience increased strength and endurance (Lintunen et al., 1984). The effect of personal appearance seems very important, as physical attractiveness is generally considered to be associated with other favorable personal qualities and enhanced social power (Berscheid & Walster, 1972; Miller, 1970; Sigall, Page, & Brown, 1971).

Gender differences regarding appearance have been shown to increase during adolescence, favoring boys (Marsh, 1989).There is considerable evidence that gender stereotypes exist, with regard to characteristics and behaviors. The feminine stereotype in Western societies is equated with being weak, helpless, graceful, non-athletic, emotional, and passive, whereas the masculine one is equated with being strong, forceful, dominating, athletic, brave, and competitive (Klomsten et al., 2004). Males are also believed to worry less about appearance than females. For adolescent boys, the social norm of a masculine and athletic body is the reference, but for adolescent girls the emphasis is on conforming to established standards of physical attractiveness, e.g. the unrealistically thin and perfectly featured ideal (Low et al., 2003). Research indicates that girls tend to be more discontent about their body than boys, starting from an early age and continuing into adulthood, and that adolescent girls typically see themselves as overweight even though they are in normal weight (Rosenblum & Lewis, 1999; Spaeth & Schlicht, 2000). Boys have been found to have a significantly higher global physical self-concept and self-esteem than girls, with the physical appearance subdomain of the global physical self-concept predicting most strongly global self-esteem (Klomsten et al., 2004).

Biological sex and gender differences may further explain behavioral changes observed during puberty. Males have been observed to become more evening oriented than females, although this difference seems to diminish with age (Randler & Engelke, 2019). The sex hormones testosterone and estrogen may have different effects on the circadian shift in adolescence, with testosterone being positively correlated with eveningness in men (Randler et al., 2012), but social norms for male and female behavior may also be important. Playing computer games in the evenings may be more socially normal for boys, whereas focus on appearance with high grooming requirements in the morning may be the social norm for girls. In a study that examined the relationship between sleep habits and activity patterns, adolescents with a late bed time-late rise time chronotype were around three times more likely to have high screen time and around two times more likely to have low moderate-to-vigorous physical activity than their early bed time-early rise time peers (Olds, Maher & Matricciani, 2011). Sleep pattern behavior in adolescence is though not only influenced by sleep pattern preference and sex/gender differences, as factors such as school schedule and increasing homework, less parental regulation, growing social lives, part-time employment and more extracurricular activities may also play important roles (Patte, Qian, & Leatherdale, 2017).

In summary, biological sex and socially constructed gender differences have been observed with respect to mental health, body image and sleep outcomes in adolescence, underscoring the importance to adjust/stratify for sex in statistical analyses.

2 Aims

Few studies have explored the relation between sedentary behavior (with screen time being the main contributor among adolescents) and mental health in youth (Biddle & Asare, 2011). The few studies to do so have not all accounted for levels of physical activity (Biddle & Asare, 2011), although there is a growing evidence that physical activity may have beneficial effects on mental health as well as sleep quality in adolescents (Lang et al, 2016). As pointed out by Trinh et al. (2015), very few studies examining the effects of both physical activity and sedentary behavior on mental health have looked at their potential interrelated effects, but rather their independent effects. The very few studies examining interrelated effects have looked at college students (Feng et al., 2014; Wu et al., 2015) and pre- or early adolescents (Cao et al., 2011; Hamer et al., 2009; Kremer et al., 2014), and data on adolescents in their mid-teens are scarce (Trinh et al., 2015).

It is also evident from the literature review that it is important to determine the impact of modifiable behaviors, such as screen time and physical activity, on adolescent sleep habits. However, such studies are scarce and have mostly relied on subjective measures of sleep and activity (Becker et al., 2017). More studies are needed where sleep parameters (especially sleep quality and stability) and activity are evaluated objectively in the free-living environment, which provides more accurate measures than the traditional self- or parental reports (Bin et al., 2012; Nixon et al., 2008).

Body dissatisfaction may have harmful consequences for the health and well-being of adolescents and it is therefore important to evaluate potential determinants of this negative feeling. Screen time has been suggested to be one such determinant of body dissatisfaction in adolescence. Most prior research on the relationship between screen time and body image in adolescents has focused on girls (Anez et al., 2018; Sladek et al., 2014) and composite screen time. Thus, there is a knowledge gap with respect to this relationship among boys and the effects of screen use subtypes on body image of adolescents. There is also a shortage of longitudinal data on the effects of screen time on this outcome.

The **overall aim** of the dissertation was to investigate the relationship of screen time and physical activity with sleep parameters and mental well-being in a cohort of Icelandic adolescents.

The **specific aims** and corresponding research questions were:

Aim I: To examine the independent and interactive associations of screen time and physical activity with mental health, at age 15.

Research questions:

- Are adolescents reporting fewer hours of screen time less likely to report symptoms of depression, anxiety and somatization, low self-esteem and life dissatisfaction?
- Are adolescents with higher levels of physical activity less likely to report symptoms of depression, anxiety and somatization, low self-esteem and life dissatisfaction?
- Are adolescents with both fewer reported hours of screen time and higher levels of physical activity at the lowest risk of reporting symptoms of depression, anxiety and somatization, low self-esteem and life dissatisfaction?

Aim II: To examine associations of screen time and physical activity with stability in sleep parameters, at age 15, using objective measures for sleep and physical activity.

Research questions:

- Are fewer reported hours of screen time associated with more stable sleep duration, quality and timing among adolescents?
- Are higher levels of physical activity associated with more stable sleep duration, quality and timing among adolescents?

Aim III: To examine the relationship between screen time and body image in adolescents, both cross-sectionally at ages 15 and 17, and longitudinally between these timepoints, in a sex-specific manner.

Research questions:

- Are there sex differences in the relationship between reported screen time and body image in adolescents?
- Does the relationship between reported screen time and body image in adolescents depend on the type of screen usage?
- Is higher reported screen time across the two-year period between ages 15 to 17 associated with less favorable body image at age 17?

3 Methods

3.1 Design and study population

This dissertation results from the research project "*Health behavior of Icelandic youth*" (HBIY), which is a longitudinal study designed to track the status and changes of various health parameters in a cohort of children born in 1999. This cohort originated from a previous study conducted in 2006-2008, titled "*Lifestyle of 7-9-year-old children; intervention towards better health"*, in which 321 pupils from six randomly selected primary schools in the metropolitan area of Reykjavik were invited to participate, 267 of which agreed (Magnusson, Sigurgeirsson, Sveinsson, & Johannsson, 2011b). In the spring of 2015, all 411 students (age 15-16) enrolled in 10th grade at the respective schools received an invitation letter to participate in HBIY, irrespective of their participation in the prior study. Of these 411, 315 agreed to participate (77%) and 301 participated satisfactorily. Inclusion criteria of valid measurements for the variables of main interest in studies I and II of the dissertation was fulfilled for around 81% of participants (244-247). In the early spring of 2017, all study participants from 2015 (baseline) were invited to participate in follow-up measurements. Majority of the baseline participants (age 15) were in 2017 attending various secondary schools in metropolitan Reykjavik. All other individuals born in 1999 and attending these schools were also invited. The total number of invitees was 512, 236 of which agreed to participate. Eligible for study III of the dissertation were those who had complete data at baseline and participated in the follow-up study with complete data, a total of 152 (95 girls and 57 boys) adolescents. An overview of the study participation is given in Figure 3 and Table 1 shows the design and main variables of each of the three studies of the dissertation.

In 2015, non-participation was mainly due to absence from school on measurement days and lack of interest in the study. In 2017, invited participants were attending secondary school or working, and fewer were willing to participate than in 2015, due to more diversified and busy schedules or lack of interest in the study. In addition, some of the baseline participants had moved abroad or out of the Reykjavik metropolitan area and some could not be located.

Written informed consent was obtained from all participants and their guardians. Strict procedures were followed to ensure confidentiality. The research project was approved by the Icelandic Data Protection Authority, the National Bioethics Committee (VSNb2015020013/13.07) and the Icelandic Radiation Safety Authority.

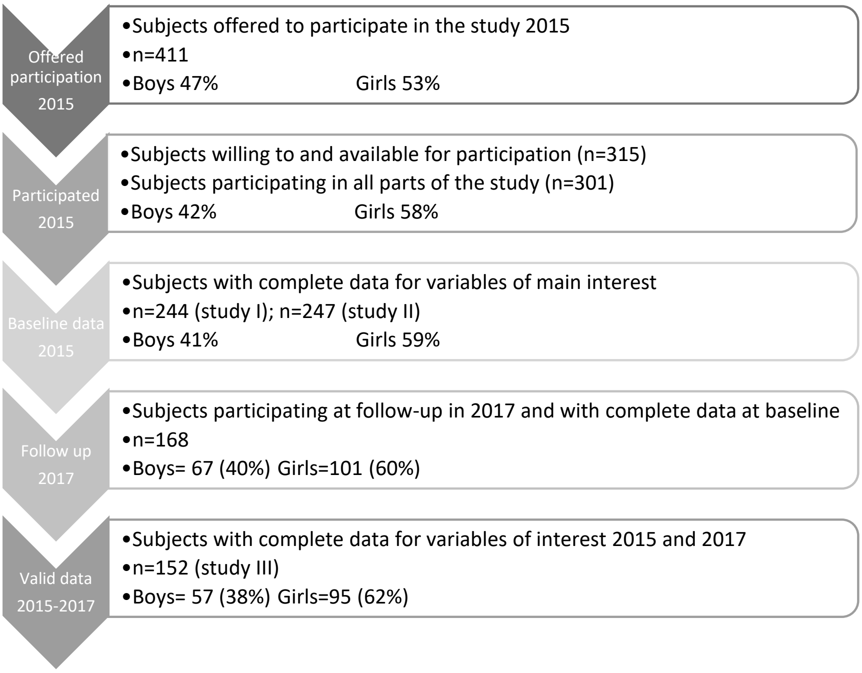

Figure 3. Participation in the study.

Table 1. Design and main variables of studies I, II and III.

	Study design	Time point(s)	Participants	Main explanatory variable(s)	Outcome variable(s)
Study I	Cross-sectional	2015	244	Screen time[a], Physical activity[a,b]	Mental health[a,c]
Study II	Cross-sectional	2015	247	Screen time[a], Physical activity[b]	Sleep parameters[b,d]
Study III	Cross-sectional	2015 and 2017	152	Screen time[a]	Body image[a]
	Longitudinal	2015 to 2017	152	Screen time[a]	Body image[a]

[a]subjective (self-reported via questionnaire)
[b]objective (by accelerometry)
[c]symptoms of depression, anxiety and somatic complaints, life satisfaction and self-esteem
[d]parameters for duration, quality and timing of sleep (see section 3.2.3 for definitions of parameters)

3.2 Measures

Data collection at baseline was performed between mid-April and early June of 2015. Participants provided information regarding their socioeconomic background, health and lifestyle by answering a tablet-based questionnaire administered at school under the supervision of research team members. It included questions about socioeconomic status (parental education), participation in screen-based activities, weekly amount of VPA, body image and mental health status (symptoms of depression, anxiety and somatic complaints, self-esteem and life satisfaction). Objective measurements of free-living physical activity and sleep, weight, height and body composition were also performed. Measurements were repeated in 2017, between February and May, for longitudinal changes from age 15 to 17. At both timepoints participants answered the questionnaire during the same week that they were being monitored for physical activity and sleep, and all measurements for each participant were completed within a period of 10 days.

3.2.1 Physical activity

3.2.1.1 Actigraphy measured total physical activity

Free-living physical activity was objectively measured using small (3.8 cm x 3.7 cm x 1.8 cm) and lightweight (27 g) triaxial raw signal accelerometer-based Actigraph activity monitors (model GT3X+, Actigraph Inc., Pensacola Florida). Each participant was asked to continuously wear the monitor on his/her non-dominant wrist for 7 consecutive days, five school days and two non-school days. A minimum of 3 valid school days and 1 valid non-school day was set as an inclusion criterion. Valid activity days were defined as days with ≥ 14 h of wear-time (out of the 24 h period from 12 midnight to 12 midnight the following day). The monitor recorded raw triaxial data (in milliG's) sampled at 80 samples per second (Hz). Data was later reduced to the vector magnitude of activity counts over 60 s epoch (counts per min = cpm, as a unit of activity) using Actilife 6 software (Actigraph Inc., Pensacola, FL, USA; version 6.13.0). Wear-time was detected automatically with customized programs in Matlab (The Mathworks, Natick, MA, USA; version R2013a).

3.2.1.2 Self-reported vigorous physical activity (VPA)

Participants were asked the following question: "How often, per week, do you perform physical activity that makes you breathe more rapidly or sweat?" The question was scored on a six-point Likert scale, with the following response options: 1 = "never", 2 = "less than once a week", 3 = "once a week", 4 = "2-3 times a week", 5 = "4-5 times a week", 6 = "almost every day". For the purpose of the present analysis, the variable was recoded into the following four groups: Low = "once a week or less", Medium ="2-3 times a week", High = "4-5 times a week", Very high = "almost every day". When examining interrelated effects of screen-based activities and VPA, a more simplified categorization of VPA was used: lower = "3 times a week or less" and higher = "4 times a week or more".

3.2.2 Screen time

Participants were asked to report how many hours per day on average, separately for school days and non-school days, they played computer games, watched TV/DVD/internet material, used the internet for web-browsing/Facebook/e-mail and participated in "other" computer use. Each item was scored on a seven-point Likert scale, with the following response options: 1 = "none", 2 = "about ½ h", 3 = "1 up to 2 h", 4 = "2 up to 3 h", 5 = "3 up to 4 h", 6 = "4 to 5 h" and 7 = "more than 5 h". Average daily hours for each type of screen-based activity were computed using the midpoint for each scoring category (a value of 5.5 h was used for the highest category), for school days and non-school days separately as well as combined (using weighted averages for school days and non-school days). All screen-based activities were then summed for a total daily screen time (h/day) for school days, non-school days and across the entire week. The total daily screen time across the week was then categorized as follows: 1 = "less than 2 h", 2 = "2 h to up to 4 h", 3 = "4 h to up to 6 h", 4 = "6 h to up to 8 h" and 5 = "8 h or more". A more simplified categorization, based on ranking into lower and upper half around the group median value, was used when the interrelated effects of screen-based activities and VPA were examined (study I). Ranking into lower and upper half around the group median value was likewise used in study III. Previous studies have typically defined high screen time as greater than 2 h/day, based on international recommendations. In the current study, however, the group median for total daily screen time was used as the cut-point since very few participants (n=8 or 3.3%) averaged ≤ 2 h/day.

3.2.3 Sleep

Free-living sleep was measured using Actigraph GT3X+ accelerometers, in the same manner as described for physical activity (see section 3.2.1.1). Valid sleep days were defined as days with ≥ 14 h of wear-time (out of the 24 h period from 12 midnight to 12 midnight the following day). A minimum of 3 valid school nights (Sunday through Thursday nights) and 1 valid non-school night (Friday and Saturday night and nights prior to holidays) of sleep was set as an inclusion criterion (Rognvaldsdottir et al., 2017). Sleep parameters for the duration, quality and timing of sleep (see Table 2) were computed for all days, school days and non-school days using the ActiLife 6 software from Actigraph (version 6.12.0), using the well validated Sadeh automatic sleep detection algorithm for adolescents (Sadeh, Sharkey, & Carskadon, 1994), implemented in the Actilife software. Detected sleep periods were verified and manually adjusted, if needed. Participants were asked to fill out a complimentary sleep diary, while their sleep was being objectively measured, reporting their bedtime and rise time each day as well as commenting on any artefact (e.g. paper-route, studying for an exam). Sleep diaries were used to aid in the verification and adjustments in the Actilife software. For especially difficult files, joint decisions on sleep period adjustments were made by 2-4 members of the research team. The individual´s standard deviation of each sleep parameter was used to convey within-subject night-to-night variability. The mean value for school-nights was subtracted from the mean value for non-school nights for each sleep parameter to obtain the within-subject weekend shift in that parameter. Thus, a 1 h weekend shift in total sleep time would represent 1 h longer mean sleep on weekends compared with mean sleep on weekdays.

Table 2. Sleep parameters for analysis.

Sleep parameter	Abbreviation	Definition	Unit
Sleep duration			
Total rest time	TRT	time between bed-time and rise-time (rest period)	Hours or Minutes
Total sleep time	TST	sleep time during rest period	Hours or Minutes
Sleep quality			
Sleep onset latency	SOL	time it takes to go from wakefulness to sleep	Minutes
Number of awakenings	NOA	number of transitions from sleep to wakefulness, during the rest period	Counts
Sleep efficiency	SLE	total sleep time divided by total rest time and multiplied by 100	%
Sleep timing			
Bed time	BT	time of going to bed	Clock time
Rise time	RT	time of getting out of bed	Clock time

3.2.4 Depression, anxiety and somatic complaints

A 22-item version of the Subscales of the Symptom Checklist 90 (SCL-90) (Derogatis et al., 1974) was used to assess symptoms of depression (10 items), anxiety (4 items) and somatic complaints (8 items). Participants were asked how often they had experienced symptoms of these conditions during the preceding week. Each item was rated on a five-point Likert scale: 1 = "almost never", 2 = "seldom", 3 = "sometimes", 4 = "often" and 5 = "almost always". The following cut-offs, based on the midpoint of possible scores, were used to define a healthy versus an unhealthy score for dichotomization: depression symptoms ≥ 30 points, anxiety symptoms ≥ 12 points and somatic complaints ≥ 24 points. This 22-item version of the SCL-90, using the same cut-offs, has previously been employed in a study on mental well-being among Icelandic adolescents (Gestsdottir et al., 2015). Cronbach´s alpha was used to evaluate the internal consistency of the scales in study I (age 15), it was α = 0.94 for depression, α = 0.88 for anxiety and α = 0.88 for somatic complaints. At age 17 (study III), Cronbach´s alpha for depression was 0.92.

3.2.5 Global self-esteem

Global self-esteem was assessed using the Rosenberg Self-Esteem Scale (Rosenberg et al., 1995). The scale consists of 10 statements, each rated as positive or negative, with four response options: 0 = "strongly agree", 1 = "somewhat agree", 2 = "somewhat disagree" and 3 = "strongly disagree". A score ≥ 15 points reflects a greater level of self-esteem whereas a score <15 points indicates low self-esteem and scores were dichotomized accordingly for analysis. The Rosenberg scale has been widely used for evaluating self-esteem of young people, and its reliability and validity are well documented (Kling et al., 1999). Cronbach´s alpha for the scale in study I (age 15, N=244) was 0.92, and in study III (N=152) it was α = 0.91 at age 15 and α = 0.93 at age 17.

3.2.6 Life satisfaction

The Diener´s Satisfaction with Life Scale (SWLS), a measure of global cognitive judgments of satisfaction with one's life, was used for estimating life satisfaction of participants (Diener, Emmons, Larsen, & Griffin, 1985). The scale contains 5 items rated on a 7-point Likert scale, with the following response options: 1 = "strongly disagree“, 2 = "disagree“, 3 = "somewhat disagree“, 4 = "neither agree nor disagree“, 5 = "somewhat agree“, 6 = "agree“, 7 = "strongly agree“. A score of 20 represents a neutral point on the scale, with higher score indicating more satisfaction and lower score indicating less satisfaction and scores were dichotomized accordingly for analysis. Scores on the SWLS have been shown to correlate with measures of mental health and the scale is reported to have a high internal consistency and good test-retest correlations (Pavot & Diener, 1993). Cronbach´s alpha for the scale in study I was 0.93.

3.2.7 Body image

Body image was evaluated with five items from the Body and Self-Image subscale of the Offer Self-Image Questionnaire (OSIQ) (Offer, Ostrov, Howard, & Dolan, 1992). Participants rated how well the following statements described them: “When I think about how I will look in the future, I am happy”, “I frequently feel ugly and unattractive”, “I am proud of my body”, “I am happy with the way my body has changed in recent years”, and “I feel strong and healthy”. A four-point scale was used for all statements, ranging from 1 = “describes me very well” to 4 = “doesn´t describe me at all”. If necessary, responses were recoded such that higher scores reflected more positive body image, yielding a total score in the range of 5-20. The internal consistency of the scale was satisfactory at both baseline (age 15) and follow-up (age 17), with Cronbach’s alphas = 0.83 and 0.82, respectively. This 5 item scale has been verified for validity and reliability (Bjarnason & Thorlindsson, 1993) and used in previous studies on Icelandic adolescents (Eidsdottir, Kristjansson, Sigfusdottir, Garber, & Allegrante, 2014; Gestsdottir et al., 2015; Ingolfsdottir, Asgeirsdottir, Gunnarsdottir, & Bjornsson, 2014; Vilhjalmsson, Kristjansdottir, & Ward, 2011).

3.2.8 Covariates

Body composition and parental education were selected as covariates, based on prior studies and our own correlation analysis. Less favorable body composition has been linked to more screen time (Suchert et al., 2016) and lower physical activity levels (Miguel-Berges, Reilly, Moreno Aznar, & Jimenez-Pavon, 2018). Parental education, an indicator of socioeconomic status, may affect youngsters' participation in recreational activities; higher level of parental education has been linked to less screen time (Overby, Klepp, & Bere, 2013) and more physical activity among adolescents (Ferreira et al., 2007). Body composition and parental education have also been related to mental health and sleep parameters. Higher adiposity has been linked to depressive symptoms, lower self-esteem and health-related quality of life (Reddon et al., 2017; Morrison, Shin, Tarnopolsky, & Taylor, 2015), and body dissatisfaction (Gao et al., 2016). Low educational attainment of parents, especially mothers, has been shown to independently associate with less utilization of child mental health resources, and increased severity and duration of mental health problems of children (Park, Fuhrer, & Quesnel-Vallee, 2013; McLaughlin et al., 2011; Reiss, 2013). Less favorable body composition has also been associated with late bed time and inadequate sleep duration in adolescence (Garaulet et al., 2011), and abdominal obesity has been associated with nightly variability in sleep duration (He et al., 2015). Inconsistent findings have been reported regarding the relationship between parental education and sleep, low parental education has been found to correlate with sleep problems in adolescence (Johnson, Cohen, Kasen, First, & Brook, 2004), whereas adolescents having parents with higher educational level had shorter sleep duration in another study (Zapata Roblyer & Grzywacz, 2015).

3.2.8.1 Body composition

Body mass index (BMI, kg/m^2) was calculated from the measurements of weight (kg) and height (m). Standing height was measured to the nearest mm with a transportable stadiometer (Seca model 217, Seca Ltd., Birmingham, UK). Body weight was measured to the nearest 0.1 kg on a calibrated scale (Seca model 813, Seca Ltd., Birmingham, UK), with participants wearing light clothing. Age- and sex-specific cut-off points used for determining overweight and obesity were according to Cole and colleagues (Cole, Bellizzi, Flegal, & Dietz, 2000). Whole-body and regional soft tissue composition was measured by dual energy X-ray absorptiometry (DXA) using a Lunar bone densitometer (GE Healthcare, Madison, Wisconsin USA), to give percentage body fat. The validity of DXA as an assessment tool for body composition has been verified in research using the four-component model as a criterion (Modlesky et al., 1999; Arngrimsson et al., 2000). All DXA-scans were performed and analysed by a certified radiologist at the facilities of the Icelandic Heart Association in Kopavogur, Iceland.

3.2.8.2 Parental education

Educational level of father and mother was reported by the participants, given the following seven categories to choose from: 1 = “elementary degree”, 2 = “secondary degree”, 3= “trade school degree”, 4= “university degree”, 5 = “other”, 6 = “do not know”, 7 = “do not want to answer”. Categories 2 and 3 and categories 6 and 7 were then combined to give variables for the educational level of mother and father with the following categories: 1 = “basic level”, 2 = “middle level”, 3 = “university level” and 4 = “not stated”. Two new binary variables, university education of mother and university education of father, were then coded using the 2 following categories: 1 = “mother/father with university degree” and 0 = “mother/father without university degree”. A third binary variable was also created, university education of parents, with the following categories: 1 = “at least one parent with university education” and 0 = “neither parent with university education”. Only parents with known educational level were included in the statistics for the binary variables, i.e. those with parental education level “not stated” were removed from calculations.

3.2.8.3 Other covariates

When investigating the relationship of screen time and PA with mental health in study I, we adjusted for sex in addition to maternal education and body composition. As the prevalence of reported symptoms of mental health problems was much lower among boys, it was not statistically feasible to run sex-specific analyses in that study, so instead we adjusted for sex in the analyses. In study II (screen time and PA vs. sleep) and study III (screen time vs. body image) we were, however, able to run sex-specific analyses. In study II, apart from using percentage body fat and parental education as covariates, actigraphy-measured physical activity was used as an adjustment factor in analyses with screen time as the explanatory variable and vice versa. In a supplementary analysis, models were further adjusted for total sleep time and daylength (hours of daylight). Daylight is a potential determinant of adolescent sleep, and may give rise to increased sleep duration during winter months and shorter duration in summer (Thorleifsdottir, Bjornsson, Benediktsdottir, Gislason, & Kristbjarnarson, 2002; Nixon et al., 2008). Daylight may also affect physical activity of youngsters, and seasonal variations in outdoor play and activity have been observed (Rich, Griffiths, & Dezateux, 2012). Information on daylength (hours of daylight) was obtained from the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory Solar Calculator (Earth System Reserach Laboratory, 2015). Self-reported vigorous physical activity and depression score were used as adjustment factors in study III, along with percentage body fat. In a supplementary analysis for the longitudinal data in study III, models were further adjusted for baseline self-esteem and body image.

3.3 Statistical analyses

Descriptive summaries are presented as means and standard deviations for continuous variables and as frequencies and percentages for categorical variables. Distributional properties of study variables were examined using distribution analyses. Model performance of all linear regressions was verified by analyzing the output diagnostics (linearity and independence, normality and homoscedasticity of residuals). Sex differences were evaluated by t-tests for continuous variables and chi-square tests for categorical variables. Paired t-tests were used to compare measures on school days and non-school days, and at ages 15 and 17. Customized programs written with Matlab software (The Mathworks, Natick, MA, USA; version R2013a) were used to compile daily and weekly averages of objectively measured physical activity and sleep. Significant differences or relations were accepted at $\alpha < 0.05$. Statistical analyses were performed using SAS statistical software, version 9.4 (SAS Institute Inc., Cary, NC; www.sas.com).

3.3.1 Study I

Pearson‘s correlational analysis was used to evaluate relationships between the main variables of interest. Poisson regression analysis was performed to calculate the relative risk (RR) and 95% confidence intervals (CIs) of reporting symptoms of depression, anxiety, somatic complaints, low self-esteem, and life dissatisfaction with respect to screen time, frequency of self-reported vigorous physical activity, and objectively measured total physical activity. First, separate Poisson regressions were performed between each independent variable and each mental health outcome. The sample was then divided into the following four groups, based on the total daily screen time and self-reported vigorous physical activity: higher screen time + less frequent vigorous physical activity (reference group), higher screen time + more frequent vigorous physical activity, lower screen time + less frequent vigorous physical activity and lower screen time + more frequent vigorous physical activity. These groups were used as an independent variable in the interactive Poisson regression analysis.

All Poisson regression models were adjusted for the following potential confounders: sex, body fat percentage and maternal education. We did not adjust for sleep as it was negligibly correlated with the mental health outcomes (see Appendix B, Supplementary tables 1-3).

3.3.2 Study II

Linear models were used to explore potential associations of average daily screen time and physical activity with mean values of sleep parameters across the entire week. The main regression analysis of the study was then performed, to evaluate the association of average daily screen time and physical activity with nightly variations and weekend shifts in sleep parameters. We started with univariate linear regression analyses and then went on to multivariate linear models to explore a) the effects of screen time on nightly variations and weekend shifts in sleep parameters, adjusting for physical activity, body fat percentage and parental education and b) the effects of physical activity on nightly variations and weekend shifts in sleep parameters, adjusting for screen time, body fat percentage and parental education. In additional analyses, models were further adjusted for total sleep time and daylength. We did not adjust for mental health as it was negligibly correlated with the sleep outcomes (see Appendix B, Supplementary tables 1-3). Analyses were performed both for the total group and the sexes separately, as we observed a sex difference in behavioral variables (screen time and physical activity) and sleep parameters, and because sex specific data is lacking from the literature. Cohen´s d was calculated to estimate the effect size of significant associations (d = mean difference between groups, divided by the pooled standard deviation, see https://www.socscistatistics.com/effectsize/default3.aspx).

3.3.3 Study III

Cross-sectional associations between screen time and body image were assessed using linear regression, with both unadjusted models and models adjusted for body fat percentage, depression score, and vigorous physical activity. Covariates were selected based on prior research (Gao et al., 2016; Hrafnkelsdottir et al., 2018; Kelly, Bulik, & Mazzeo, 2011; Stice & Whitenton, 2002; Tremblay et al., 2011b; Vilhjalmsson et al., 2011) and bivariate correlation analysis. Screen time variables included total screen time, game playing, watching TV/DVD/internet material, and internet use (Facebook/web-browsing/e-mail) on all days, and total screen time on school days and non-school days. We tested for an interaction between screen time and vigorous physical activity, with respect to body image. Separate regressions were run for boys and girls at ages 15 and 17. Participants were then categorized by total screen use relative to the median at ages 15 and 17 (5.1 h/day and 6.0 h/day, respectively), yielding the following longitudinal groups: above median screen use at both ages (High-High, HH), above the median at 15 and below at 17 (High-Low, HL), below the median at 15 and above at 17 (Low-High, LH), and below median screen use at both ages (Low-Low, LL). Longitudinal regression analysis assessed the relationship between longitudinal screen use and body image at age 17, with LL as the reference group and baseline values (age 15) for all covariates. Cross-sectional regression results are presented as standardized betas and adjusted R^2 coefficients to indicate relative strength of associations and percentage of explained variance in body image, respectively. Longitudinal regression results are presented as unstandardized betas. Cohen´s d was calculated to estimate the effect size of significant associations.

4 Results

4.1 Screen time

4.1.1 Screen time at age 15

Screen time of participants at baseline (age 15) is shown in Table 3. Average reported total screen time over the entire week was 5.6 ± 2.3 h/day, around 40 min longer for boys than girls ($p = 0.03$). Median screen time for the study sample was 5.3 h/day, the 10th percentile was at 2.9 h/day, the lower quartile at 4.1 h/day, the upper quartile at 7.0 h/day, and the 90th percentile at 9.0 h/day. Around 40% of participants reported having screen time in the range of 4-6 h/day, whereas only around 3% reported screen time of 2 h or less. Screen time was higher on non-school days than school days ($p < 0.0001$), the increase was, on average, 60 min for girls and 78 min for boys. Boys reported almost 1 h higher screen time on non-school days than girls ($p = 0.01$).

Table 3. Screen time at age 15.

	All (n=247)	Boys (n=103)	Girls (n=144)	p-value[b]
Screen time[a], h/day, mean (SD)				
All days				
Total	5.6 (2.3)	6.0 (2.3)	5.3 (2.3)	**0.03**
Game playing	1.0 (1.3)	1.9 (1.3)	0.3 (0.7)	**< 0.0001**
Internet: Facebook, browsing, mail	2.2 (1.3)	1.7 (0.9)	2.6 (1.4)	**< 0.0001**
Watching TV/DVD/Internet	1.7 (0.9)	1.6 (0.9)	1.7 (0.9)	0.18
Other	0.7 (0.8)	0.8 (0.8)	0.7 (0.9)	0.49
School days	5.3 (2.3)	5.6 (2.2)	5.0 (2.4)	0.06
Non-school days	6.4 (2.7)[c]	6.9 (2.8)[c]	6.0 (2.7)[c]	**0.01**
Screen time categories, h/day, n (%)				0.24
x ≤ 2	8 (3.3)	1 (1.0)	7 (4.9)	
2 < x ≤ 4	49 (20.1)	16 (16.0)	33 (22.9)	
4 < x ≤ 6	99 (40.6)	42 (42.0)	57 (39.6)	
6 < x ≤ 8	45 (18.4)	20 (20.0)	25 (17.4)	
8 < x	43 (17.6)	21 (21.0)	22 (15.3)	

SD = standard deviation, n/N = number

[a]Range (h/day): 0.9-11.9 (all days), 0.5-11.5 (school days), 1.0-14.0 (non-school days); 10th percentile (h/day, all days): 2.9 (all), 3.5 (boys), 2.5 (girls); 90th percentile (h/day, all days): 9.0 (all), 9.3 (boys), 8.5 (girls)

[b]p-values for tests of between sex differences, significant values are bolded

[c]Indicates difference between school days and non-school days ($p < 0.0001$)

4.1.2 Changes in screen time between ages 15 and 17

Changes in screen time between ages 15 and 17 are shown in Table 4, for the subset of 152 participants (57 boys and 95 girls) with complete data at both timepoints. Median value for total daily screen time (N=152) was 5.1 h at age 15 and 6.0 h at age 17. Average total daily screen time was somewhat higher for boys than girls in 2015 (6.0 vs. 5.4 h, $p = 0.14$), but had become equal for the sexes in 2017 (6.4 h), due to a significant increase between timepoints for girls ($p < 0.05$). Both sexes had higher screen time on non-school days than school days at age 15 (1.4 h difference, both $p < 0.0001$), this difference was smaller at age 17 (1.0 h for boys and 0.8 h for girls (both $p \leq 0.001$)). Girls spent most of their screen time on the internet in 2015, whereas boys preferred game playing. The pattern of activities changed significantly between 2015 and 2017 among boys, they spent more time on the internet and less time playing computer games in 2017. Girls spent similar time in the various screen time activities at both timepoints, except that there was a significant increase in "other" activities between 2015 and 2017. As is reported in Table 5, about 37% of boys and 28% of girls remained above the median screen time from age 15 to 17 (HH group), while 30% of boys and 33% of girls were below median screen time at both ages (LL group). About 19% of boys and 18% of girls went from above median screen time at age 15 to below at 17 (HL group), while 14% of boys and 21% of girls showed the opposite trend (LH group).

Table 4. Characteristics of the study subjects (57 boys and 95 girls) at age 15 and 17.

	15y		p[a]	17y		p[a]
	Boys	Girls		Boys	Girls	
Age, years, mean (SD)	15.9 (0.3)	16.0 (0.3)		17.8 (0.3)	17.8 (0.3)	0.12
Screen time, h/day, mean (SD)						
Days						
All days	6.0 (2.3)	5.4 (2.4)	0.14	6.4 (2.7)	6.4 (2.7)[b]	0.91
School days	5.6 (2.2)	5.0 (2.5)	0.17	6.1 (2.8)	6.2 (2.9)[b]	0.80
Non-school days	7.0 (2.7)[c]	6.4 (3.0)[c]	0.20	7.1 (3.0)[c]	7.0 (2.9)[c]	0.79
Activities						
Games	1.9 (1.2)	0.3 (0.8)	**<0.0001**	1.4 (1.2)[b]	0.4 (1.0)	**<0.0001**
Internet	1.7 (0.9)	2.6 (1.4)	**<0.0001**	2.3 (1.3)[b]	2.8 (1.2)	**0.03**
Viewing	1.7 (0.9)	1.8 (1.0)	0.46	1.8 (1.0)	1.9 (1.1)	0.33
Other	0.7 (0.8)	0.7 (0.9)	0.70	0.8 (0.9)	1.3 (1.3)[b]	**0.01**
Vigorous PA, times/week, mean (SD)	5.1 (1.1)	4.6 (1.4)	**0.02**	4.8 (1.3)[b]	4.4 (1.4)	0.06
Vigorous PA, categories, N (%)			**0.01**			**0.02**
Less (< 4x/week)	12 (21.0)	39 41.0)		18 (31.6)	49 (51.6)	
More (≥ 4x/week)	45 (79.0)	56 (59.0)		39 (68.4)	46 (48.4)	
Body fat, %, mean (SD)	17.1 (6.2)	30.1 (6.7)	**<0.0001**	17.6 (6.5)	31.2 (7.3)[b]	**<0.0001**
BMI, mean (SD)	21.3 (2.8)	22.3 (3.4)	0.05	22.4 (3.1)[b]	23.0 (4.6)[b]	0.35
Body image score, mean (SD)	16.4 (2.7)	14.3 (3.1)	**<0.0001**	16.5 (2.4)	14.6 (3.1)	**<0.0001**
Depression score, mean (SD)	14.6 (6.9)	20.4 (10.4)	**<0.0001**	16.3 (7.3)[b]	20.3 (9.2)	**0.006**
Self-esteem score, mean (SD)	22.2 (6.3)	20.1 (6.6)	0.07	23.2 (6.1)	20.7 (7.0)	**0.03**

PA = physical activity

[a]p-value < 0.05 (bolded) between sexes at 15y or 17y
[b]p < 0.05 between 15y and 17y
[c]p < 0.0001 between school days and non-school days

Table 5. Participants´ distribution in categories of daily screen time at 15y to 17y.

	Boys		Girls	
	N	%	N	%
Total screen time all days				
HH	21	36.8	27	28.4
HL	11	19.3	17	17.9
LH	8	14.1	20	21.1
LL	17	29.8	31	32.6
Total screen time non-school days				
HH	20	35.1	26	27.4
HL	11	19.3	17	17.9
LH	11	19.3	23	24.2
LL	15	26.3	29	30.5
Total screen time school days				
HH	22	38.6	24	25.3
HL	10	17.5	19	20.0
LH	7	12.3	19	20.0
LL	18	31.6	33	34.7

HH: above median screen time at 15y and 17y
HL: above median screen time at 15y but below median screen time at 17y
LH: below median screen time at 15y but above median screen time at 17y
LL: below median screen time at 15y and 17y

4.2 Physical activity

4.2.1 Actigraphy measured total physical activity at age 15

Baseline data (age 15) for actigraphy measured total physical activity is presented in Table 6. Average number of valid actigraphy days was 6.6 ± 0.6. Boys and girls had similar physical activity over the entire week and on school days, but girls averaged about 13% higher activity than boys on non-school days ($p = 0.002$). Participants of both sexes recorded higher activity on school days than non-school days (+33.8% for boys and +18.5% for girls, both $p < 0.0001$). At follow-up (age 17), objectively measured total physical activity was not correlated with screen time and body image ($r = -0.033$, $p = 0.70$, and $r = -0.063$, $p = 0.45$, respectively). Thus it was not included in study III and is not presented here.

4.2.2 Self-reported vigorous physical activity at ages 15 and 17

At age 15 almost two-thirds (66%) of the sample reported engaging in VPA at least 4 times a week, this number was 71% for boys and around 62% for girls (Table 6). Corresponding numbers for the longitudinal sub-set (N=152) were 66% for all, 79% for boys and 59% for girls (Table 4). This percentage became lower at age 17, it was 56% for all, 68% for boys and 48% for girls (Table 4). Significantly more boys than girls in the longitudinal sample were in the VPA≥4x/week category at both ages (Table 4). Boys reported significantly more frequent vigorous physical activity than girls at age 15, but this frequency for boys was significantly lower at age 17 as compared to age 15 (Table 4).

Table 6. Physical activity at age 15.

	All (n=247)	Boys (n=103)	Girls (n=144)	p-value[b]
Physical activity[a], cpm/day, mean (SD)				
All days	2037 (471)	1993 (445)	2069 (488)	0.21
School days	2206 (510)	2205 (484)	2207 (529)	0.97
Non-School days	1773 (540)[c]	1648 (535)[c]	1863 (528)[c]	**0.002**
Accelerometer compliance				
Wear time, h/day, mean (SD)	23.81 (0.36)	23.74 (0.41)	23.86 (0.31)	**0.01**
Valid days, n, mean (SD)	6.61 (0.62)	6.50 (0.63)	6.69 (0.61)	**0.02**
Vigorous PA, self-reported, n (%)				0.12
Less (< 4x/week)	85 (34.4)	30 (29.1)	55 (38.2)	
More (≥ 4x/week)	162 (65.6)	73 (70.9)	89 (61.8)	

SD = standard deviation, cpm = counts per minute, n/N = number

[a]Mean of total vector magnitude activity/wear time; Range (cpm/day): 969-3366 (all days), 1099-3677 (school days), 563-3828 (non-school days); 10[th] percentile (cpm/day, all days): 1425 (all), 1409 (boys), 1516 (girls); 90[th] percentile (cpm/day, all days): 2671 (all), 2569 (boys), 2760 (girls)

[b]p-values for tests of between sex differences, significant values are bolded

[c]Indicates difference between school days and non-school days (p < 0.0001)

4.3 Mental health and body image

4.3.1 Mental health at age 15

At baseline the average score for depression, anxiety and somatic complaints was significantly higher for girls than boys (all p < 0.0001, Table 7). Likewise, the prevalence of symptoms of depression, anxiety, and somatic complaints was significantly higher among girls (15-22%) than boys (3-8%). The average score for self-esteem and life satisfaction did not differ significantly between the sexes, nor the prevalence of low self-esteem (score < 15) and life dissatisfaction (score ≤ 20). Low self-esteem was reported by 12% of boys and 18% of girls, whereas life dissatisfaction was reported by 24% of boys and 17% of girls. Mental health variables were highly intercorrelated (see Appendix B, Supplementary table 4).

4.3.2 Mental health at age 17

Mean depression score was higher for girls than boys at age 17 ($p < 0.01$, N=152), but there was a significant increase in the score for boys between age 15 and 17 (Table 4). Boys had higher average self-esteem score at age 17 than girls ($p = 0.03$). The score did not change significantly between timepoints, for either sex.

Table 7. Mental health at age 15.

	Total (n=244)	**Males (n=100)**	**Females (n=144)**	**p-value[a]**
Depression				
Score, mean (SD)	17.6 (8.9)	14.4 (6.3)	19.7 (9.8)	**< 0.0001**
Symptoms (score > 30), n (%)	26 (10.7)	4 (4.0)	22 (15.3)	**< 0.005**
Anxiety				
Score, mean (SD)	6.6 (3.6)	5.3 (2.5)	7.6 (4.0)	**< 0.0001**
Symptoms (score > 12), n (%)	34 (13.9)	3 (3.0)	31 (21.5)	**< 0.0001**
Somatic complaints				
Score, mean (SD)	15.6 (6.6)	13.1 (5.2)	17.3 (7.0)	**< 0.0001**
Symptoms (score > 24), n (%)	35 (14.3)	8 (8.0)	27 (18.8)	**0.02**
Self-esteem				
Score, mean (SD)	21.3 (6.8)	22.1 (7.0)	20.7 (6.7)	0.11
Low self-esteem (score < 15), n (%)	38 (15.6)	12 (12.0)	26 (18.1)	0.20
Life satisfaction				
Score, mean (SD)	26.1 (7.1)	26.1 (7.7)	26.1 (6.6)	0.99
Life dissatisfaction (score ≤ 20), n (%)	48 (19.7)	24 (24.0)	24 (16.7)	0.16

SD = standard deviation
[a]p-value < 0.05, for differences between sexes, was considered statistically significant

4.3.3 Body Image

Average body image score was significantly higher for boys, both at age 15 and 17 (around 16.5 for boys vs. around 14.5 for girls, $p < 0.0001$, Table 4). The score did not change significantly between timepoints, for either sex. The average body image score was significantly lower for girls reporting total screen time above the median value at ages 15 and 17 (HH group) compared to girls with total screen time below the median value at both timepoints (LL group), 13.4 vs.15.5, or 14% lower for HH girls. For boys, the body image score did not differ between the HH and LL groups.

4.4 Sleep

Objectively measured sleep data was used as an outcome measure in cross-sectional analyses at baseline (age 15), with the main focus on variability (night-to-night variation and weekend shift) in sleep parameters.

4.4.1 Average values of sleep parameters

Mean values of sleep quality and duration did not differ between the sexes, as is shown in Table 8. The average sleep and rest durations across the week (6.6 ± 0.7 h/night and 7.5 ± 0.7 h/night, respectively) were below the recommended minimum of 8 h/night. Over the entire week, the number of awakenings was on average 20 per night and average sleep efficiency was 87.8%. Boys had on average 15 min later bed and rise times than girls across the week, this difference was around 35 min on non-school days (all $p < 0.05$).

4.4.2 Night-to-night variation in sleep parameters

Average night-to-night variations in sleep time, rest time, bed time and rise time all exceeded 1 h, with rise time having the highest variability around 100 min (Table 9). Variability in number of awakenings was about 6/night and variation in sleep efficiency was 4%. Variations in all sleep parameters, except sleep onset latency, were significantly greater for boys than girls (p-values from 0.001 to 0.04).

4.4.3 Weekend shift in sleep parameters

There was around 1 h weekend shift towards longer sleep and rest durations but the higher number of awakenings indicated lower sleep quality on non-school nights (all $p < 0.0001$, Table 8). Similarly, bed and rise times shifted to later hours on non-school days (both $p < 0.0001$), more so for boys, who went to bed 96 min later and rose 3 h later on non-school nights, while girls went to bed 69 min later and rose about 2.5 h later (differences between sexes both $p < 0.005$).

Table 8. Sleep parameters mean values at age 15.

	All (n=247)	Boys (n=103)	Girls (n=144)	P[a]
Sleep/rest duration				
TST, h/night, mean (SD)				
All days	6.6 (0.7)	6.6 (0.7)	6.6 (0.6)	0.43
School days	6.2 (0.7)	6.2 (0.8)	6.2 (0.7)	0.92
Non-School days	7.3 (1.1)**	7.2 (1.3)**	7.4 (1.0)**	0.19
TRT, h/night, mean (SD)				
All days	7.5 (0.7)	7.5 (0.7)	7.6 (0.7)	0.60
School days	7.1 (0.8)	7.1 (0.9)	7.1 (0.8)	0.95
Non-School days	8.4 (1.3)**	8.3 (1.5)**	8.4 (1.1)**	0.43
Sleep quality				
SLE, %, mean (SD)				
All days	87.8 (4.2)	87.6 (3.9)	87.9 (4.5)	0.58
School days	88.0 (4.5)	88.0 (4.6)	88.0 (4.5)	0.92
Non-School days	87.5 (4.8)	86.9 (4.2)*	87.9 (5.2)	0.09
SOL, min, mean (SD)				
All days	1.6 (0.8)	1.6 (0.8)	1.6 (0.7)	0.83
School days	1.6 (1.0)	1.6 (1.0)	1.6 (1.0)	0.91
Non-School days	1.6 (1.2)	1.6 (1.3)	1.6 (1.2)	0.98
NOA, N, mean (SD)				
All days	20.0 (5.6)	20.0 (5.5)	19.9 (5.7)	0.92
School days	18.5 (5.6)	18.2 (5.7)	18.6 (5.4)	0.56
Non-School days	22.8 (8.0)**	23.6 (8.3)**	22.3 (7.8)**	0.21
Sleep timing				
BT, o´clock, mean (SD (min))				
All days	00:46 (53)	00:55 (51)	00:40 (53)	**0.047**
School days	00:20 (53)	00:24 (55)	00:17 (51)	0.29
Non-School days	01:40 (75)**	02:00 (84)**	01:26 (64)**	**0.0012**
RT, o´clock, mean (SD (min))				
All days	08:21 (43)	08:30 (47)	08:15 (40)	**0.008**
School days	07:26 (36)	07:31 (41)	07:22 (31)	0.08
Non-School days	10:10 (82)**	10:31 (85)**	09:55 (76)**	**0.0005**

TST=total sleep time, TRT=total rest time, SLE=sleep efficiency, SOL=sleep onset latency, NOA=number of awakenings, BT=bed time, RT=rise time, SD=standard deviation, h=hours, min=minutes, n/N = number

[a]p-values for tests of between sex differences, significant values are bolded

Difference between school days and non-school days is marked *p < 0.05 and **p < 0.0001

Table 9. Sleep parameters night-to-night variability at age 15.[a]

	All (n=247)	Boys (n=103)	Girls (n=144)	p[b]
TST, min, mean (SD)	75.8 (37.2)	81.8 (44.5)	71.6 (30.5)	**0.04**
TRT, min, mean (SD)	85.6 (42.0)	94.5 (48.6)	79.2 (35.5)	**0.008**
SLE, %, mean (SD)	4.0 (1.6)	4.3 (1.7)	3.8 (1.6)	**0.02**
SOL, min, mean (SD)	1.7 (0.7)	1.6 (0.6)	1.7 (0.7)	0.27
NOA, N, mean (SD)	6.2 (2.6)	6.8 (2.8)	5.6 (2.3)	**0.001**
BT, min, mean (SD)	67.7 (39.5)	77.9 (52.0)	60.4 (25.5)	**0.002**
RT, min, mean (SD)	99.3 (40.4)	107.4 (45.0)	93.5 (35.8)	**0.01**

TST=total sleep time, TRT=total rest time, SLE=sleep efficiency, SOL=sleep onset latency, NOA=number of awakenings, BT=bed time, RT=rise time, SD=standard deviation, min=minutes, n/N = number

[a]across the entire week

[b]p-values for tests of between sex differences, significant values are bolded

4.5 Incomplete data and dropout

At baseline, participants with incomplete data did not differ from those with complete data, exept that their score for somatic complaints was higher and the percentage of parents with university degree was lower (Appendix B, Supplementary table 5). Individuals participating only at baseline did not differ from those participating at both baseline and follow-up, regarding all the main variables used in the longitudinal analysis in study 3 (Appendix B, Supplementary table 6). Similarly, there was no significant difference between participants and dropouts at follow-up for all the main sleep parameters, except that dropouts had somewhat more awakenings than participants (Appendix B, Supplementary table 6).

4.6 Covariates

4.6.1 Body composition

At age 15, average value for BMI was 21.9 kg/m^2, the prevalence of being overweight was approximately 16% and around 3% of the group were obese (Table 10). Body fat percentage was significantly higher for girls than boys at both ages ($p < 0.0001$), around 31% vs. 18%, and it increased significantly between age 15 and 17 for the girls ($p <0.05$, Table 4). Boys and girls had similar average BMI (between 22 and 23 kg/m^2) at age 17, and both sexes increased significantly in this parameter between age 15 and 17, as should be expected biologically (Table 4).

Table 10. Anthropometric and socioeconomic characteristics of participants at age 15.

	Total (n=244)	Males (n=100)	Females (n=144)	p[a]
BMI, kg/m^2, mean (SD)	21.9 (3.1)	21.5 (2.8)	22.3 (3.2)	0.06
Overweight[b], n (%)	39 (16.0)	11 (11.0)	28 (19.4)	
Obese[c], n (%)	7 (2.9)	2 (2.0)	5 (3.5)	
Body fat, %, mean (SD)	25.3 (9.0)	17.7 (6.6)	30.5 (6.3)	**< 0.0001**
Mothers with university degree, N (%)	146 (59.8)	66 (66.0)	80 (55.6)	0.10
Parents with university degree, N (%)	171 (69.2)	73 (70.9)	98 (68.1)	0.64

BMI = body mass index, SD = standard deviation
[a]p-value < 0.05, for differences between sexes, was considered statistically significant
[b]boys: 28.88 kg/m^2 > BMI ≥ 23.90 kg/m^2, girls: 29.43 kg/m^2 > BMI ≥24.37 kg/m^2 (Cole et al., 2000)
[c]boys: BMI ≥ 28.88 kg/m^2, girls: BMI ≥ 29.43 kg/m^2 (Cole et al., 2000)

4.6.2 Parental education

Approximately 70% of participants had at least one parent with a university degree and around 60% had a mother with a university education (Table 10). There was not a significant sex difference in parental education.

4.6.3 Daylength

Average duration of daylight over the study period was 17.5±1.9 h/day, ranging from 15.2 to 20.4 h/day, with no difference found between the sexes (p = 0.66). Daylength was significantly correlated with actigraphy measured total physical activity (r = 0.212, p = 0.0008) but not with screen time (r = -0.111, p = 0.08).

4.7 Screen time, vigorous physical activity and mental health at age 15, Study I

After adjusting for potential confounders (sex, maternal education and percentage body fat), reporting less screen time at age 15 was associated with a significantly lower risk of reporting symptoms of depression (RR = 0.33, 95% CI = 0.14-0.76) and anxiety (RR = 0.44, 95% CI = 0.23-0.84) (Table 11), and low self-esteem (RR = 0.31, 95% CI = 0.15-0.66) and life dissatisfaction (RR = 0.38, 95% CI = 0.20-0.72) (Table 12). Self-reported vigorous physical activity showed similar associations (Tables 11 and 12). Objectively measured physical activity was, however, not associated with any of the mental health outcomes (Tables 11 and 12), despite being positively correlated to self-reported vigorous physical activity (r = 0.27, p < 0.0001). The relative risk of reporting somatic complaints was marginally lower for those reporting lower screen time (RR = 0.55, 95% CI = 0.29-1.03) but this outcome was unrelated to both self-reported vigorous physical activity and objectively measured physical activity (Table 11).

Table 11. Associations of screen time and physical activity with symptoms of depression, anxiety and somatic complaints at age 15.

	Depressive symptoms		Anxiety symptoms		Somatic complaints	
	Yes, N (%[a])	**RR[b] (95% CI)**	**Yes, N (%[a])**	**RR[b] (95% CI)**	**Yes, N (%[a])**	**RR[b] (95% CI)**
Total screen time[c]						
Below median	7 (5.7)	**0.33 (0.14, 0.76)*** **	12 (9.8)	**0.44 (0.23, 0.84)** **	13 (10.7)	0.55 (0.29, 1.03)
Above median	19 (15.6)	Ref.	22 (18.0)	Ref.	22 (18.0)	Ref.
Vigorous PA, subjective						
Less (< 4x/week)	17 (19.5)	Ref.	22 (25.3)	Ref.	14 (16.1)	Ref.
More (≥ 4x/week)	9 (5.7)	**0.31 (0.14, 0.71)** ***	12 (7.6)	**0.35 (0.18, 0.67)** ****	21 (13.4)	0.93 (0.50, 1.76)
Total PA, objective[d]						
Below median	11 (9.0)	Ref.	14 (11.5)	Ref.	17 (13.9)	Ref.
Above median	15 (12.3)	1.24 (0.60, 2.56)	20 (16.4)	1.38 (0.74, 2.54)	18 (14.8)	0.99 (0.53, 1.85)

RR = relative risk, CI = confidence interval, PA = physical activity
[a]Percent of the subgroup
[b]Adjusted for sex, body fat percentage and maternal education
[c]Median value for total screen time = 5.3 h/day
[d]Median value for total PA = 1975 cpm/day
**p < 0.05; ***p < 0.01; ****p <0.001

Table 12. Associations of screen time and physical activity with low self-esteem and life dissatisfaction at age 15.

	Low self-esteem		Life dissatisfaction	
	Yes, N (%[a])	**RR[b] (95% CI)**	**Yes, N (%[a])**	**RR[b] (95% CI)**
Total screen time[c]				
Below median	9 (7.4)	**0.31 (0.15, 0.66)** ***	12 (9.8)	**0.38 (0.20, 0.72)** ***
Above median	29 (23.8)	Ref.	36 (29.5)	Ref.
Vigorous PA, subjective				
Less (<4x/week)	21 (24.1)	Ref.	25 (28.7)	Ref.
More (≥4x/week)	17 (10.8)	**0.48 (0.26, 0.90)** **	23 (14.7)	**0.58 (0.35, 0.96)** **
Total PA, objective[d]				
Below median	23 (18.9)	Ref.	27 (22.1)	Ref.
Above median	15 (12.3)	0.64 (0.35, 1.19)	21 (17.2)	0.84 (0.51, 1.39)

RR = relative risk, CI = confidence interval, PA = physical activity
[a]Percent of the subgroup; [b]Adjusted for sex, body fat percentage and maternal education;
[c]Median value for total screen time = 5.3 h/day; [d]Median value for total PA = 1975 cpm/day
**$p < 0.05$; ***$p < 0.005$

After adjusting for sex, maternal education and percentage body fat, participants reporting both less screen time and more frequent vigorous physical activity had a significantly lower risk of reporting symptoms of depression (RR = 0.06, 95% CI = 0.01-0.41), anxiety (RR = 0.16, 95% CI = 0.06-0.45), low self-esteem (RR = 0.16, 95% CI = 0.05-0.48) and life dissatisfaction (RR = 0.30, 95% CI = 0.15-0.61) compared with those reporting both greater screen time and less frequent vigorous physical activity (Tables 13 and 14). A significantly lower risk of reporting life dissatisfaction was also found for those reporting having both less screen time and less frequent vigorous physical activity (RR = 0.26, 95% CI = 0.08-0.80) compared with those reporting more screen time and less frequent vigorous physical activity. No associations were observed between the combined screen time-vigorous physical activity subgroups and their reported somatic complaints.

Table 13. Interactive effects of screen time and vigorous PA on symptoms of depression, anxiety and somatic complaints.

VPA (x/wk)	Screen time (h/day)	N (subgroup)	Depressive Symptoms		Anxiety Symptoms		Somatic Complaints	
			Yes, N(%[a])	RR[b] (95% CI)	Yes, N(%[a])	RR[b] (95% CI)	Yes, N(%[a])	RR[b] (95% CI)
<4	> 5.3	54	11 (20.4)	Ref.	14 (25.9)	Ref.	8 (14.8)	Ref.
<4	< 5.3	33	6 (18.2)	0.87 (0.38, 2.00)	8 (24.2)	0.89 (0.44, 1.80)	6 (18.2)	1.25 (0.49, 3.19)
≥4	> 5.3	68	8 (11.8)	0.74 (0.30, 1.84)	8 (11.8)	0.65 (0.29, 1.44)	14 (20.6)	1.78 (0.79, 4.01)
≥4	< 5.3	89	1 (1.1)	**0.06 (0.01, 0.41)****	4 (4.5)	**0.16 (0.06, 0.45)*****	7 (7.9)	0.57 (0.22, 1.44)

PA = physical activity; VPA = vigorous physical activity; x/wk = times per week; h = hour; N = number; RR = relative risk, CI = confidence interval
[a]Percent of the subgroup
[b]Adjusted for sex, body fat percentage and maternal education
*p<0.05; **p<0.005; ***p<0.0005

Table 14. Interactive effects of screen time and vigorous PA on life dissatisfaction and low self-esteem.

VPA (x/wk)	Screen time (h/day)	N (subgroup)	Life dissatisfaction		Low Self-Esteem	
			Yes, N(%[a])	RR[b] (95% CI)	Yes, N (%[a])	RR[b] (95% CI)
<4	> 5.3	54	22 (40.7)	Ref.	16 (29.6)	Ref.
<4	< 5.3	33	3 (9.1)	**0.26 (0.08, 0.80)***	5 (15.2)	0.53 (0.21, 1.30)
≥4	> 5.3	68	14 (20.6)	0.55 (0.30, 1.00)	13 (19.1)	0.73 (0.37, 1.45)
≥4	< 5.3	89	9 (10.1)	**0.30 (0.15, 0.61)****	4 (4.5)	**0.16 (0.05, 0.48)****

PA = physical activity, VPA = vigorous physical activity, x/wk = times per week; h = hour; N = number; RR = relative risk, CI = confidence interval
[a]Percent of the subgroup
[b]Adjusted for sex, body fat percentage and maternal education
*p<0.05; **p<0.005; ***p<0.0005

4.8 Screen time, physical activity and sleep at age 15 – Study II

4.8.1 Screen time and physical activity vs. average sleep parameters

In linear models adjusted for physical activity, body fat percentage and parental education, screen time was significantly associated with later bed time ($p = 0.03$) and less rest ($p = 0.02$) and sleep durations (borderline, $p = 0.05$), but not with rise time or sleep quality markers. With each additional hour of screen time, rest and sleep durations were reduced by 2.8 min and 2.2 min, respectively, and there was a 0.12 min delay in bed time.

Physical activity was inversely associated with number of awakenings ($p = 0.0002$), rise time ($p = 0.0003$), and sleep and rest durations (both $p < 0.0001$), in linear models adjusted for screen time, body fat percentage and parental education. With each additional 100 cpm/day of physical activity there was a reduction in rest and sleep durations of 3.1 min and 2.5 min, respectively, as well as 0.3 fewer awakenings and 0.15 min earlier rise time.

4.8.2 Screen time and night-to-night variation in sleep parameters

The results of the linear regression analyses between screen time and night-to-night variations in sleep parameters are shown in Table 15. Screen time was significantly related to night-to-night variations in total sleep time, total rest time, bed time, and rise time (all $p < 0.005$). Significance persisted even after adjusting for body fat percentage, parental education, and physical activity (p-values from 0.0001 to 0.03). Standardized betas (see Table 16) demonstrated that screen time was most strongly associated with variations in bed time (0.254), followed by variability in total sleep (0.216,) and rest times (0.215). Further adjustment for total sleep time and daylength did not meaningfully change the results of the analyses (see Supplementary table 7, Appendix B). When regressions were performed separately by sex, the associations only remained significant for boys. With each additional hour in screen time, the nightly variation in rest and sleep duration of boys increased by 8.2 min and 7.4 min, respectively, and their nightly variation in bed and rise times increased by 7.8 min and 5.6 min, respectively. Boys in the 90th percentile of screen time, as compared to boys in the 10th percentile, had 43 min higher nightly variability in sleep duration (Cohen´s d = 0.82 (TST) and 1.16 (TRT), and their variability in bed and rise times was 46 min and 32 min higher, respectively (Cohen´s d = 0.99 and 1.94, respectively). We did not observe significant associations between total screen time and variations in sleep quality parameters.

In analyses for subtypes of screen use (see Table 17), game playing was associated with variability in sleep parameters studied (p-values from <0.0001 to 0.04), except for sleep onset latency. Watching TV/DVD/internet material was associated with variability in rest and sleep durations (both $p < 0.005$) but spending time on the internet for web-browsing/Facebook/e-mail was associated with less variability in sleep efficiency ($p = 0.04$). When subtype regressions were stratified by sex, most associations remained significant for boys but not girls, although the association for variability in sleep efficiency became non-significant for both sexes. In addition, we observed significant associations between internet use and variability in rest and sleep durations for boys (both $p = 0.03$), but not girls or the total group.

Table 15. Linear relationships between screen time and night-to-night variations in sleep parameters at age 15.[a]

	All (N=247)			Boys (N=103)			Girls (N=144)		
	β	SE	p[b]	β	SE	p[b]	β	SE	p[b]
SD_Total sleep time (min)									
Unadjusted	3.813	1.010	**<0.001**	6.300	1.865	**0.001**	1.683	1.109	0.13
Adjusted[c]	3.566	1.074	**0.001**	7.416	2.041	**<0.001**	0.795	1.207	0.51
SD_Total rest time (min)									
Unadjusted	4.425	1.138	**<0.001**	7.395	2.019	**<0.001**	1.719	1.294	0.19
Adjusted[c]	4.012	1.208	**0.001**	8.203	2.216	**<0.001**	0.522	1.395	0.71
SD_Sleep efficiency (%)									
Unadjusted	-9.1×10^{-3}	0.045	0.84	-0.024	0.074	0.75	-0.024	0.057	0.68
Adjusted[c]	0.012	0.048	0.79	-0.018	0.081	0.82	0.003	0.061	0.97
SD_Sleep onset latency (min)									
Unadjusted	0.009	0.019	0.65	0.030	0.027	0.27	-6.6×10^{-4}	0.027	0.98
Adjusted[c]	0.008	0.021	0.72	0.045	0.030	0.13	-0.010	0.030	0.74
SD_Number of awakenings (n)									
Unadjusted	0.129	0.071	0.07	0.254	0.120	**0.04**	-0.010	0.084	0.90
Adjusted[c]	0.069	0.073	0.34	0.196	0.128	0.13	-0.073	0.088	0.41
SD_Bed time (min)									
Unadjusted	4.020	1.070	**<0.001**	6.160	2.210	**0.007**	1.760	0.913	0.06
Adjusted[c]	4.469	1.135	**<0.001**	7.795	2.400	**0.002**	1.478	1.011	0.15
SD_Rise time (min)									
Unadjusted	3.270	1.110	**0.003**	4.690	1.930	**0.02**	1.670	1.310	0.20
Adjusted[c]	2.453	1.149	**0.03**	5.573	2.086	**0.009**	0.151	1.403	0.91

SD = standard deviation, β = unstandardized regression coefficient, SE = standard error, min = minutes, n/N = number; [a]screen time (h/day) and night-to-night variations (as SDs) in sleep parameters across the week, [b]$p < 0.05$ (bolded) was considered to show statistically significant relationship between screen time and outcomes, [c]adjusted for physical activity, body fat% and parental education

Table 16. Standardized Betas for significant linear relationships between screen time and sleep variability at age 15.[a,b]

	All (N=247)			Boys (N=103)			Girls (N=144)		
	Std. β	**SE**	**p[c]**	**Std. β**	**SE**	**p[c]**	**Std. β**	**SE**	**p[c]**
SD_Total sleep time	0.216	1.074	**0.0010**	0.371	2.041	**0.0005**	0.059	1.207	0.51
SD_Total rest time	0.215	1.208	**0.0010**	0.376	2.216	**0.0004**	0.033	1.395	0.71
SD_Bed time	0.254	1.135	**0.0001**	0.334	2.400	**0.0016**	0.131	1.011	0.15
Shift[d]_Bed time	0.174	0.0013	**0.007**	0.251	0.0026	**0.02**	0.104	0.0013	0.24
SD_Rise time	0.137	1.149	**0.0337**	0.276	2.086	**0.0089**	0.010	1.403	0.91
Shift[d]_Rise time	0.140	0.0016	**0.03**	0.235	0.0027	**0.03**	0.042	0.002	0.64

ST = screen time, SD = standard deviation, β = standardized regression coefficient, SE = standard error, n/N = number
[a]Values for screen time and night-to-night variations (as SDs) in sleep parameters are for the entire week
[b]Models were adjusted for body fat percentage, parental education and physical activity
[c]p-value < 0.05 (bolded) was considered to show statistically significant relationship between screen time and outcome variable
[d]Shift = weekend shift, the difference between non-school days and school days.

Table 17. Linear relationships between subtypes of screen use and night-to-night variations in sleep parameters at age 15.[a]

		All (N=247)			Boys (N=103)			Girls (N=144)		
		β	**SE**	**p[b]**	**β**	**SE**	**p[b]**	**β**	**SE**	**p[b]**
Sleep duration	**SD_Total sleep time** (min)									
	Game playing	5.567	2.091	**0.008**	9.820	3.832	**0.01**	-3.225	3.605	0.37
	Internet: Facebook, browsing, mail	3.189	1.940	0.100	10.424	4.887	**0.03**	2.337	1.833	0.20
	Watching TV/DVD/Internet	8.155	2.583	**0.002**	17.525	4.667	**0.0002**	2.237	2.766	0.42
	SD_Total rest time (min)									
	Game playing	7.448	2.337	**0.001**	11.244	4.154	**0.007**	-4.064	4.161	0.33
	Internet: Facebook, browsing, mail	2.857	2.186	0.191	11.34	5.317	**0.03**	2.216	2.121	0.30
	Watching TV/DVD/Internet	8.552	2.913	**0.003**	18.968	5.081	**0.0002**	1.904	3.197	0.55
Sleep quality	**SD_Sleep efficiency** (%)									
	Game playing	0.188	0.091	**0.04**	0.111	0.147	0.45	0.018	0.183	0.92
	Internet: Facebook, browsing, mail	-0.169	0.084	**0.04**	-0.274	0.185	0.14	-0.078	0.093	0.40
	Watching TV/DVD/Internet	0.004	0.114	0.97	-0.139	0.186	0.45	0.138	0.140	0.32
	SD_Sleep onset latency (min)									
	Game playing	-0.013	0.040	0.74	0.060	0.054	0.27	-0.134	0.090	0.14
	Internet: Facebook, browsing, mail	-0.012	0.037	0.75	0.012	0.069	0.86	-0.018	0.046	0.70
	Watching TV/DVD/Internet	0.092	0.049	0.06	0.088	0.068	0.19	0.103	0.069	0.14
	SD_Number of awakenings (n)									
	Game playing	0.468	0.138	**0.0007**	0.647	0.226	**0.004**	-0.255	0.263	0.33
	Internet: Facebook, browsing, mail	-0.149	0.130	0.25	-0.238	0.296	0.42	-0.001	0.135	0.99
	Watching TV/DVD/Internet	0.056	0.176	0.75	0.413	0.293	0.16	-0.131	0.202	0.52
Sleep timing	**SD_Bed time** (min)									
	Game playing	9.838	2.173	**<0.0001**	13.927	4.379	**0.002**	0.245	3.046	0.94
	Internet: Facebook, browsing, mail	1.959	2.077	0.35	9.753	5.720	0.09	1.726	1.547	0.26
	Watching TV/DVD/Internet	3.785	2.801	0.18	8.660	5.718	0.13	0.554	2.335	0.81
	SD_Rise time (min)									
	Game playing	5.348	2.213	**0.016**	8.680	3.831	**0.02**	0.845	4.195	0.84
	Internet: Facebook, browsing, mail	1.097	2.058	0.59	6.618	4.918	0.18	0.135	2.140	0.95
	Watching TV/DVD/Internet	5.409	2.760	0.05	9.504	4.855	0.05	2.928	3.208	0.36

SD = standard deviation, β = unstandardized regression coefficient, SE = standard error, min = minutes, n/N = number,
[a]Time spent on subtypes of screen use (h/day) and night-to-night variations (as SDs) in sleep parameters for the entire week, models were adjusted for physical activity, body fat percentage, and parental education.
[b]p-value < 0.05 (bolded) was considered to show statistically significant relationship between screen time variables and sleep outcomes

4.8.3 Physical activity and night-to-night variation in sleep parameters

Results of the linear regression analyses between physical activity and night-to-night variations in sleep parameters are shown in Table 18. Physical activity was inversely related to night-to-night variations in number of awakenings ($p < 0.0001$) and rise time ($p = 0.002$), even after adjusting for body fat percentage, parental education, and screen time ($p = 0.0001$ and 0.013, respectively). The association was stronger for variability in number of awakenings than rise time according to standardized beta values (-0.251 vs. -0.161, Table 19). When the analyses were performed for each sex separately, variation in number of awakenings remained significantly associated with physical activity for both sexes, but variability in rise time was only significant for girls. Further adjustment for total sleep time and daylength did not meaningfully change the results of the regression analyses (see Supplementary table 8, Appendix B). With each additional 100 cpm/day in physical activity, the variability in number of awakenings decreased by 0.14 and the variability in rise time decreased by 1.4 min (total group). Participants in the 90th percentile of physical activity, as compared to participants in the 10th percentile, had reduced variability in the number of awakenings of 1.7 (Cohen´s d = 0.88) and decreased variability in rise time of 17 min (Cohen´s d = 1.83). We did not observe significant associations between physical activity and night-to-night variations in total sleep or rest times, sleep efficiency, sleep onset latency or bed time.

Table 18. Linear relationships between physical activity and night-to-night variations in sleep parameters at age 15.[a]

	All (N=247)			Boys (N=103)			Girls (N=144)		
	β	**SE**	**p[b]**	**B**	**SE**	**p[b]**	**β**	**SE**	**p[b]**
Sleep duration									
SD_Total sleep time (min)									
Unadjusted	-0.008	0.005	0.13	-0.006	0.010	0.58	-0.008	0.005	0.15
Adjusted[c]	-0.003	0.005	0.56	0.0038	0.010	0.71	-0.005	0.005	0.31
SD_Total rest time (min)									
Unadjusted	-0.012	0.006	**0.04**	-0.012	0.011	0.27	-0.010	0.006	0.10
Adjusted[c]	-0.007	0.006	0.24	-0.0015	0.011	0.89	-0.008	0.006	0.22
Sleep quality									
SD_Sleep efficiency (%)									
Unadjusted	2.2×10^{-4}	2.2×10^{-4}	0.32	2.3×10^{-4}	3.7×10^{-4}	0.54	5.5×10^{-4}	2.6×10^{-4}	**0.04**
Adjusted[c]	1.8×10^{-4}	2.2×10^{-4}	0.42	-2.5×10^{-4}	4.0×10^{-4}	0.53	5.1×10^{-4}	2.7×10^{-4}	0.06
SD_Sleep onset latency (min)									
Unadjusted	1.6×10^{-5}	9.5×10^{-5}	0.87	1.7×10^{-4}	1.4×10^{-4}	0.22	9.0×10^{-5}	1.3×10^{-4}	0.48
Adjusted[c]	3.9×10^{-5}	9.8×10^{-5}	0.69	2.8×10^{-4}	1.5×10^{-4}	0.06	-8.5×10^{-5}	1.3×10^{-4}	0.53
SD_Number of awakenings (n)									
Unadjusted	-1.4×10^{-3}	3.3×10^{-4}	**<0.001**	-0.002	5.9×10^{-4}	**0.003**	-0.001	3.8×10^{-4}	**0.006**
Adjusted[c]	-1.4×10^{-3}	3.5×10^{-4}	**<0.001**	-0.002	6.3×10^{-4}	**0.015**	-0.001	3.9×10^{-4}	**0.006**
Sleep timing									
SD_Bed time (min)									
Unadjusted	4.3×10^{-4}	0.005	0.94	0.007	0.012	0.55	-0.001	0.004	0.80
Adjusted[c]	0.006	0.005	0.30	0.019	0.012	0.11	0.001	0.004	0.82
SD_Rise time (min)									
Unadjusted	-0.017	0.005	**0.002**	-0.015	0.010	0.14	-0.016	0.006	**0.008**
Adjusted[c]	-0.014	0.005	**0.013**	-0.010	0.010	0.32	-0.015	0.006	**0.016**

SD = standard deviation, β = unstandardized regression coefficient, SE = standard error, min = minutes, n/N = number
[a]Physical activity (counts/min/day) and night-to-night variations (as SDs) in sleep parameters for the entire week
[b]p-value < 0.05 (bolded) was considered to show statistically significant relationship between physical activity and outcome variables
[c]Adjusted for screen time, body fat percentage and parental education

Table 19. Standardized Betas for significant linear relationships between physical activity and sleep variability.[a,b]

	β	SE	p[c]
Screen time (h/day)[a]			
TST NSchD – SchD (min)	-0.024	0.037	0.51
TRT NSchD – SchD (min)	-1.92	2.60	0.46
BT NSchD – SchD (min)	4.90 (boys: 8.78; girls: 2.16)	1.87 (boys: 3.74; girls: 1.87)	**0.007** (**boys: 0.02**; girls: 0.24)
RT NSchD – SchD (min)	4.90 (boys: 8.64; girls: 1.37)	2.30 (boys: 3.89; girls: 2.88)	**0.03** **(boys: 0.03**; girls: 0.64**)**
NOA NSchD – SchD (N)	-0.09	0.20	0.64
SLE NSchD – SchD (%)	-3.7×10^{-4}	0.12	1.00
SOL NSchD – SchD (min)	0.07	0.04	0.12
Physical activity (cpm/day)[b]			
TST NSchD – SchD (min)	-0.023 (boys: -7.2×10^{-4}; girls: -2.5×10^{-4})	0.011 (boys: 3.5×10^{-4}; girls: 1.9×10^{-4})	**0.03** **(boys: 0.04**; girls: 0.18**)**
TRT NSchD – SchD (min)	-0.027 (boys: -0.045; girls: -0.019)	0.012 (boys: 0.025; girls: 0.013)	**0.03** (boys: 0.08; girls: 0.15)
BT NSchD – SchD (min)	6.9×10^{-3}	8.6×10^{-3}	0.42
RT NSchD – SchD (min)	-0.019	0.011	0.09
NOA NSchD – SchD (N)	-2.0×10^{-3} (boys: -1.1×10^{-3}; girls: -2.1×10^{-3})	9.4×10^{-4} (boys: 1.8×10^{-3}; girls: 1.0×10^{-3})	**0.04** **(**boys: 0.53; **girls: 0.05)**
SLE NSchD – SchD (%)	1.5×10^{-4}	5.6×10^{-4}	0.79
SOL NSchD – SchD (min)	-6.2×10^{-5}	2.1×10^{-4}	0.77

TST = total sleep time, TRT = total rest time, SLE = sleep efficiency, SOL = Sleep onset latency, NOA = number of awakenings, BT = bed time, RT = rise time, NSchD = non-school days, SchD = school days, h = hours, min = minutes, cpm = counts per minute, N = number, β = unstandardized regression coefficient, SE = standard error
[a]Adjusted for physical activity, body fat percentage and parental education
[b]Adjusted for screen time, body fat percentage and parental education
[c]p-value < 0.05 (bolded) was considered to show statistically significant relationship between screen time/physical activity and outcome variables

4.8.4 Screen time and physical activity vs. weekend shift in sleep parameters

Average total screen time was positively associated with greater weekend shift in bed and rise times after adjusting for physical activity, body fat percentage and parental education (Table 20; $p = 0.007$ and 0.03, respectively), with the shift in bedtime having the stronger association according to standardized beta values (0.174 vs. 0.140, Table 16). Game playing was the only subtype of screen use significantly associated with weekend shift in bed and rise times (Table 21; $p = 0.0002$ and $p = 0.002$, respectively). When performed separately by sex, these associations were only significant for boys (both $p < 0.05$). With each additional hour in screen time, the weekend shift in bed and rise times of boys increased by 8.8 min and 8.6 min, respectively. Both these weekend shifts were around 50 min greater for boys in the 90^{th} vs. the 10^{th} percentile of screen time (Cohen´s $d = 0.4$).

Physical activity was negatively associated with weekend shift in sleep time, rest time and number of awakenings (all $p < 0.05$, Table 20) after adjusting for screen time, body fat percentage and parental education, with all relationships showing a similar strength of association (standardized beta = -0.14, Table 19). When performed separately by sex, physical activity was only significantly associated with weekend shift in sleep time for boys ($p = 0.04$) and number of awakenings for girls ($p = 0.05$). With each additional 100 cpm/day in physical activity, there was a reduction in the weekend shift in number of awakenings by 0.2 and in rest and sleep durations by 2.7 min and 2.3 min, respectively (total group). Participants in the 90^{th} percentile of physical activity, as compared to participants in the 10^{th} percentile, had around 30 min less weekend shifts in rest and sleep durations (Cohen´s $d = 0.2$), and less shift in number of awakenings of 2.4 (Cohen´s $d = 0.4$).

Table 20. Linear relationships between weekend shifts in sleep parameters and screen time/physical activity at age 15.

	β	SE	p[c]
Screen time (h/day)[a]			
TST NSchD – SchD (min)	-0.024	0.037	0.51
TRT NSchD – SchD (min)	-1.92	2.60	0.46
BT NSchD – SchD (min)	4.90 (boys: 8.78; girls: 2.16)	1.87 (boys: 3.74; girls: 1.87)	**0.007** (**boys: 0.02**; girls: 0.24)
RT NSchD – SchD (min)	4.90 (boys: 8.64; girls: 1.37)	2.30 (boys: 3.89; girls: 2.88)	**0.03** (**boys: 0.03**; girls: 0.64)
NOA NSchD – SchD (N)	-0.09	0.20	0.64
SLE NSchD – SchD (%)	-3.7×10^{-4}	0.12	1.00
SOL NSchD – SchD (min)	0.07	0.04	0.12
Physical activity (cpm/day)[b]			
TST NSchD – SchD (min)	-0.023 (boys: -7.2×10^{-4}; girls: -2.5×10^{-4})	0.011 (boys: 3.5×10^{-4}; girls: 1.9×10^{-4})	**0.03** (**boys: 0.04**; girls: 0.18)
TRT NSchD – SchD (min)	-0.027 (boys: -0.045; girls: -0.019)	0.012 (boys: 0.025; girls: 0.013)	**0.03** (boys: 0.08; girls: 0.15)
BT NSchD – SchD (min)	6.9×10^{-3}	8.6×10^{-3}	0.42
RT NSchD – SchD (min)	-0.019	0.011	0.09
NOA NSchD – SchD (N)	-2.0×10^{-3} (boys: -1.1×10^{-3}; girls: -2.1×10^{-3})	9.4×10^{-4} (boys: 1.8×10^{-3}; girls: 1.0×10^{-3})	**0.04** (boys: 0.53; **girls: 0.05**)
SLE NSchD – SchD (%)	1.5×10^{-4}	5.6×10^{-4}	0.79
SOL NSchD – SchD (min)	-6.2×10^{-5}	2.1×10^{-4}	0.77

TST = total sleep time, TRT = total rest time, SLE = sleep efficiency, SOL = Sleep onset latency, NOA = number of awakenings, BT = bed time, RT = rise time, NSchD = non-school days, SchD = school days, h = hours, min = minutes, cpm = counts per minute, N = number, β = unstandardized regression coefficient, SE = standard error
[a]Adjusted for physical activity, body fat percentage and parental education
[b]Adjusted for screen time, body fat percentage and parental education
[c]p-value < 0.05 (bolded) was considered to show statistically significant relationship between screen time/physical activity and outcome variables

Table 21. Linear relationships between subtypes of screen use and weekend shift in bed and rise times at age 15.[a]

	All (N=247)			Boys (N=103)			Girls (N=144)		
	β	SE	p[b]	β	SE	p[b]	β	SE	p[b]
WS_Bed time (min)									
Game playing	0.0089	0.0024	**0.0002**	0.0138	0.0046	**0.0025**	0.0054	0.0039	0.17
Internet: Facebook, browsing, mail	0.0012	0.0023	0.61	0.0090	0.0060	0.13	0.0002	0.0020	0.91
Watching TV/DVD/Internet	-0.0019	0.0031	0.54	-0.0041	0.0060	0.50	-0.0003	0.0030	0.93
WS_Rise time (min)									
Game playing	0.0090	0.0030	**0.002**	0.0127	0.0048	**0.009**	0.0043	0.0060	0.47
Internet: Facebook, browsing, mail	-0.0004	0.0028	0.90	0.0024	0.0063	0.70	-0.0001	0.0031	0.98
Watching TV/DVD/Internet	0.0058	0.0037	0.12	0.0093	0.0062	0.14	0.0033	0.0046	0.47

WS = weekend shift, β = unstandardized regression coefficient, SE = standard error, min = minutes, N = number,
[a]Time spent on subtypes of screen use (h/day) and weekend shift (Non-schooldays – Schooldays) in bed and rise times, models were adjusted for physical activity, body fat percentage, and parental education
[b]p-value < 0.05 (bolded) was considered to show statistically significant relationship between screen time and outcome variables

4.9 Screen time and body image – Study III

Linear regression analyses demonstrated that screen time variables were only significantly associated with body image score for girls but not boys. The association was observed both cross-sectionally at ages 15 and 17 and longitudinally between timepoints.

4.9.1 Cross-sectional association at age 15

Total daily screen time (all days, non-school days and school days), time spent in game playing and watching TV/DVD/internet material were all negatively associated with body image score for girls (all $p < 0.001$, Table 22). The effect size was strong, according to the calculated Cohen´s d for the highest 20% as compared with the lowest 20% in total daily screen time ($d = 1.11$, all days). Associations remained significant, except for total screen time on school days, when the data were adjusted for body fat percentage, depression, and vigorous physical activity (all $p < 0.05$). We did not find a significant interaction between screen time and vigorous physical activity, for either sex. Total screen time, body fat percentage and depression score were all significantly related to body image score in the adjusted model, explaining 40% of the variance in body image score.

4.9.2 Cross-sectional association at age 17

Total daily screen time (all days and non-school days), game playing, internet use (Facebook/web-browsing/e-mail), and watching TV/DVD/internet material, were all negatively associated with body image score for girls ($p = 0.0002$ to 0.03, Table 22). The effect size was strong, according to the calculated Cohen´s d for the highest 20% as compared with the lowest 20% in total daily screen time ($d = 0.81$, all days). Associations became non-significant when the data were adjusted for body fat percentage, depression, and vigorous physical activity. Whereas screen time on non-school days had the strongest association with body image score, screen time on school days was not associated with this outcome. We did not find a significant interaction between screen time and vigorous physical activity, for either sex. Vigorous physical activity and depression score were significantly related to body image score in the adjusted model, explaining 31% of the observed variance in body image score.

Table 22. Linear relationships between hours of average daily screen time and body image score.

	15y (2015)				17y (2017)			
	Boys		Girls		Boys		Girls	
	β	p[a]	β	p[a]	β	p[a]	β	p[a]
Total screen time[b] – all days[c]								
Unadjusted	-0.174	0.20	-0.424	**<.0001**	0.067	0.62	-0.257	**0.01**
Adjusted[d]	-0.029	0.81	-0.201	**0.03**	0.088	0.49	-0.032	0.74
Total screen time[b] - non-school days								
Unadjusted	-0.135	0.32	-0.400	**<.0001**	0.024	0.86	-0.378	**0.0002**
Adjusted[d]	0.041	0.73	-0.210	**0.02**	0.044	0.73	-0.171	0.07
Total screen time[b] - school days								
Unadjusted	-0.182	0.18	-0.378	**0.0002**	0.080	0.55	-0.186	0.07
Adjusted[d]	-0.060	0.61	-0.158	0.08	0.099	0.43	0.024	0.80
Game playing[c]								
Unadjusted	-0.158	0.24	-0.396	**<.0001**	-0.002	0.99	-0.227	**0.03**
Adjusted[d]	-0.109	0.37	-0.211	**0.02**	-0.043	0.75	-0.129	0.14
Watching TV/DVD/internet material[c]								
Unadjusted	-0.112	0.40	-0.338	**0.0008**	0.098	0.47	-0.225	**0.03**
Adjusted[d]	-0.026	0.83	-0.204	**0.03**	0.064	0.62	0.023	0.81
Internet use (Facebook/email/web-browsing)[c]								
Unadjusted	0.062	0.65	-0.192	0.06	0.137	0.31	-0.223	**0.03**
Adjusted[d]	0.070	0.54	-0.016	0.86	0.128	0.33	-0.055	0.55

β = standardized regression coefficient
[a]p-value < 0.05 (bolded) for body image vs. screen time variables
[b]Total screen time (h/day) = game playing + watching TV/DVD/internet material + internet use (Facebook/e-mail/web-browsing)
[c]weighted average for non-school days and school days
[d]adjusted for body fat percentage, depression score, and vigorous physical activity

4.9.3 Longitudinal association at age 15 to 17

Having screen time above the median value at both timepoints (all days), as compared with having screen time below the median both years (group HH vs. group LL), was negatively associated with body image score at age 17 among girls ($p = 0.005$, Table 23). The effect size was of medium strength, according to the calculated Cohen´s d for the HH group compared with the LL group ($d = 0.67$, all days). The association remained significant after adjustment for baseline (age 15) body fat percentage, depression score, and vigorous physical activity ($p = 0.03$). Adding baseline body image score to the adjusted model did not meaningfully change the results ($p = 0.04$). Further adding baseline self-esteem to the model did not change the results ($p = 0.04$). This negative association was stronger for screen time on non-school days ($p = 0.0002$ for unadjusted model and $p = 0.002$ for adjusted model) but was not observed for screen time on school days. We also found a negative association between screen time on non-school days and body image for the LH group compared to the LL group ($p = 0.03$ for both unadjusted and adjusted models).

Table 23. Categorical total daily screen time from age 15 to 17 versus age 17 body image.

	Boys		Girls	
	β	**p**[a]	**β**	**p**[a]
All days				
Unadjusted				
HH	0.168	0.83	-2.141	**0.005**
LH	0.882	0.38	-0.948	0.26
HL	0.791	0.38	-0.607	0.49
LL	Ref.		Ref.	
Adjusted[b]				
HH	-0.060	0.94	-1.705	**0.03**
LH	0.309	0.77	-0.893	0.28
HL	0.297	0.75	0.058	0.95
LL	Ref.		Ref.	
School days				
Unadjusted				
HH	0.086	0.91	-1.269	0.13
LH	0.722	0.51	-0.640	0.47
HL	0.322	0.74	0.097	0.91
LL	Ref.		Ref.	
Adjusted[b]				
HH	-0.179	0.82	-0.694	0.41
LH	0.179	0.88	-0.279	0.76
HL	-0.138	0.89	1.156	0.22
LL	Ref.		Ref.	
Non-school days				
Unadjusted				
HH	-0.233	0.78	-2.984	**0.0002**
LH	1.048	0.27	-1.747	**0.03**
HL	1.048	0.27	-1.491	0.09
LL	Ref.		Ref.	
Adjusted[b]				
HH	-0.599	0.48	-2.568	**0.002**
LH	0.452	0.66	-1.797	**0.03**
HL	0.610	0.53	-1.363	0.13
LL	Ref.		Ref.	

β = unstandardized regression coefficient; [a]p-value < 0.05 (bolded) for body image vs. screen time category; [b]Adjusted for body fat percentage, depression score and vigorous physical activity
HH: above median screen time at 15y and 17y; 21 boys (36.8%), 27 girls (28.4%)
HL: above median screen time at 15y but below median screen time at 17y; 11 boys (19.3%), 17 girls (17.9%)
LH: below median screen time at 15y but above median screen time at 17y; 8 boys (14.1%), 20 girls (21.1%)
LL: below median screen time at 15y and 17y; 17 boys (29.8%), 31 girls (32.6%)

5 Discussion

The aim of this doctoral study was to explore the relationship of two behavioral factors, screen time and physical activity, with mental health and sleep outcomes in a cohort of Icelandic adolescents. It was observed that mid-teen adolescents reporting less screen time and more frequent vigorous physical activity were less likely to report symptoms of depression, anxiety, low self-esteem, and life dissatisfaction. Individuals who reported a combination of engaging in less screen time and more frequent vigorous physical activity had the lowest risk of reporting negative mental health symptoms, suggesting a synergistic relationship between the two behaviors on mental health outcomes. These results contribute to the limited knowledge base of the interactive effects of screen time and physical activity on mental health among adolescents in their mid-teens and address the lack of information on this topic in Icelandic adolescents. Greater screen time and less physical activity were also associated with more irregular sleep patterns, especially among boys. These findings are an important contribution to the very limited literature on the relationship between screen use/physical activity and intra-individual variations in sleep parameters in adolescents. To the best of our knowledge, this is the first study to examine such relationships, using objective measures. In addition, our results confirm a negative cross-sectional association between screen time and body image for adolescent girls and further demonstrate that girls with consistently higher than median screen time over a two-year period rated their body image lower than girls with below median screen time over this time interval.

5.1 Status, sex differences and changes in main variables

The average values and sex differences in the main variables of interest (studies I-III) are discussed in this section, as well as the changes between age 15 and 17 for the main variables in study III.

5.1.1 Screen time

The average total daily screen use reported by participants in our study (ca. 6 h/day) was around or slightly below the level (6-8 h/day) reported in various other countries (Bucksch et al., 2016; Rideout et al., 2015; Houghton et al., 2015). It was somewhat higher for boys than girls at age 15, which agrees with prior findings (Bucksch et al., 2016), but had become equal for the sexes by age 17, due to a more profound increase between timepoints for girls, especially on school days. The observed increase in total screen time between ages 15 and 17 agrees with prior findings that levels of screen use tend to be higher in older children (Pate et al., 2011; Rideout et al., 2015), possibly due to more screen-based homework and/or less parental monitoring of screen use. For both sexes, spending between 4 and 6 h/day in screen-based activities was most commonly reported, and only a very small minority reported screen time below 2 h/day. Participants of both sexes reported their screen time higher on non-school days than school days. There was a sex difference regarding screen activities, girls reported spending more time on the internet than boys, whereas boys reported more game playing than girls (although the internet use of boys increased and their game playing decreased between ages 15 and 17). These results are in line with previous findings across various countries, including Iceland *(*Bucksch et al., 2016; Rideout et al., 2015; World Health Organization, 2016c). The sex/gender differences might be explained in terms of boys having higher levels of testosterone and being biologically more driven to the excitement and competition in gaming (Terlecki et al., 2011). Girls might be more interested in social connectedness and/or social comparison with others via social media (Liu, 2017). Around two thirds of the longitudinal study sample (study III) had stable screen usage across the study period, i.e. were either high or low screen users at both age 15 and 17, whereas participants in the remaining third of the group either increased or decreased their screen use. This is in line with observations that screen time tracks in a moderate-to-large way ($r \geq 0.30$) during childhood and adolescence into adulthood (Biddle et al., 2010). To conclude, screen use among Icelandic adolescents seems to be similar to what has been reported for other study populations, by far exceeding the recommended daily time.

5.1.2 Physical activity

As has been described previously for this sample (Rognvaldsdottir et al., 2018), boys and girls had at age 15 similar objectively measured physical activity over the entire week and on school days, but girls had higher levels of activity on non-school days. This came as a surprise and disagrees with prior studies (Dencker & Andersen, 2008; Magnusson et al., 2011a) reporting higher levels of physical activity among boys than girls. Both sexes recorded higher levels of activity on school days compared to non-school days. Around two-thirds of the sample reported engaging in VPA at least 4 times a week at age 15, but this proportion was lower at age 17. This agrees with previous findings that physical activity levels tend to decline during adolescence (Dumith et al., 2011; Ortega et al., 2015). Also, in line with prior findings (Dencker & Andersen, 2008; Magnusson et al., 2011a), higher percentage of boys than girls reported engaging in VPA at least 4 times a week, at both ages. The sex-differences in objectively measured activity on non-school days and weekly frequency of VPA might be an indication of different activity patterns among the sexes. Boys might be participating more frequently in organized sports of vigorous intensity on school days but tend to be more sedentary during non-school days, as compared to girls. Lower levels of objectively measured activity on non-school days among boys might also be explained by participation in non-weight bearing activity, which accelerometers may be unable to detect. More participation in intensive competitive sports among boys might be explained by their higher levels of testosterone, as compared to girls. This may also potentially be the result of difference in gender stereotypes; the masculine type is equated with being athletic whereas the feminine one with being non-athletic (Klomsten et al., 2004).

5.1.3 Mental health and body image

Prevalence of symptoms of depression, anxiety, and somatic complaints in the study sample was between 11-14%, which is in line with estimated values previously reported (Magnusson, 2004). Values were 2-7 fold higher among girls than boys and the sex difference was most profound for symptoms of anxiety. This agrees with the previous literature, where females have typically been found to report symptoms of mental health problems more frequently than males (Urrila et al., 2015; Maras et al., 2015; Vila et al., 2009). This difference has been explained in terms of biological sex differences in hormonal levels and stress response, as well as gender inequity and gender roles (Seedat et al., 2009). It should also be kept in mind that instruments used for evaluating the mental health status of adolescents might be working differently for boys and girls (Kleppang and Hagquist, 2016), potentially distorting results and making comparison between sexes difficult. The average scores for the mental health outcomes evaluated in the dissertation are similar to those previously observed in a population sample of Icelandic adolescents (Gestsdottir et al., 2015), and the proportion reporting high symptoms of depression and anxiety are in line with those observed in a nationwide sample of Icelandic mid-teens in 2015 (Thorisdottir et al., 2017). The average score for self-esteem and life satisfaction did not differ between the sexes at age 15, but boys had higher average self-esteem score at age 17. Low self-esteem was reported by 16% of participants, the percentage was not statistically different between the sexes. This is in line with the literature (Kling et al., 1999) and previous findings for Icelandic adolescents (Gestsdottir et al., 2015). Life dissatisfaction was reported by 20% of the study sample without any statistical difference between the sexes. Previous studies have shown inconclusive results regarding sex differences in adolescent life satisfaction (Jovanović, 2016), but our results agree with previous findings reported for Icelandic adolescents (Gestsdottir et al., 2015). This was also true for the average body image score, which was higher for boys than girls at both age 15 and 17. That finding is in an agreement with prior results for Icelandic adolescents (Asgeirsdottir et al., 2012; Gestsdottir et al., 2015) as well as for adolescents across various countries in Europe and North-America (Al Sabbah et al., 2009). Gender differences in body image have been explained by appearance becoming ever more important for girls than boys in adolescence (Marsh, 1989), with the unrealistically thin and perfectly featured ideal as the reference for girls (Low et al., 2003). Along with earlier pubertal maturation of girls, with increases in body fat, this may result in body dissatisfaction (Rosenblum & Lewis, 1999; Brooks-Gunn et al., 2002; Lintunen et al., 1984). Furthermore, boys have been found to have a significantly higher global physical self-concept and self-esteem than girls (Klomsten et al., 2004). Body image score did not change significantly between ages 15 to 17 for either sex, which is in line with prior Icelandic results

(Gestsdottir et al., 2015). Higher scores for older adolescents, especially girls, have been reported in other populations (Al Sabbah et al., 2009; Dion et al., 2015).

In summary, the prevalence, sex differences and changes with age in the mental health variables examined in this doctoral study agree with previous findings for Icelandic adolescents and most of the ones reported for other populations.

5.1.4 Sleep

The mean values of sleep parameters have previously been evaluated for this study cohort (Rognvaldsdottir et al., 2017), but it is worth mentioning that we did not observe sex differences in the mean values for sleep/rest duration and sleep quality, but boys had later bed and rise times than girls. This agrees with adolescent boys being more evening oriented than adolescent girls due to higher levels of testosterone (Randler & Engelke, 2019) but may also be the result of gender norm differences, with boys staying up late playing computer games while girls may be more preoccupied with their appearance and want to rise at an earlier time for grooming purposes.

The main emphasis in this thesis is on the intra-individual variability of sleep duration, quality and timing. The amount of night-to-night variability in sleep duration was quite substantial (up to 1.5 h) and it was greater than the weekend shift (which was around 1 h). This is in line with previous findings from studies measuring variation in sleep duration in population-based adolescent samples either objectively (He et al., 2015) or by self-report (Fuligni & Hardway, 2006). Both nightly variation and weekend shift in sleep duration observed in these studies were, however, lower than ours, possibly due to methodological differences. Prior studies on night-to-night variations in sleep efficiency and number of awakenings are lacking, but in our study nightly variations in these parameters were greater than the weekend shifts. Nightly variability in sleep parameters across the week, with variability on school days being an important contributor, may therefore be of a special importance and our regression analyses showed that both screen time and physical activity were in general associated more strongly with night-to-night variation in sleep parameters than the weekend shift. The nightly variations in bed and rise times were also substantial (up to almost 2 h), although lower than the weekend shifts (which were up to almost 2.5 h). We are unaware of any prior studies on youth measuring nightly variations in bed and rise times, but two studies evaluating weekend shifts with self-report (Jarrin, McGrath, & Drake, 2013; Hayes et al., 2017) found the same shift in bed time (Jarrin et al., 2013; Hayes et al., 2017) but less shift in rise time (Jarrin et al., 2013) than we did. Nightly variation in all sleep parameters (except in sleep onset latency), and weekend shift in bed and rise times, were significantly greater for boys than girls. This sex difference disagrees with the results of the only prior study found on sex-specific variability in adolescent sleep parameters, where self-reported nightly variation and weekend shift in sleep duration were slightly greater for girls than boys (Fuligni & Hardway, 2006). To conclude, Icelandic adolescents have highly irregular sleep patterns, especially boys.

5.2 Screen time, physical activity and mental health – Study I

In the first study of this dissertation the aim was to explore relations of screen time and physical activity with mental health outcomes, first independently and then interactively.

Participants who reported engaging in less than the median screen time had a reduced risk of reporting symptoms of negative mental health compared with those reporting screen time greater than the median value. This finding was relatively consistent across mental health outcomes, with reductions in relative risk ranging from 56-69% for reports of symptoms of depression and anxiety, low self-esteem, and life dissatisfaction. These results are in line with recent reviews reporting that increased participation in screen based activities in leisure time may be linked to poorer mental health among adolescents, including depressive symptomatology and psychological distress, decreased perceptions of self-worth, and lower perceived quality of life and self-esteem (Suchert et al., 2015; Hoare et al., 2016; Tremblay et al., 2011).

Participating in vigorous physical activity at least 4 times/week was associated with reduced risk (42-69%) of reporting the various mental health problems examined in our study, excluding somatic complaints. Previous findings on the impact of vigorous physical activity on mental health in youth have been mixed, perhaps due to variations in participant age and methodologies used to evaluate physical activity and mental health outcomes (Poitras et al., 2015). In a study on Chinese college students (Wu et al., 2015), depression and anxiety were not associated with the frequency of physical activity alone but were negatively associated with a measure that also accounted for intensity and duration of the activity. Other studies have reported no association between self-reported vigorous or moderate-to-vigorous physical activity in adolescents and symptoms of depression and anxiety (Feng et al., 2014; Trinh et al., 2015) and low self-esteem (Trinh et al., 2015). Life satisfaction was, however, associated with self-reported physical activity in Iranian youth (Matin et al., 2017), and quality of life was related to self-reported weekly frequency of moderate-to-vigorous physical activity in a study by Iannotti et al. (2009).

Despite a positive correlation between self-reported vigorous physical activity and objectively measured total activity, the objectively measured physical activity was surprisingly not associated with the mental health outcomes in our study. It is possible that the intensity of the activity must be above certain threshold to provide mental health benefits, although prior research has been inconclusive in this regard (Jayakody et al., 2014; Perraton et al., 2010). A recent review reported indications of beneficial effects of objectively measured total physical activity on mental health among adolescents (Poitras et al., 2016). However, it was concluded that relationships were more consistent and robust for higher versus lower intensity physical activity. Using self-reported physical activity, Mekary et al. (2013) found that substituting 60 minutes/day of brisk/very brisk walking for television watching was more protective against depression than the same amount of average-paced walking. Their results also indicated that walking at an easy pace was not protective against depression. Conversely, in a review of exercise interventions to reduce or prevent anxiety and depression in youth (Larun, Nordheim, Ekeland, Hagen, & Heian, 2006), the authors concluded that exercise intensity had little impact on depression and anxiety scores in the general population of children and adolescents.

Participants reporting a combination of less screen time and more frequent vigorous physical activity had the lowest risk of reporting negative mental health symptoms. This agrees with the results of the few prior studies examining such interrelated effects, in younger (Cao et al., 2011; Hamer et al., 2009; Kremer et al., 2014) and older adolescents (Feng et al., 2014; Wu et al., 2015). The risk reduction for the less screen time-more frequent vigorous physical activity group, compared with the more screen time-less frequent vigorous physical activity group, was very substantial for symptoms of depression and anxiety (84-94%) and greater than that observed in the studies mentioned above for other age-groups of adolescents. The less screen time-more frequent vigorous physical activity group was also least likely to report low self-esteem (84% reduced risk), which supports prior findings by Trinh et al. (2015). Significantly lower risk of reporting life dissatisfaction was found in our study for those with less screen time, independent of the frequency of vigorous physical activity. In comparison, an interactive analysis conducted by Matin et al. (2017) showed that the joint effect of low screen time and high physical activity was most strongly associated with life satisfaction in Iranian youth.

In summary, our results indicate that less screen time and more frequent vigorous physical activity are both independently and interactively associated with less risk of reporting mental health problems, low self-esteem and life dissatisfaction.

5.3 Screen time, physical activity and sleep – Study II

In the second study of the dissertation, the aim was to assess the relationship of screen time and physical activity with the duration, timing and quality of sleep. The main outcome of interest was the variability in sleep parameters, as less is known about the relations between these behaviors and sleep stability as compared to sleep averages.

It was found that greater screen time, especially game playing, was associated with greater night-to-night variations in bed time, rise time, rest duration and sleep duration, and greater weekend shifts in bed and rise times. Game playing was furthermore associated with higher variability in the number of awakenings and in sleep efficiency. Total screen time was also associated with later bed time and less rest and sleep durations. Additionally, we found that the increase in reported screen time on non-school days was correlated with the shift toward later bed time on non-school days.

Our sex specific linear regression analyses showed that associations between screen time and variability in sleep were significant for boys but not girls. Since boys had higher levels of screen time and more profound nightly variation in sleep and weekend shifts in sleep timing, stronger associations between screen time and sleep variations for boys were not surprising. Among the subtypes of screen use, game playing was most often associated with variability and weekend shift in sleep parameters. Higher percentage of boys than girls preferred this type of screen use in our study, which may further explain the sex differences in our results.

Although the observed increases in the variability in sleep parameters among boys with each additional hour of screen time were modest (ranging from 5.6 to 8.8 min), the cumulative effect of screen use on the stability of sleep parameters may have public health relevance. Boys in the 90th percentile of screen time, as compared to boys in the 10th percentile, had considerably higher nightly variability in sleep duration, bed and rise times, as well as substantially greater weekend shift in bed and rise times. The effect size was large for the nightly variability (Cohen´s d ranged from 0.8-1.9) and larger than for the weekend shift where the effect was moderate (Cohen´s d = 0.4). This higher variability, especially in the nightly variation, may negatively affect the health, functionality and well-being of individuals with the highest screen time.

Collectively, these findings support a growing body of research that suggests that screen time disrupts bed time routine and sleep duration (LeBourgeois et al., 2017; Hale et al., 2018, Olds et al., 2011) and also previous findings based on self-report that adolescents with more screen/computer use experience greater nightly variation in sleep duration (Fuligni & Hardway, 2006), and greater weekend shift in bed time (Hayes et al., 2017). Although mechanisms for sleep disruption by screen usage remain uncertain, factors such as direct displacement of sleep by screen time (which may be affected by the developmental circadian shift to more eveningness and/or gender norms, especially for boys (as introduced in section 1.6)), screen-light altering peak melatonin release, and arousal from screen usage are all thought to contribute (LeBourgeois et al., 2017; Hale et al., 2018; Gerber et al., 2014).

We observed that physical activity was associated with less sleep and rest durations and earlier rise time, possibly due to direct displacement of sleep by physical activity. Higher levels of physical activity have been associated with better sleep quality in adolescents (Lang et al., 2013; Hayes et al., 2017; Gerber et al., 2014; Lang et al., 2016) but studies of its association with adolescent sleep duration have yielded mixed results (Lang et al., 2016; Hayes et al., 2017; Ortega et al., 2011; Laurson et al., 2014). Similarly, prior population-based studies exploring the relationship between physical activity and sleep variability in adolescents and children have produced inconsistent results (Hayes et al., 2017; Stone et al., 2013). However, these studies were limited to self- or parent-report and focused only on weekend shifts in sleep. Our results, obtained using objective measures, suggest that physical activity contributes to both better and more consistent sleep quality since physical activity was inversely associated with the mean value, night-to-night variation and weekend shift in awakenings. We also found that greater physical activity was associated with less nightly variation in rise time and smaller weekend shifts in sleep and rest durations, indicating that it may also promote more consistent sleep patterns. Daylength was found to be correlated with actigraphy measured total physical activity (total group and girls), as has been reported previously (Rognvaldsdottir et al., 2018; Rich et al., 2012), but it was not correlated with sleep duration and adjusting for daylength in the regression analysis between these variables did not change our results.

In contrast to the effects of screen use on the variability in sleep observed only for boys, we found that the relationship between physical activity and night-to-night variation in rise time was significant for girls but not boys. This discrepancy may be due to insufficient power in our sex specific analyses**,** which should be interpreted with caution due to our limited sample size.

Participants (total group) in the 90th percentile of physical activity, as compared to participants in the 10th percentile, had considerably less variability and weekend shift in number of awakenings, decreased variability in rise time, and less weekend shift in rest and sleep durations. The effect size was large for the nightly variability (Cohen´s d > 0.8) and larger than for the weekend shift (Cohen´s d = 0.2-0.4) where the effect was small-to-medium. The lower variability, especially the nightly variation, supports the notion that by promoting stable sleep patterns, being physically active may have definite and positive effects on health and well-being.

Taken together, these results suggest that physically active students have more consistent sleep quality and routine across the week and less need for catch-up sleep on non-school days than their more sedentary counterparts. These findings are consistent with the idea that some of the physiological effects of physical activity, including enhanced body temperature control and melatonin production, may be favorable to sleep regulation (Chennaoui et al., 2015).

5.4 Screen time and body image – Study III

In the third study of this dissertation, the aim was to explore cross-sectional and longitudinal relationships between screen time and body image. A consistent, negative cross-sectional relationship was found between body image score and total screen time and time spent on various screen activities for girls at ages 15 and 17. These results were supported by the longitudinal observation that girls with higher-than-average total screen time at both ages had lower body image scores at age 17 than girls with below average screen time at both ages, even after adjusting for potential confounders. Our results broadly agree with previous cross-sectional studies on the association of media and body image (Dumas & Desroches, 2019; Holland & Tiggemann, 2016; López-Guimerà et al., 2010) and with the few longitudinal studies on this subject that have in most cases found time spent on social network sites (Holland & Tiggemann, 2016), and reading magazines and watching TV (López-Guimerà et al., 2010; Schooler & Trinh, 2011) being predictive of body dissatisfaction. Taken together, these findings suggest that media use may play a causal role in the development of body dissatisfaction.

We observed striking sex differences in this study, with no significant associations between screen time and body image for boys, but consistent negative cross-sectional and longitudinal relationship between these variables for girls. The effect size, comparing the highest 20% in daily screen time across the week with the lowest 20%, was strong for the cross-sectional associations (Cohen´s d = 1.11 at age 15, and d = 0.81 at age 17). It was of medium strength for the longitudinal association, comparing the groups with above vs. below the median daily screen time across the week at both ages 15 and 17 (HH group vs. LL group, Cohen´s d = 0.67). Results of the few prior studies that have analysed this topic in both sexes have been mixed. Studies on total screen use (Suchert et al., 2015), computer use in leisure time (Anez et al., 2018), TV watching (Schooler & Trinh, 2011) and Facebook use (Thompson & Lougheed, 2012) have found an association between screen time and body dissatisfaction in girls but not boys. However, as reviewed by Holland and Tiggeman (2016), a few studies on social media use and body image have not observed gender differences. The influence of media on body image may be stronger for girls than boys due to the extensive promotion of an unrealistic thin-beauty ideal for women by the media and objectification of the female body in Western societies (Calado et al., 2011; Swami et al., 2010). Studies have shown that girls tend to be more discontent about their body than boys from an early age, and that adolescent girls typically see themselves as overweight even though they are in normal weight (Rosenblum & Lewis, 1999; Spaeth & Schlicht, 2000). In addition, earlier pubertal maturation with increases in body fat among girls has been linked to body dissatisfaction (Brooks-Gunn et al., 2002; Lintunen, 1984). This may result in greater self-monitoring of appearance among girls, potentially with more screen time spent on appearance related issues, leading to higher levels of body dissatisfaction in females than males (Holland & Tiggemann, 2016). Adolescent girls also tend to have lower self-esteem (Aslund, Starrin, & Nilsson, 2010; Kling et al., 1999) and more depressive symptoms (Patton & Viner, 2007) than adolescent boys, which may make them more vulnerable to the negative effects of mass media (Ahadzadeh, Sharif, & Ong, 2017; Suchert et al., 2015). In addition, the quality of social relationships has been found to be positively associated with screen use among boys (Finne, Bucksch, Lampert, & Kolip, 2014), which may have beneficial influences on their overall mental well-being (Suchert et al., 2015). Furthermore, in contrast to girls, early-developing boys have been found to be more satisfied with their body than their late-maturing male peers, as they experience increased strength and endurance (Lintunen et al., 1984). In our study, girls had lower average body image score and higher depression score than boys at both age 15 and 17, and lower self-esteem score at age 17.

Screen time, both total time and time spent in subcategories, was more strongly associated with body image score at age 15 than 17. This was despite an increase in screen time between age 15 and 17 for girls, whereas body image score remained similar between these ages. It can be speculated that greater publicity and awareness of the negative effects of unrealistic body standards presented by the media and increased maturity with age could have contributed to this finding. Results from a recent study on adolescent girls suggest that both parental involvement and school environment may play crucial roles in protecting them from the detrimental effects that social media use may have on their body image (Burnette, Kwitowski, & Mazzeo, 2017). Positive mother-adolescent relationship may be especially beneficial in this respect (de Vries, Vossen, & van der Kolk-van der Boom, 2019).

Total screen time on non-school days was more strongly related to body image than total screen time on school days, more so at age 17. A possible explanation may be the higher average screen time observed on non-school days, and likely longer continuous periods of screen use on these days. This could be especially relevant at age 17, as parental supervision may have decreased between ages 15 and 17. These results agree with a study on Spanish adolescents that found computer use in leisure time on non-school days, but not school days, to be associated with body dissatisfaction among girls (Anez et al., 2018).

Game playing was most strongly associated with body image score at both ages, followed closely by watching TV/DVD/internet material, but internet use (Facebook/e-mail/web-browsing) was only associated with body image at age 17. Prior research has focused on the cross-sectional relationship between TV use and body image, and has found inverse association between these variables, explained by the exposure to thin-ideal images and self-objectification (Levine & Murnen, 2009; López-Guimerà et al., 2010; Schneider et al., 2013). According to a recent systematic review, female characters in video games are typically objectified and hypersexualized with disproportionate body parts, which may lead to self-objectification in female players (Gestos, Smith-Merry, & Campbell, 2018), more so than television use (Karsay, Knoll, & Matthes, 2018). Most prior research has found social media use negatively associated with body image (Dumas & Desroches, 2018; Fardouly & Vartanian, 2016; Holland & Tiggemann, 2016), with a few exceptions (Fardouly, Diedrichs, Vartanian, & Halliwell, 2015; Schneider et al., 2013). Thus, the lack of association between internet use and body image at age 15 came as a surprise but may be due to the phrasing of our question on internet use, which included Facebook but no other social media sites that later became increasingly popular. In addition, the distinction between internet use and watching internet material may have been unclear and perhaps resulted in the former being misclassified as the latter.

We adjusted for depression, body composition, and vigorous physical activity in our analyses. It is, however, up for debate whether some or all of these variables are confounders or intermediates in a causal pathway between screen time and body image dissatisfaction. Depression may also be the result of body dissatisfaction (Eidsdottir et al., 2014; Holland & Tiggemann, 2016). Regardless, total screen time was a significant explanatory variable for body image in girls at age 15 independent of these covariates. This effect of screen time was not observed, however, at age 17, where depression and vigorous physical activity were the only variables significantly associated with body image in the fully adjusted model. Altogether, these results are consistent with screen time having both direct effects on body image and indirect effects via depression and vigorous physical activity. In the longitudinal analysis, the results were independent of the above listed covariates, as well as baseline body image and self-esteem.

In summary, negative cross-sectional and longitudinal associations were found between screen time (especially game playing) and body image score, for girls only.

5.5 Strengths and limitations

A definite strength of this doctoral study is the unusually diverse data collected at both age 15 and 17, which makes it possible to explore both cross-sectional and longitudinal relations between behavioral factors and various health related outcomes for adolescents. Another strength of the three studies of the doctoral thesis is the use of objective measurements of total physical activity and sleep by accelerometers, and of body fat percentage by DXA-scanning. Still another advantage is the available information on the subtypes of screen use, and screen time on non-school days as well as on school days. The participation rate (77%) was also quite high and the study sample represents a relatively large portion of the total number (n = 4,254, thereof n = 1,355 living in Reykjavik) of 15-year-old Icelandic adolescents in the year of 2015 (Statistics Iceland, 2015; Statistics Iceland, 2020). It should also be noted that the Icelandic population is ethnically and socio-economically homogeneous, with little variation between geographic areas (Statistics Iceland, 2018). Moreover, about two thirds of the Icelandic population resides in the Reykjavik metropolitan area. The socio-economic status of the students in our cohort of individuals born in 1999 was, furthermore, not found to differ between the participating schools in a previous study (Magnusson, Hrafnkelsson, Sigurgeirsson, Johannsson, & Sveinsson, 2012). It is therefore likely that the results reported in this thesis are representative for the Icelandic population of this age. Indeed, our results are very similar to those previously reported for Icelandic adolescents, regarding mental health status, in both urban and rural areas (Gestsdottir et al., 2015; Thorisdottir et al., 2017). Further, there are specific strengths to each of the three studies. A strength of study I is the number and diversity of the mental health outcomes being evaluated; the agreement of results across these outcomes adds to the value of the study findings. In study II the effects of screen time and physical activity on diverse sleep parameters are assessed, in sex-specific manner. The main strength of study III is the longitudinal design that enabled us to evaluate the effects of screen time on body image, across the two-year period from age 15 to 17. The cross-sectional and longitudinal results agree, strengthening the credibility of our findings. Our follow-up time of 2 years is, furthermore, longer than that used in most previous studies in this field. Finally, analyses were performed separately by sex, which adds to the limited data on sex-based difference in the relationship between screen time and body image.

A limitation of the study is the self-report of screen time and vigorous physical activity which is subject to recall and reporting biases. In addition, we did not have information about the timing of these behaviors within the day, which would have been valuable to have for establishing temporal relations between the exposure (screen use/physical activity) and the outcome (sleep) and combat reverse causality. Our questionnaire included separate questions for time spent on individual screen based activities (games, TV/DVD watching, web/browsing/social-media/email, and other screen usage) which were combined for the total screen time used in our analyses, i.e. participants were not asked to estimate their total screen use. While this approach can potentially provide more detailed information on screen-based activities, this may have resulted in an over-estimation of total screen time, as multi-tasking on different screens, such as watching TV and using a smart-phone at the same time, is quite prevalent in youth (Rideout, 2015). On the other hand, we did not specifically ask about smart-phone use and our question on internet use only included Facebook and lacked other social media platforms at age 15, which may have led to under reporting of internet use and total screen time at that age. Misclassification of social media use as watching material via the internet may also be present.

Although employing accelerometers in the measurement of total physical activity, we were unable to obtain objective measure of vigorous activity since there are currently no agreed upon intensity cut-points for wrist-worn accelerometers for youth. Another limitation with using actigraphy is the disadvantage that accelerometers may be unable to detect non-weight-bearing physical activity, such as cycling (Butte et al., 2012), resulting in a possible under-estimation of physical activity levels and diminished associations between physical activity and the outcomes of interest.

The current study analysed nightly sleep periods only, as there is no accepted criterion for scoring actigraph-assessed naps (Jakubowski et al., 2017) and the sleep detection algorithm may be inadequate to detect them in our analysis. The participants sleep diaries did not clearly state napping behavior and thus no naps where included in the analysis. This excluding of naps could have affected our results as napping among this age group has been shown to be a prominent behavior and found to be associated with both shorter and more disrupted night-time sleep (Jakubowski, Hall, Lee, & Matthews, 2017).

We adjusted for several potential confounders in our analyses, but residual confounding due to other factors (such as diet and pubertal timing) may be present. Furthermore, the cross-sectional design in studies I and II does not allow us to determine causal relationships between study variables. Reverse causality cannot be ruled out, e.g. participants reporting mental health problems or having irregular sleep patterns might tend to be socially isolated and spend more time in screen-based activities and less time in physical activity than their peers. The generalizability of our findings in study II (with variability in sleep parameters as outcomes) to other adolescent populations is somewhat unclear as objective measurements of sleep patterns are scarce and the measures for physical activity and self-reported screen use differ between studies. The northern latitude and homogeneous racial and ethnic composition of Iceland may further limit the generalizability of the findings. Finally, although we have no evidence to suggest that the non-participants at baseline (age 15, N = 96) differed from the general student population in terms of socioeconomic status, lifestyle habits (including physical activity and screen time), mental health status, body image and/or sleep habits, we cannot rule out the possibility of selection bias.

6 Public Health Implications

The frequency of mental disorders and its potential long-term consequences warrant research in relation to risk and protective factors and strongly entail a need to identify strategies to prevent and reduce this public health problem. The results of the studies presented in this thesis compliment the growing evidence supporting the importance of distinguishing the independent and interactive effects of physical activity and screen time on adolescent mental health, and point to the need to construct interventions that can tease out the mechanisms that are associated with this relationship. Adopting a multi-level approach among academic administrators and educators is necessary when promoting physical activity and demoting screen time and other sedentary behavior among youth.

Further, the findings of the studies presented here may have implications for primary and secondary prevention of mental health problem in adolescents, considering that physical activity levels in adolescence could predict mental health outcomes in both adolescence and adulthood. Thus, public health policy should focus on reducing sedentary time and maintaining sufficient moderate to vigorous levels of physical activity. In that regard, elucidating a better understanding of any association between duration and types of screen time behaviors and mental health may be crucial to developing effective strategies to prevent or treat anxiety and depression in youth. With increased understanding of this relationship, the inclusion of screen time in clinical assessment of children and adolescents seeking treatment for anxiety or depression may inform mental health practitioners in their treatment planning.

There is mounting evidence of the importance of sufficient duration and stability of sleep and the results presented here increase our understanding of potential risk factors and may indicate possible intervention strategies. Whether interventions aimed at increasing public health should focus on individuals or to the environments where people live is an important issue. Lately, transition of public health activities based mostly on education and individual behavior to a broader ecologic approach draws on clinical, educational, environmental, social, and policy interventions whose interactions may reduce unfavorable behavior among youth.

7 Summary and conclusions

Our data suggest that less screen time and more frequent vigorous physical activity are not only separately but also interactively associated with less risk of reporting symptoms of depression, anxiety, low self-esteem and life dissatisfaction. These results contribute to the limited knowledge base of the interactive effects of screen time and physical activity on mental health among adolescents in their mid-teens. Less screen time and more physical activity were also both associated with less variable sleep patterns, especially among boys. Our findings suggest that the cumulative negative effect of screen use on the stability of sleep parameters may have public health relevance, whereas being physically active may have definite and positive effects on the health, functionality and well-being of adolescents. Finally, our cross-sectional and longitudinal data support the notion that screen use plays a role in the development of body dissatisfaction among girls. Limiting screen time may help to mitigate body dissatisfaction in this group. The observed sex differences in this dissertation indicate that the sexes may be differently susceptible to the effects of screen use on health outcomes. Overall, the findings of this dissertation highlight the potential health benefits of limiting screen time and being physically active during adolescence, and support the latest public health recommendations for more active and less sedentary/screen-based lifestyle, in which individuals are advised to not only move more but also to sit less. Authorities and parents are, therefore, encouraged to provide a supportive environment for youngsters to develop such a lifestyle.

8 Future perspectives

Our results, regarding the effects of screen use and physical activity on mental health and sleep stability, support public health recommendations that guide youth towards more active and less sedentary/screen-based lifestyle. However, further longitudinal and intervention studies are needed to determine whether the relationships of screen time and physical activity with these outcomes are causal.

To date, most previous studies on the effects of screen time on health outcomes, including those described in this dissertation, rely on self-reported screen time. Objective measures of screen use such as wearable video-camera technology may be more accurate and will likely be used in the future but are still in their infancy. In the meantime, subjective measures of screen use can be improved by asking participants to estimate their total screen use and time spent on mobile (smart phones, tablets) vs. stationary devices. Questions on social media use should also preferably contain as many relevant social media platforms as possible (Facebook, Twitter, Instagram, Snapchat). Furthermore, in research on the effects of screen use on sleep parameters, it would be beneficial to ask participants to fill out screen use diaries containing discrete time periods to get more detailed information on the timing of screen use within each 24 hour period.

In this dissertation, information on vigorous physical activity was obtained via self-report, as there is currently no agreed upon method to identify vigorous activity from wrist-based accelerometer data in adolescents. Although we found that our subjective measure of vigorous activity correlated with the objectively measured total physical activity, validated algorithms to parse activity intensity from wrist worn accelerometers may provide a more accurate measure for future studies.

In research on school-age adolescents, seasonal variations regarding daylength, climate, and demands of schoolwork could affect results. In this thesis, the data used was collected in springtime, at both age 15 and 17. At the former age, participants were graduating from elementary school and preparing for their final exams. This seasonal timing and scholarly strain could have affected their daily leisure time activities, mental health and sleep. It would therefore be of interest to conduct a similar study in a different season, to assess if these factors may have played a role.

The sex differences in screen use and in the observed associations of screen use with sleep and body image indicate that the sexes may be differently susceptible to the effects of screen use on health outcomes. Future investigators should keep this in mind to appropriately power sex-specific studies. Further, sex-specific approaches need to be considered in the designing of strategies to lower screen use among adolescents. Sex may also play a role when measuring body image score, the measure used to assess this outcome may be less suitable to evaluate bodily feelings among boys than girls. In addition, measures on body image varies greatly among studies and more standardization is needed in the evaluation of this parameter.

The study cohort used in this dissertation was first measured at age 7, and then again at ages 9, 15 and 17. This has made longitudinal analyses possible, and it would be interesting to analyse the mental health outcomes in study I in a longitudinal format (from age 15 to 17), as was done in study III for body image. It would, furthermore, be very interesting to conduct further follow-up measurements to yield information on various health and lifestyle factors of the individuals as young adults and to track potential changes from adolescence to young adulthood.

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Paper I

PLOS ONE

RESEARCH ARTICLE

Less screen time and more frequent vigorous physical activity is associated with lower risk of reporting negative mental health symptoms among Icelandic adolescents

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Abstract

Objective

Few studies have explored the potential interrelated associations of screen time and physical activity with mental health in youth, particularly using objective methods. We examined cross-sectional associations of these variables among Icelandic adolescents, using objective and subjective measurements of physical activity.

Methods

Data were collected in the spring of 2015 from 315 tenth grade students (mean age 15.8 years) in six elementary schools in metropolitan Reykjavík, Iceland. Participants reported, via questionnaire, on demographics, weekly frequency of vigorous physical activity, daily hours of screen time and mental health status (symptoms of depression, anxiety and somatic complaints, self-esteem and life satisfaction). Total physical activity was measured over one week with wrist-worn accelerometers. Body composition was determined by DXA-scanning. Poisson regression analysis was used to explore independent and interactive associations of screen time and physical activity with mental health variables, adjusting for gender, body fat percentage and maternal education.

Results

Less screen time (below the group median of 5.3 h/day) and more frequent vigorous physical activity ($\geq$4x/week) were each associated with reporting fewer symptoms of depression, anxiety, low self-esteem, and life dissatisfaction. No significant associations were observed between objectively measured physical activity and mental health outcomes. Interactive regression analysis showed that the group reporting both less screen time and more

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frequent vigorous physical activity had the lowest risk of reporting symptoms of depression, anxiety, low self-esteem, and life dissatisfaction.

Conclusions

Reports of less screen time and more frequent vigorous physical activity were associated with lower risk of reporting mental health problems among Icelandic adolescents. Those who reported a combination of engaging in less screen time and more frequent vigorous physical activity had the lowest risk, suggesting a synergistic relationship between the two behaviors on mental health outcomes. Our results support guiding youth towards more active and less sedentary/screen-based lifestyle.

Introduction

Mental health may be positively influenced by self-esteem and life satisfaction but negatively affected by mental disorders, such as depression, anxiety and somatic complaints [1]. The prevalence of mental disorders, including depression and anxiety, has increased over the past decades [2] and now accounts for 30% of the global non-fatal disease burden, affecting close to 10% of the world´s population [3]. Prevalence of mental health problems rises sharply in adolescence [4,5], with depression and anxiety being among the leading causes of the burden of disease and disability in youth [6]. These syndromes often manifest physically as somatic complaints [7]. A study on the secular trend in symptoms of depression and anxiety among Icelandic adolescents reported increases in symptoms and more frequent visits to psychiatrists, psychologists and social workers during the period 1997–2006 [8]. Poor life satisfaction is strongly associated with mortality in adults [9] and psychosocial and behavioral problems [10] and violence [11] in adolescents. Mental well-being is highly affected by self-esteem among adolescents [12] and low self-esteem has been linked to increased depression and anxiety [13]. Depression and anxiety are strong predictors of negative health and psychosocial outcomes, including academic difficulties, behavioral problems, low self-esteem, substance abuse, and suicide [14]. Furthermore, youth experiencing anxiety and depression are at significantly increased risk of these conditions in adulthood [14]. The identification of risk factors and/or protective factors during adolescence is therefore a very important public health issue.

Parallel to the rise in mental health disorders in the past decades has been an increased usage of leisure-time screen based media [15] and a considerable reduction in the level of physical activity [16,17], particularly in adolescents [17–19]. Not surprisingly, excessive screen-based activities and limited physical activity have been proposed as potential risk factors for mental health problems [20–22]. Studies examining the effects of both screen time and physical activity on mental health have typically investigated their separate effects but not their potential interrelated effects [20,23]. These factors may operate synergistically to affect mental health, high levels of screen time and low levels of physical activity have been found to interact and lead to increased mental health problems among college students [24,25] and in children during pre- or early adolescence [26–28]. Less is known about these interactive effects in youngsters in their mid-teens. Further, most prior studies have relied solely on self-reported physical activity, rather than using objective measures.

The purpose of this study was to examine both the separate and interactive associations of screen time and physical activity with self-reported mental health in Icelandic adolescents. We hypothesized that: 1) study participants with fewer hours of screen time would be less likely to report experiencing symptoms of poor mental health, 2) participants with higher levels of physical activity would also be less likely to report having symptoms of poor mental health, and 3) participants with both fewer hours of screen time and higher levels of physical activity would have the lowest risk of reporting mental health problems.

Methods

Sample and data collection

Four hundred and eleven tenth-grade students (age 15–16 years, 47% boys and 53% girls) from six elementary schools in metropolitan Reykjavik, Iceland, were invited to participate in the study; 315 (79%) of which agreed to participate. Non-participation was mainly due to absence from school during measurement days and lack of interest in the study. Data collection was performed between mid-April and early June of 2015. Participants provided information regarding their background, health and lifestyle by answering a tablet-based questionnaire (in Icelandic) administered at school under the supervision of research team members. The questionnaire addressed age, sex, maternal education (as a proxy for socioeconomic status), participation in screen-based activities, weekly frequency of vigorous physical activity, symptoms of mental health problems (depression, anxiety and somatic complaints), self-esteem and life satisfaction. Objective measurements of free-living physical activity, weight, height and body composition were also performed. Written informed consent was obtained from all participants and their guardians. Strict procedures were followed to ensure confidentiality. The research project was approved by the Icelandic Data Protection Authority and the National Bioethics Committee as well as the Icelandic Radiation Safety Authority.

Exposure measures

Self-reported vigorous physical activity. Participants were asked the following question: „How often, per week, do you perform physical activity that makes you breathe more rapidly or sweat? The variable was scored on a six-point Likert scale, with the following response options: 1 = "never", 2 = "less than once a week", 3 = "once a week", 4 = "2–3 times a week", 5 = "4–5 times a week", 6 = "almost every day". For analysis, the variable was recoded using the following two categories: Less frequently = "less than 4 times a week" and more frequently = "4 times a week or more", based on international physical activity guidelines stating that children and adolescents should participate in vigorous-intensity physical activity at least 3 days a week [29].

Objectively measured physical activity. Free-living physical activity was objectively measured using small (3.8 cm x 3.7 cm x 1.8 cm) and lightweight (27 g) triaxial raw signal accelerometer-based Actigraph activity monitors (model GT3X+ ActiSleep, Actigraph Inc. Pensacola Florida). Each participant was asked to continuously wear the monitor on his/her non-dominant wrist for 7 consecutive days. A minimum of 3 valid schooldays and 1 valid non-schoolday was set as an inclusion criterion. Days with a wear-time of $\geq$ 14 h from 12 midnight to 12 midnight the following day were considered valid. Raw triaxial data (in milliG's) sampled at 80 samples per second (Hz) were reduced to the vector magnitude of activity counts over 60 s epoch and averaged over all valid days using Actilife software from Actigraph (Pensacola, FL, USA; version 6.13.0) and customized programs in Matlab (The Mathworks, Natick, MA, USA; version R2013a). Participants were categorized as having higher and lower levels of objective total physical activity, using the group median value as a cut-off.

Self-reported screen time. Participants were asked to report on how many hours per day on average, separately for weekdays and weekend-days, they played computer games, watched TV/DVD/internet material, used the internet for web-browsing/Facebook/e-mail and participated in „other"computer use. Each item was scored on a seven-point Likert scale, with the following response options: 1 = "none", 2 = "about ½ h", 3 = "1 up to 2 h", 4 = "2 up to 3 h", 5 = "3 up to 4 h", 6 = "4 to 5 h" and 7 = "more than 5 h". Average daily hours for each type of screen-based activity were computed, using the midpoints for scoring categories and weighted averages for weekdays and weekend-days. All screen-based activities were then summed for a total daily screen time (h/day) and participants were sorted into high and low screen time groups based on their relation to the group median value.

Outcome measures

Mental health problems. A 22-item version of the Subscales of the Symptom Checklist 90 (SCL-90) [30] was used to assess symptoms of depression (10 items), anxiety (4 items) and somatic complaints (8 items). Participants were asked how often they had experienced symptoms of these conditions during the preceding week. Each item was rated on a five-point Likert scale: 1 = "almost never", 2 = "seldom", 3 = "sometimes", 4 = "often"and 5 = "almost always". The following cut-offs, based on the midpoint of possible scores, were used to define a healthy versus an unhealthy score: depression symptoms $\geq$ 30 points, anxiety symptoms $\geq$ 12 points and somatic complaints $\geq$ 24 points. This 22-item version of the SCL-90, using the same cut-offs, has previously been employed in a study on mental well-being among Icelandic adolescents [31].

Global self-esteem. Global self-esteem was assessed using the Rosenberg Self-Esteem Scale [32]. The scale consists of 10 statements, each rated as positive or negative, with four response options: 0 = "strongly agree", 1 = "somewhat agree", 2 = "somewhat disagree"and 3 = "strongly disagree". A score $\geq$ 15 points reflects a greater level of self-esteem. The Rosenberg scale has been widely used for evaluating self-esteem of young people, and its reliability and validity are well documented [33].

Life satisfaction. The Diener´s Satisfaction with Life Scale (SWLS), a measure of global cognitive judgments of satisfaction with one's life, was used for estimating life satisfaction of participants [34]. The scale contains 5 items rated on a 7-point Likert scale, with the following response options: 1 = "strongly disagree", 2 = "disagree", 3 = "somewhat disagree", 4 = "neither agree nor disagree", 5 = "somewhat agree", 6 = "agree", 7 = "strongly agree". A score of 20 represents a neutral point on the scale, with higher score indicating more satisfaction and lower score indicating less satisfaction. Scores on the SWLS have been shown to correlate with measures of mental health and the scale is reported to have a high internal consistency and good test-retest correlations [35].

Covariates

Body composition and maternal education were selected as covariates, based on prior studies and our own correlation analysis. Previous research has identified associations between body composition and screen time [36–38], physical activity [38,39] and mental health [40–42]. Our data confirm these associations, as body composition was significantly correlated with physical activity, screen time, and all the mental health outcomes. Education of parents, especially mothers, has been found to associate with the mental health of their offspring [43]. Maternal education is an indicator of socioeconomic position, which may affect youngsters' participation in recreational activities, including screen-based activities [44] and physical activity [45]. Furthermore, low educational attainment of parents has been shown to independently associate with less utilization of child mental health resources, and increased severity and duration of mental health problems of children [46,47].

Body composition. Body mass index (BMI, kg/m^2) was calculated from measurements of weight (kg) and height (m). Standing height was measured to the nearest mm with a transportable stadiometer (Seca model 217, Seca Ltd., Birmingham, UK). Body weight was measured to the nearest 0.1 kg on a calibrated scale (Seca model 813, Seca Ltd., Birmingham, UK), with participants wearing light clothing. These measurements were performed at individual schools. Whole-body and regional soft tissue composition was measured by dual energy X-ray absorptiometry (DXA) using a Lunar bone densitometer (GE Healthcare, Madison, Wisconsin USA) to obtain percentage body fat. All DXA-scans were run by the same certified radiologist at the facilities of the Icelandic Heart Association in Kopavogur, Iceland.

Maternal education. Educational level of mother was reported by the participants, given the following seven categories to choose from: 1 = "elementary degree", 2 = "secondary degree", 3 = "trade school degree", 4 = "university degree", 5 = "other", 6 = "do not know", 7 = "do not want to answer". These options were recoded into a new binary variable, university education of mother, with the following categories: 1 = "having university degree" and 0 = "not having university degree".

Statistical analysis

Descriptive summaries are presented as means and standard deviations for continuous variables and as frequencies and percentages for categorical variables. Sex differences were evaluated by t-tests for continuous variables and chi-square tests for categorical variables. Pearson's correlational analysis was used to evaluate relationships between the main variables of interest. Poisson regression analysis was performed to calculate the relative risk (RR) and 95% confidence intervals (CIs) of reporting symptoms of depression, anxiety, somatic complaints, low self-esteem, and life dissatisfaction with respect to screen time, frequency of self-reported vigorous physical activity, and objectively measured total physical activity. First, separate Poisson regressions were performed between each independent variable (i.e. total daily screen time, subjective vigorous physical activity, and objective total physical activity) and each mental health outcome. The sample was then divided into the following four groups, based on the total daily screen time and subjective vigorous physical activity, for interactive Poisson regression analysis: higher screen time + less frequent vigorous physical activity (reference group), higher screen time + more frequent vigorous physical activity, lower screen time + less frequent vigorous physical activity and lower screen time + more frequent vigorous physical activity. Since objective total physical activity was not associated with the mental health outcomes in the univariate analysis, an analogous interactive analysis using screen time and objective total physical activity was not performed. All Poisson regression models were adjusted for the following potential confounders: sex, body fat percentage and maternal education. Significant differences or relations were accepted at $\alpha < 0.05$. Statistical analyses were performed using SAS statistical software, version 9.4 (SAS Institute Inc., Cary, NC; www.sas.com).

Results

Characteristics of participants

The inclusion criteria of valid measurements for free-living physical activity (a minimum of 3 weekdays and 1 weekend day) was fulfilled for 272 participants, 248 of which also had complete self-reported data for screen time, vigorous physical activity and mental health variables. Four participants had values for screen time exceeding the upper limit for that variable (mean + 2.5 SD) and were thus removed as outliers. The removal did not meaningfully change the results of our regression analyses. The final study sample consisted of 244 participants, 100 boys and 144 girls.

Characteristics of participants are shown in Table 1, for the total group as well as boys and girls separately. The mean age of participants was 15.8 years. Average total screen time was

Table 1. Characteristics of the study subjects.

	Total (n = 244)	Males (n = 100)	Females (n = 144)	p-value[3]
Age, years, mean (SD)	15.8 (0.3)	15.8 (0.3)	15.9 (0.3)	0.07
BMI, kg/m^2, mean (SD)	21.9 (3.1)	21.5 (2.8)	22.3 (3.2)	0.06
Normal (BMI: $20 < x \leq 25$), n (%)	193 (79.4)	83 (83.8)	110 (76.4)	
Overweight (BMI: $25 < x \leq 30$), n (%)	26 (10.7)	7 (7.1)	19 (13.2)	
Obese (BMI: $30 < x$), n (%)	5 (2.1)	1 (1.0)	4 (2.8)	
Underweight (BMI: $x \leq 20$), n (%)	19 (7.8)	8 (8.1)	11 (7.6)	
Body fat, %, mean (SD)	25.3 (9.0)	17.7 (6.6)	30.5 (6.3)	**< 0.0001**
Vigorous PA, subjective, n (%)				0.12
Less (< 4x/week)	87 (35.7)	30 (30.0)	57 (39.6)	
More (≥ 4x/week)	157 (64.3)	70 (70.0)	87 (60.4)	
Total PA[1], objective, cpm/day, mean (SD)	2039 (472)	1993 (452)	2071 (484)	0.20
Below median (N = 122; 53 males, 69 females)	1673 (241)	1650 (244)	1691 (239)	0.34
Above median (N = 122; 47 males, 75 females)	2404 (345)	2380 (289)	2420 (378)	0.53
Screen time[2], h/day, mean (SD)	5.8 (2.5)	6.2 (2.4)	5.5 (2.6)	**0.04**
Below median (N = 122; 42 males, 80 females)	3.8 (1.1)	4.1 (0.9)	3.7 (1.1)	0.12
Above median (N = 122; 58 males, 64 females)	7.7 (2.0)	7.7 (2.0)	7.7 (2.1)	0.74
Screen time categories, h/day, n (%)				0.24
$x \leq 2$	8 (3.3)	1 (1.0)	7 (4.9)	
$2 < x \leq 4$	49 (20.1)	16 (16.0)	33 (22.9)	
$4 < x \leq 6$	99 (40.6)	42 (42.0)	57 (39.6)	
$6 < x \leq 8$	45 (18.4)	20 (20.0)	25 (17.4)	
$8 < x$	43 (17.6)	21 (21.0)	22 (15.3)	
Depression				
Score, mean (SD)	17.6 (8.9)	14.4 (6.3)	19.7 (9.8)	**< 0.0001**
Symptoms (score > 30), n (%)	26 (10.7)	4 (4.0)	22 (15.3)	**< 0.005**
Anxiety				
Score, mean (SD)	6.6 (3.6)	5.3 (2.5)	7.6 (4.0)	**< 0.0001**
Symptoms (score > 12), n (%)	34 (13.9)	3 (3.0)	31 (21.5)	**< 0.0001**
Somatic complaints				
Score, mean (SD)	15.6 (6.6)	13.1 (5.2)	17.3 (7.0)	**< 0.0001**
Symptoms (score > 24), n (%)	35 (14.3)	8 (8.0)	27 (18.8)	**0.02**
Self-esteem				
Score, mean (SD)	21.3 (6.8)	22.1 (7.0)	20.7 (6.7)	0.11
Low self-esteem (score < 15), n (%)	38 (15.6)	12 (12.0)	26 (18.1)	0.20
Life satisfaction				
Score, mean (SD)	26.1 (7.1)	26.1 (7.7)	26.1 (6.6)	0.99
Life dissatisfaction (score ≤ 20), n (%)	48 (19.7)	24 (24.0)	24 (16.7)	0.16
Maternal education				
University education	146 (59.8)	66 (66.0)	80 (55.6)	0.10
No university education	98 (40.2)	34 (34.0)	64 (44.4)	

BMI = body mass index, PA = physical activity, SD = standard deviation

[1]mean of total vector magnitude activity/wear time; total group median = 2039 cpm/day

[2]weighted average for the week (5 weekdays and 2 weekend-days); total group median = 5.3 h/day

[3]p-value < 0.05, for differences between sexes, was considered statistically significant

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5.8 ± 2.5 h/day (median 5.3 h/day), significantly greater for boys than girls (p = 0.04). Spending between 4 and 6 h/day in screen based activities was most common, for both sexes (around 40%), and only a very small minority reported screen time below 2 h/day. Almost two-thirds reported engaging in vigorous physical activity ≥ 4 times a week. Prevalence of symptoms of depression, anxiety, and somatic complaints was significantly higher among girls (15–22%) than boys (3–8%). Low self-esteem was reported by 16% and life dissatisfaction by 20% of participants. Average value for BMI was 21.9 kg/m^2, the prevalence of being overweight (BMI between 25 and 30 kg/m^2) was approximately 11% and around 2% of the group were obese (BMI ≥ 30 kg/m^2). Average body fat percentage was 25.3%, significantly higher for girls than boys (p < 0.0001).

Regression analysis

Tables 2 and 3 show the associations of screen time, self-reported vigorous physical activity and objectively measured physical activity with self-reported measures of mental health status, i.e. symptoms of anxiety, depression, and somatic complaints (Table 2) and self-esteem and life dissatisfaction (Table 3). After adjustment for potential confounders (sex, maternal education and percentage body fat), reporting less screen time was associated with a significantly lower risk of reporting symptoms of depression (RR = 0.33, 95% CI = 0.14–0.76), anxiety (RR = 0.44, 95% CI = 0.23–0.84), low self-esteem (RR = 0.31, 95% CI = 0.15–0.66) and life dissatisfaction (RR = 0.38, 95% CI = 0.20–0.72). Self-reported vigorous physical activity showed similar associations (Tables 2 and 3), but objectively measured physical activity was not associated with any of the mental health outcomes (despite being positively correlated to self-reported vigorous physical activity (see S1 and S2 Tables). The relative risk of reporting somatic complaints was marginally lower for those reporting lower screen time (RR = 0.55, 95% CI = 0.29–1.03) but this outcome was unrelated to both self-reported vigorous physical activity and objectively measured physical activity (Table 2).

Table 2. Associations of screen time and physical activity with symptoms of depression, anxiety and somatic complaints.

	Depressive symptoms		Anxiety symptoms		Somatic complaints	
	Yes, N (%[a])	RR[b] (95% CI)	Yes, N (%[a])	RR[b] (95% CI)	Yes, N (%[a])	RR[b] (95% CI)
Total screen time[c]						
Below median	7 (5.7)	**0.33 (0.14, 0.76)*****	12 (9.8)	**0.44 (0.23, 0.84)****	13 (10.7)	0.55 (0.29, 1.03)
Above median	19 (15.6)	Ref.	22 (18.0)	Ref.	22 (18.0)	Ref.
Vigorous PA, subjective						
Less (< 4x/week)	17 (19.5)	Ref.	22 (25.3)	Ref.	14 (16.1)	Ref.
More (≥ 4x/week)	9 (5.7)	**0.31 (0.14, 0.71)** ***	12 (7.6)	**0.35 (0.18, 0.67)** ****	21 (13.4)	0.93 (0.50, 1.76)
Total PA, objective[d]						
Below median	11 (9.0)	Ref.	14 (11.5)	Ref.	17 (13.9)	Ref.
sAbove median	15 (12.3)	1.24 (0.60, 2.56)	20 (16.4)	1.38 (0.74, 2.54)	18 (14.8)	0.99 (0.53, 1.85)

RR = relative risk, CI = confidence interval, PA = physical activity

[a]Percent of the subgroup

[b]Adjusted for sex, body fat percentage and maternal education

[c]Median value for total screen time = 5.3 h/day

[d]Median value for total PA = 1975 cpm/day

**p < 0.05

***p < 0.01

****p <0.001

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Table 3. Associations of screen time and physical activity with low self-esteem and life dissatisfaction.

	Low self-esteem		Life dissatisfaction	
	Yes, N (%[a])	RR[b] (95% CI)	Yes, N (%[a])	RR[b] (95% CI)
Total screen time[c]				
Below median	9 (7.4)	**0.31 (0.15, 0.66)** ***	12 (9.8)	**0.38 (0.20, 0.72)** ***
Above median	29 (23.8)	Ref.	36 (29.5)	Ref.
Vigorous PA, subjective				
Less (<4x/week)	21 (24.1)	Ref.	25 (28.7)	Ref.
More (≥4x/week)	17 (10.8)	**0.48 (0.26, 0.90)** **	23 (14.7)	**0.58 (0.35, 0.96)** **
Total PA, objective[d]				
Below median	23 (18.9)	Ref.	27 (22.1)	Ref.
Above median	15 (12.3)	0.64 (0.35, 1.19)	21 (17.2)	0.84 (0.51, 1.39)

RR = relative risk, CI = confidence interval, PA = physical activity

[a]Percent of the subgroup

[b]Adjusted for sex, body fat percentage and maternal education

[c]Median value for total screen time = 5.3 h/day

[d]Median value for total PA = 1975 cpm/day

**$p < 0.05$

***$p < 0.005$

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Dividing the participants into four subgroups based on both self-reported screen time and vigorous physical activity (Table 4) revealed that those reporting both less screen time and more frequent vigorous physical activity had a significantly lower risk of reporting symptoms of depression (RR = 0.06, 95% CI = 0.01–0.41), anxiety (RR = 0.16, 95% CI = 0.06–0.45), low self-esteem (RR = 0.16, 95% CI = 0.05–0.48) and life dissatisfaction (RR = 0.30, 95% CI = 0.15–0.61) compared with those reporting both greater screen time and less frequent vigorous physical activity, after adjusting for sex, maternal education and percentage body fat. A significantly lower risk of reporting life dissatisfaction was also found for those reporting having both less

Table 4. Interactive effects of screen time and vigorous PA on mental health.

VPA (x/wk)	Screen time (h/day)	N (subgroup)	Depressive Symptoms		Anxiety Symptoms		Somatic Complaints		Life dissatisfaction		Low Self-Esteem	
			Yes,N (%[a])	RR[b] (95% CI)	Yes, N (%[a])	RR[b] (95% CI)	Yes, N (%[a])	RR[b] (95% CI)	Yes, N (%[a])	RR[b] (95% CI)	Yes, N (%[a])	RR[b] (95% CI)
<4	> 5.3	54	11 (20.4)	Ref.	14 (25.9)	Ref.	8 (14.8)	Ref.	22 (40.7)	Ref.	16 (29.6)	Ref.
<4	< 5.3	33	6 (18.2)	0.87 (0.38, 2.00)	8 (24.2)	0.89 (0.44, 1.80)	6 (18.2)	1.25 (0.49, 3.19)	3 (9.1)	**0.26 (0.08, 0.80)***	5 (15.2)	0.53 (0.21, 1.30)
≥4	> 5.3	68	8 (11.8)	0.74 (0.30, 1.84)	8 (11.8)	0.65 (0.29, 1.44)	14 (20.6)	1.78 (0.79, 4.01)	14 (20.6)	0.55 (0.30, 1.00)	13 (19.1)	0.73 (0.37, 1.45)
≥4	< 5.3	89	1 (1.1)	**0.06 (0.01, 0.41)****	4 (4.5)	**0.16 (0.06, 0.45)*****	7 (7.9)	0.57 (0.22, 1.44)	9 (10.1)	**0.30 (0.15, 0.61)****	4 (4.5)	**0.16 (0.05, 0.48)****

PA = physical activity, VPA = vigorous physical activity, RR = relative risk, CI = confidence interval

[a]Percent of the subgroup

[b]Adjusted for sex, body fat percentage and maternal education

*$p<0.05$

**$p<0.005$

***$p<0.0005$

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screen time and less frequent vigorous physical activity compared with those reporting more screen time and less frequent vigorous physical activity. No associations were observed between the combined screen time-vigorous physical activity subgroups and their reported somatic complaints.

Discussion

In this study, we observed that reports of less screen time and more frequent vigorous physical activity were each associated with a lower risk of reporting symptoms of depression, anxiety, low self-esteem, and life dissatisfaction. Furthermore, those who reported a combination of engaging in less screen time and more frequent vigorous physical activity had the lowest risk of reporting negative mental health symptoms, suggesting a synergistic relationship between the two behaviors on mental health outcomes.

We found that those who reported engaging in less than the median screen time of 5.3 h/day had a reduced risk of reporting symptoms of negative mental health compared with those reporting screen time greater than 5.3 h/day. This finding was relatively consistent across mental health outcomes, with reductions in relative risk ranging from 56–69% for reports of symptoms of depression and anxiety, low self-esteem, and life dissatistifaction. These results are in line with recent reviews reporting that increased participation in screen based activities in leisure time may be linked to poorer mental health among adolescents, including depressive symptomatology and psychological distress, decreased perceptions of self-worth, and lower perceived quality of life and self-esteem [21,22,37]. Our results support most of the previous findings in other adolescent age groups, of studies with similar design [23–25]. In a study by Trinh et al. [23] on Canadian youth (age 13–18 years, mean age 15.8 years), higher screen time was associated with symptoms of psychological distress (including anxiety) and depression, and lower self-esteem. Similarly, studies on Chinese college students found screen time to negatively impact reported symptoms of depression [24,25] and anxiety [25]. Consistent with our findings, a negative linear relationship between screen time and quality of life has been reported [48]. A study on Iranian youth [49] found, however, no association between screen time and life satisfaction. These prior studies define high screen time as greater than 2 h/day according to international recommendations. In the current study, however, the group median for total daily screen time was used as the cut-point since very few participants (n = 8 or 3.3%) averaged $\leq$ 2 h/day.

Participating in vigorous physical activity at least 4 times/week was associated with reduced risk (42–69%) of reporting the various mental health problems examined in our study (excluding somatic complaints). Previous findings on the impact of vigorous physical activity on mental health in youth have been mixed, perhaps due to variations in participant age and methodologies to evaluate physical activity and mental health outcomes [50]. In a study on Chinese college students [25], depression and anxiety were not found to be associated with frequency of physical activity alone, but were negatively associated with a measure that also accounted for intensity and duration of the activity. Further, self-reported vigorous or moderate-to-vigorous physical activity in adolescents was not found to be associated with symptoms of depression and anxiety [23,24] or low self-esteem [23]. Life satisfaction was, however, associated with self-reported physical activity in Iranian youth [49], and quality of life was related to self-reported weekly frequency of moderate-to-vigorous physical activity in the study by Iannotti et al. [48].

Those who reported a combination of less screen time and more frequent vigorous physical activity had the lowest risk of reporting negative mental health symptoms. This finding, for adolescents in their mid-teens, agrees with the results of the few prior studies on younger [26–

28] and older adolescents [24,25]. The risk reduction for the less screen time-more frequent vigorous physical activity group, compared with the more screen time-less frequent vigorous physical activity group, was very substantial for symptoms of depression and anxiety (84–94%) and greater than that observed in the studies mentioned above for other age-groups of adolescents. The less screen time-more frequent vigorous physical activity group was also least likely to report low self-esteem (84% reduced risk), which supports prior findings by Trinh et al. [23]. Significantly lower risk of reporting life dissatisfaction was found in our study for those with less screen time, independent of the frequency of vigorous physical activity. In comparison, an interactive analysis conducted by Matin et al. [49] showed that the joint effect of low screen time and high physical activity was most strongly associated with life satisfaction in Iranian youth.

We observed a positive correlation between self-reported vigorous physical activity and objectively measured total activity (see S1 and S2 Tables). Despite this correlation, the objectively measured physical activity was surprisingly not associated with the mental health outcomes in our study. It is possible that the intensity of the activity must be above certain threshold to provide mental health benefits, although prior research has been inconclusive in this regard [51,52]. A recent review reported indications of beneficial effects of objectively measured total physical activity on mental health among adolescents [50]. However, it was concluded that relationships were more consistent and robust for higher versus lower intensity physical activity. Using self-reported physical activity, Mekary et al. [53] found that substituting 60 minutes/day of brisk/very brisk walking for television watching was more protective against depression than the same amount of average-paced walking. Their results also indicated that walking at an easy pace was not protective against depression. Conversely, in a review of exercise interventions to reduce or prevent anxiety or depression in youth, Larun et al. [54] concluded that exercise intensity had little impact on depression and anxiety scores in the general population of children and adolescents. Unfortunately, we were unable to obtain objective measures of vigorous activity since there are currently no agreed upon cut-points for wrist-worn accelerometers for youth.

It is a very important public health issue to prevent mental health problems in adolescents. As previously mentioned, depression and anxiety are not only strong predictors of negative health and psychosocial outcomes in adolescence but may also put individuals at a significantly increased risk of these conditions in adulthood [14]. Our findings suggest that limiting screen time and increasing participation in vigorous physical activity may separately, but especially in combination, have beneficial effects on mental health in adolescents. Although more detailed research is needed to confirm causality, these results support that official guidelines should not only include recommendations for promoting physical activity but also for limiting sedentary, screen based activities, to optimize mental health in youth.

Physical activity may have positive effects on mental health in adolescents via physiological, biochemical and psychological mechanisms [55]. It may improve mental health by having beneficial effects on body composition [40,42] and levels of mood-regulating neurotransmitters in the brain [56]. Regular physical activity may also promote mental health by improving self-esteem, self-efficacy and cognitive and psychological function, reducing distress [20,55], and increasing social interaction and support [55,57,58]. Increased screen time has been associated with poorer mental health among adolescents [21,22,37], potential mechanisms underlying such associations include: 1) negative effects of sedentary behavior on body composition [37]; 2) psychosocial and psychological effects, as media use via the internet provides adolescents with diverse opportunities for comparing themselves with others. Discrepancies between these publicized ideals and the self could cause social pressure and mental health problems [59]; 3) screen time may negatively affect sleep [60], which might have unfavorable effects on mental health [5]; 4) screen time may displace physical activity [61], resulting in loss of beneficial effects of exercise on mental health.

Our results contribute to the limited knowledge base of the interactive effects of screen time and physical activity on mental health among adolescents in their mid-teens, and this is the first study on this topic among Icelandic adolescents. A major strength of the study is the number and diversity of the mental health outcomes being evaluated; the agreement of results across these outcomes adds to the value of the study findings. Another strength of our study are the objective measurements of total physical activity by accelerometers, prior studies with a comparable study design have mostly evaluated physical activity by self-report alone. Still another strength is the use of DXA-measured body fat percentage as a covariate in our statistical analyses. The participation rate in the study (79%) was also quite high and the study sample represents a relatively large portion of the total number of 15 year old Icelandic adolescents in the year of 2015 (4,254 individuals, born in 1999) [62].

The cross-sectional study design does not allow us to determine causal relationships between the study variables. Reverse causality cannot be ruled out, participants reporting mental health problems might tend to be socially isolated and spend more time in screen based activities and less time in physical activity than their peers. Longitudinal studies are needed to further clarify causality between screen time, physical activity and mental health outcomes. Another limitation of the present study is the self-report of screen time and vigorous physical activity which is subject to recall and reporting biases. Our questionnaire included separate questions for time spent on individual screen based activities (games, TV/DVD watching, web/browsing/social-media/email, and other screen usage) which were combined for the total screen time used in our analyses. While this approach can potentially provide more detailed information on screen activities, this may have resulted in an over-estimation of total screen time, as multi-tasking on different screens, such as watching TV and using a smart-phone at the same time, is quite prevalent in youth [15]. It is also important to keep in mind that the questionnaire-based assessment of mental health used here is not equivalent to clinical diagnosis. Finally, although we have no evidence to suggest that the non-participants (N = 96) differed from the general student population, we cannot rule out the possibility of selection bias. Non-participants may have differed from participants in terms of socioeconomic status, lifestyle habits—including physical activity and screen time—and/or mental health status. But since they did not consent to the study we were unable to assess these potential differences.

In summary, we found that less screen time and more frequent vigorous physical activity are both separately and interactively associated with less risk of reporting symptoms of depression, anxiety, low self-esteem and life dissatisfaction in adolescents in their mid-teens. Our results support public health recommendations that guide youth towards more active and less sedentary/screen-based lifestyle. However, further research on causal relationships between physical activity, screen time and mental health is needed, i.e. longitudinal and intervention studies.

Supporting information

S1 Table. Correlation of screen time and self-reported vigorous PA with objective PA.
(DOCX)

S2 Table. Objective PA within subgroups based on reported screen time and vigorous PA.
(DOCX)

S1 Dataset. Raw data.
(XLSX)

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Paper II

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Less screen time and more physical activity is associated with more stable sleep patterns among Icelandic adolescents

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ABSTRACT

Objectives: Emerging evidence suggests that inconsistent sleep may affect physical and psychological health. Thus, it is important to identify modifiable determinants of sleep variability. Screen time and physical activity are both thought to affect sleep, but studies of their relationship to sleep variability using objective measures are lacking. We examined cross-sectional associations between these variables in mid-teen adolescents using objectively measured sleep and activity.
Methods: Wrist-worn accelerometers were used to measure one week of sleep and activity in 315 tenth grade students (mean age 15.8y) from six Reykjavík compulsory schools. Participants reported their daily hours of screen time. Regression analysis was used to explore associations of screen time and physical activity with variability in duration, quality, and timing of sleep, adjusting for DXA-measured body fat percentage, parental education, and physical activity or screen time.
Results: Screen time, especially game playing, was associated with variability in duration, timing, and quality of sleep, most strongly with variation in bedtime. Physical activity was inversely associated with variability in duration, timing, and quality of sleep, most strongly with variation in the number of awakenings. Boys had less stable sleep patterns and higher screen time than girls, and sex-specific associations of screen time with sleep variability parameters were significant for boys only.
Conclusions: Less screen time and more physical activity were independently associated with less sleep variability among mid-teen adolescents. Our results indicate that encouraging youngsters toward an active lifestyle with limited screen use may be important to achieve more consistent sleep.

Introduction

Adequate sleep is essential for the maturation, growth, daily functioning, and health of children and adolescents[1]. Insufficient sleep duration is known to have adverse effects on the health and well-being of youngsters.[2–4] However, sleep quality and timing, and consistency of sleep patterns may also affect the restorative properties of sleep and overall health.[4,5] Thus, it is recommended that adolescents not only get an adequate amount of sleep but also maintain a consistent sleep routine.[6] Two modifiable behavioral factors that are thought to affect sleep are screen time[7] and physical activity.[8]

In adolescence, a circadian shift toward later hours[9,10] may lead to sleep deprivation, especially on schooldays.[11,12] To compensate, adolescents typically sleep longer on nonschool days, i.e. there is a tendency toward weekend shift in sleep duration.[12,13] Furthermore, research indicates that intra-individual variability in sleep is common amongst adolescents, resulting in unstable sleep patterns across the week.[4] Although the causes of adolescent sleep variability are likely complex and multifaceted, potential contributors include biological changes due to puberty and brain maturation, increased academic, extracurricular, and social demands, and reduced parental supervision.[14] Participation in screen-based activities[7] and physical activity[8] may also affect the sleep health of youngsters. In recent years, screen use has increased rapidly with advances in technology, most notably with the introduction of portable devices, such as tablets and smartphones, and only a small minority of youth limits daily screen time to the recommended maximum of 2 hours.[15–17] At the same time, physical activity levels have been declining,[18–20] and minority of adolescents meets the guidelines for activity.[20–22] Greater adolescent screen time has been linked to shorter sleep duration,

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delayed bedtime, and poorer sleep quality,[7,23,24] and greater variability in sleep duration and bedtime.[25,26] The relationship between physical activity and sleep in adolescents is more complex, but greater physical activity is generally found to have beneficial effects on sleep.[9]

Although research on the effects of sleep variability on health has been limited, emerging literature indicates that it may be just as important as the mean values of sleep parameters.[4,25] For instance, in youth, inconsistent sleep patterns have been found to correlate with poorer behavioral, cognitive, and psychological functioning, unhealthy diet, increased body weight, and less favorable body composition.[4] Therefore, it is important to determine the impact of modifiable behaviors, such as screen time and physical activity, on adolescent sleep habits. However, such studies are scarce and have relied on subjective measures of sleep and activity.[4]

The main purpose of this study was to examine the relationship between variations in objectively measured sleep quantity, quality, and timing and measures of screen time and physical activity in Icelandic adolescents.

Methods

Sample and data collection

All four hundred and eleven tenth-grade students (age 15–16 years, 47% boys and 53% girls) in six compulsory schools in metropolitan Reykjavik, Iceland, were invited to participate in this cross-sectional study, 315 (79%) of which agreed to participate. Nonparticipation was mainly due to absence from school during measurement days and lack of interest in the study. Data collection was performed between mid-April and early June of 2015, with all measurements completed within a period of 7–10 days for each individual. Participants provided information regarding their socioeconomic background, health, and lifestyle by answering a tablet-based questionnaire administered at school under the supervision of research team members. Objective measurements of free-living physical activity and sleep, weight, height, and body composition were also performed. Written informed consent was obtained from all participants and their guardians. Strict procedures were followed to ensure confidentiality. The research project was approved by the Icelandic Data Protection Authority, the National Bioethics Committee (VSNb2015020013/13.07), and the Icelandic Radiation Safety Authority.

Measures

Primary measures

Screen time. Participants were asked to report on how many hours per day on average, separately for weekdays and weekend days, they played computer games, watched TV/DVD/internet material, used the internet for web-browsing/Facebook/e-mail and participated in “other” screen use. Each item was scored on a seven-point Likert scale, with the following response options: 1 = “none,” 2 = “about ½ h,” 3 = “1 up to 2 h,” 4 = “2 up to 3 h,” 5 = “3 up to 4 h,” 6 = “4 to 5 h,” and 7 = “more than 5 h.” Average daily hours for each type of screen-based activity were computed using the midpoint for each scoring category (a value of 5.5 h was used for the highest category) and weighted averages for weekdays and weekend days. All screen-based activities were then summed for total daily screen time (h/day).

Physical activity. Free-living physical activity was objectively measured using small (3.8 cm x 3.7 cm x 1.8 cm) and lightweight (27 g) triaxial raw signal accelerometer-based Actigraph activity monitors (model GT3X+, Actigraph Inc., Pensacola Florida). Each participant was asked to continuously wear the monitor on his/her nondominant wrist for 7 consecutive days. The monitor recorded raw triaxial data (in milliG‘s) sampled at 80 samples per second (Hz). Data were later reduced to the vector magnitude of activity counts over 60 s epoch (counts per min = cpm) using Actilife 6 software (Actigraph Inc., Pensacola, FL, USA; version 6.13.0). Wear-time was detected automatically with customized programs in Matlab (The Mathworks, Natick, MA, USA; version R2013a). Data were considered valid if wear-time was ≥ 14 h from 12 midnight to 12 midnight the following day. A minimum of 3 valid school days and 1 valid nonschool day of activity was set as an inclusion criterion.[27]

Sleep. Sleep was measured using Actigraph GT3X+ accelerometers, in the same manner as described above for physical activity. Data were considered valid if wear-time was ≥ 14 h from 12 noon to 12 noon the following day. A minimum of 3 valid school nights (Sunday through Thursday nights) and 1 valid nonschool night (Friday and Saturday night and nights prior to holidays) of sleep was set as an inclusion criterion.[12] Sleep parameters for the duration, quality and timing of sleep (see Table 1) were derived for school days, nonschool days, and all valid days of the week using the well-validated Sadeh automatic sleep detection algorithm for adolescents[28], implemented in the Actilife software. Detected sleep periods were verified and manually adjusted when necessary, with the aid of participant-recorded sleep logs of bedtimes and rise times (completed as part of the actigraphy study), using the Actilife software. The individual’s standard deviation of each sleep parameter was used to convey within-subject night-to-night variability. The difference in mean values between nonschool nights and school nights was calculated for each sleep parameter to obtain the within-subject weekend shift.

Covariates

Body composition and parental education were selected as covariates, based on prior studies and our own correlation analysis. More unfavorable body composition has been linked to more screen time[29] and lower physical activity levels.[30] Parental education is an indicator of socioeconomic status, which may affect youngsters’ participation in recreational activities; higher parental education has been linked to less screen time[31] and more physical activity among adolescents.[32] Body composition and parental education have also

Table 1
Sleep parameters for analysis

Sleep parameter	Abbreviation	Definition	Unit
Total rest time	TRT	time between bed-time and rise-time	Hours or Minutes
Total sleep time	TST	sleep time during rest period	Hours or Minutes
Bedtime	BT	time of going to bed	Clock time
Rise time	RT	time of getting out of bed	Clock time
Sleep onset latency	SOL	time it takes to go from wakefulness to sleep	Minutes
Number of awakenings	NOA	number of transitions from sleep to wakefulness, during the rest period	Counts
Sleep efficiency	SLE	(total sleep time divided by total rest time) x 100	%

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been related to sleep parameters. Higher body fat has been associated with late bedtime and inadequate sleep duration[2] and abdominal obesity with nightly variability in sleep duration among adolescents.[33] Low parental education has been found to correlate with sleep problems in adolescence,[34] whereas in another study, adolescents having parents with higher educational level were found to have a shorter sleep duration.[35]

Body composition. Body mass index (BMI, kg/m^2) was calculated from standing height (m) measured to the nearest mm with a stadiometer (Seca model 217, Seca Ltd., Birmingham, UK) and body weight (kg) measured to the nearest 0.1 kg on a calibrated scale (Seca model 813, Seca Ltd., Birmingham, UK). Measurements were recorded at individual schools, with participants wearing light clothing. Body fat percentage was derived from whole-body dual-energy X-ray absorptiometry (DXA) scans performed on a GE Lunar bone densitometer (GE Healthcare, Madison, Wisconsin USA) by a certified radiologist at the Icelandic Heart Association in Kopavogur, Iceland.

Parental education. Participants reported the educational levels of their parents by choosing from the following options: 1 = "elementary degree," 2 = "secondary degree," 3 = "trade school degree," 4 = "university degree," 5 = "other," 6 = "do not know," 7 = "do not want to answer." These options were used to form a new binary variable with the following categories: 1 = "at least one parent with a university degree" and 0 = "neither parent with a university degree."

Statistical analysis

Customized programs written with Matlab software (The Mathworks, Natick, MA, USA; version R2013a) were used to compile daily and weekly averages of objectively measured physical activity and sleep. Descriptive summaries are presented as means and standard deviations for continuous variables, and as frequencies and percentages for categorical variables, for all days, school days, and nonschool days. Sex differences were evaluated by unpaired *t*-tests for continuous variables and chi-square tests for categorical variables. Paired *t*-tests were used to compare measures on school days and nonschool days.

Linear models were used to explore potential associations of average daily screen time and physical activity with mean values of sleep parameters across the entire week. The main regression analysis of the study was then carried out to evaluate the association of average daily screen time and physical activity with nightly variations and weekend shifts in sleep parameters. We started with univariate linear regression analyses and then went on to multivariate linear models to explore a) the effects of screen time, both total screen time and time spent in subtypes of screen use, on nightly variations and weekend shifts in sleep parameters, adjusting for physical activity, body fat percentage, and parental education, and b) the effects of physical activity on nightly variations and weekend shifts in sleep parameters, adjusting for screen time, body fat percentage, and parental education. In additional analyses, models were further adjusted for total sleep time and daylength. Analyses were performed both for the total group and the sexes separately, as we observed a sex difference in behavioral variables (screen time and physical activity, see Table 2) and sleep parameters (see Table 3), and because sex-specific data is lacking from the literature. Significant differences or relations were accepted at $\alpha < 0.05$. Statistical analyses were performed using SAS statistical software, version 9.4 (SAS Institute Inc., Cary, NC; www.sas.com).

Results

Characteristics of participants

A total of 247 participants, 103 boys and 144 girls, had complete data according to the inclusion criteria. The characteristics of the participants are shown in Table 2. The average total screen time over the entire week was 5.6 ± 2.3 h/day, around 40 min longer for boys than girls ($p = 0.03$). Screen time was higher on nonschool days than

Table 2
Characteristics of the study participants-anthropometric and socioeconomic measures, screen time, and physical activity

	All (n=247)	Boys (n=103)	Girls (n=144)	*p*-value[c]
Age, years, mean (SD)	15.8 (0.3)	15.8 (0.3)	15.9 (0.3)	0.07
BMI, kg/m^2, mean (SD)	21.9 (3.0)	21.5 (2.8)	22.2 (3.2)	0.10
Body fat, %, mean (SD)	25.0 (8.8)	17.6 (6.5)	30.3 (6.0)	< **0.0001**
Parents with university degree, N (%)	171 (69.2)	73 (70.9)	98 (68.1)	0.64
Screen time[a], h/day, mean (SD)				
All days				
Total	5.6 (2.3)	6.0 (2.3)	5.3 (2.3)	**0.03**
Game playing	1.0 (1.3)	1.9 (1.3)	0.3 (0.7)	< **0.0001**
Internet: Facebook, browsing, mail	2.2 (1.3)	1.7 (0.9)	2.6 (1.4)	< **0.0001**
Watching TV/DVD/Internet	1.7 (0.9)	1.6 (0.9)	1.7 (0.9)	0.18
Other	0.7 (0.8)	0.8 (0.8)	0.7 (0.9)	0.49
School days	5.3 (2.3)	5.6 (2.2)	5.0 (2.4)	0.06
Nonschool days	6.4 (2.7)*	6.9 (2.8)*	6.0 (2.7)*	**0.01**
Physical activity[b], cpm/day, mean (SD)				
All days	2037 (471)	1993 (445)	2069 (488)	0.21
School days	2206 (510)	2205 (484)	2207 (529)	0.97
NonSchool days	1773 (540)*	1648 (535)*	1863 (528)*	**0.002**
Accelerometer compliance				
Wear time, h/day, mean (SD)	23.81 (0.36)	23.74 (0.41)	23.86 (0.31)	**0.01**
Valid days, n, mean (SD)	6.61 (0.62)	6.50 (0.63)	6.69 (0.61)	**0.02**

BMI = body mass index; SD = standard deviation; cpm = counts per minute; n/N = number.
[a] Range (h/day): 0.9-11.9 (all days), 0.5-11.5 (school days), 1.0-14.0 (nonschool days); 10th percentile (h/day, all days): 2.9 (all), 3.5 (boys), 2.5 (girls); 90th percentile (h/day, all days): 9.0 (all), 9.3 (boys), 8.5 (girls).
[b] Mean of total vector magnitude activity/wear time; Range (cpm/day): 969-3366 (all days), 1099-3677 (school days), 563-3828 (nonschool days); 10th percentile (cpm/day, all days): 1425 (all), 1409 (boys), 1516 (girls); 90th percentile (cpm/day, all days): 2671 (all), 2569 (boys), 2760 (girls).
[c] *p*-values for tests of between sex differences, significant values are bolded.
* Indicates difference between school days and nonschool days ($p < 0.0001$).

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Table 3
Sleep parameters mean value and night-to-night variability

	All (n=247)	Boys (n=103)	Girls (n=144)	*p*-value[b]
Sleep parameters				
Sleep/rest duration				
Total sleep time, h/night, mean (SD)				
All days	6.6 (0.7)	6.6 (0.7)	6.6 (0.6)	0.43
School days	6.2 (0.7)	6.2 (0.8)	6.2 (0.7)	0.92
Nonschool days	7.3 (1.1)**	7.2 (1.3)**	7.4 (1.0)**	0.19
Total rest time, h/night, mean (SD)				
All days	7.5 (0.7)	7.5 (0.7)	7.6 (0.7)	0.60
School days	7.1 (0.8)	7.1 (0.9)	7.1 (0.8)	0.95
Nonschool days	8.4 (1.3)**	8.3 (1.5)**	8.4 (1.1)**	0.43
Sleep quality				
Sleep efficiency, %, mean (SD)				
All days	87.8 (4.2)	87.6 (3.9)	87.9 (4.5)	0.58
School days	88.0 (4.5)	88.0 (4.6)	88.0 (4.5)	0.92
Nonschool days	87.5 (4.8)	86.9 (4.2)*	87.9 (5.2)	0.09
Sleep onset latency, min, mean (SD)				
All days	1.6 (0.8)	1.6 (0.8)	1.6 (0.7)	0.83
School days	1.6 (1.0)	1.6 (1.0)	1.6 (1.0)	0.91
Nonschool days	1.6 (1.2)	1.6 (1.3)	1.6 (1.2)	0.98
Number of awakenings, N, mean (SD)				
All days	20.0 (5.6)	20.0 (5.5)	19.9 (5.7)	0.92
School days	18.5 (5.6)	18.2 (5.7)	18.6 (5.4)	0.56
Nonschool days	22.8 (8.0)**	23.6 (8.3)**	22.3 (7.8)**	0.21
Sleep timing				
Bedtime, o'clock, mean (SD (min))				
All days	00:46 (53)	00:55 (51)	00:40 (53)	**0.047**
School days	00:20 (53)	00:24 (55)	00:17 (51)	0.29
Nonschool days	01:40 (75)**	02:00 (84)**	01:26 (64)**	**0.0012**
Rise time, o'clock, mean (SD (min))				
All days	08:21 (43)	08:30 (47)	08:15 (40)	**0.008**
School days	07:26 (36)	07:31 (41)	07:22 (31)	0.08
Nonschool days	10:10 (82)**	10:31 (85)**	09:55 (76)**	**0.0005**
Night-to-night variability in sleep parameters[a]				
Total sleep time, min, mean (SD)	75.8 (37.2)	81.8 (44.5)	71.6 (30.5)	**0.04**
Total rest time, min, mean (SD)	85.6 (42.0)	94.5 (48.6)	79.2 (35.5)	**0.008**
Sleep efficiency, %, mean (SD)	4.0 (1.6)	4.3 (1.7)	3.8 (1.6)	**0.02**
Sleep onset latency, min, mean (SD)	1.7 (0.7)	1.6 (0.6)	1.7 (0.7)	0.27
Number of awakenings, N, mean (SD)	6.2 (2.6)	6.8 (2.8)	5.6 (2.3)	**0.001**
Bedtime, min, mean (SD)	67.7 (39.5)	77.9 (52.0)	60.4 (25.5)	**0.002**
Rise time, min, mean (SD)	99.3 (40.4)	107.4 (45.0)	93.5 (35.8)	**0.01**

Difference between school days and nonschool days is marked *$p < 0.05$ and **$p < 0.0001$.
SD = standard deviation; h = hours; min = minutes; n/N = number.
[a] Across the entire week.
[b] *p*-values for tests of between sex differences, significant values are bolded.

school days ($p < 0.0001$); the increase was, on average, 60 min for girls and 78 min for boys, and boys reported almost 1 h higher screen time on nonschool days than girls ($p = 0.01$). Girls spent most of their screen time on the internet, whereas boys preferred game playing. As we have previously reported,[20] boys and girls had similar physical activity over the entire week and on school days, but girls averaged about 13% higher activity than boys on nonschool days ($p = 0.002$). Participants of both sexes recorded higher activity on school days (+33.8% for boys and +18.5% for girls, both $p < 0.0001$).

Mean values and night-to-night variability in sleep parameters are summarized in Table 3. Mean values of sleep quality and duration did not differ between the sexes. The average sleep and rest durations across the week (6.6 ± 0.7 h/night and 7.5 ± 0.7 h/night, respectively) were below the recommended minimum of 8 h/night, and the number of awakenings was on average 20/night. Boys had, on average, 15 min later bed and rise times than girls across the week, and this difference was around 35 min on nonschool days (all $p < 0.05$). Average night-to-night variations in sleep time, rest time, bedtime, and rise time all exceeded 1 h, with rise time having the highest variability around 100 min. Variability in the number of awakenings was about 6/night. Variations in all sleep parameters, except sleep onset latency, were significantly greater for boys than girls (*p*-values from 0.001 to 0.04). As we have previously reported,[12] there was around 1 h weekend shift toward longer sleep and rest durations, but a higher number of awakenings indicated lower sleep quality on weekend nights (all $p < 0.0001$). Similarly, bed and rise times shifted to later hours on weekends (both $p < 0.0001$), more so for boys, who went to bed 96 min later and rose 3 h later on nonschool nights, while girls went to bed 69 min later and rose about 2.5 h later (differences between sexes both $p < 0.005$). Participants with incomplete data on screen time and physical activity did not differ in sleep parameters from those with complete data.

Screen time and physical activity versus sleep parameters

Screen time was significantly associated with later bedtime ($p = 0.03$) and less rest ($p = 0.02$) and sleep ($p = 0.047$) durations, but not with rise time or sleep quality markers, in linear models adjusted for physical activity, body fat percentage and parental education. With each additional hour of screen time, rest and sleep durations were reduced by 2.8 min and 2.2 min, respectively, and there was a 0.12 min delay in bedtime.

Physical activity was inversely associated with the number of awakenings ($p = 0.0002$), rise time ($p = 0.0003$), and sleep and rest durations (both $p < 0.0001$) in linear models, adjusted for screen time, body fat percentage, and parental education. With each

Table 4
Linear relationships between screen time and night-to-night variations in sleep parameters[a]

	All (N=247)			Boys (N=103)			Girls (N=144)		
	β	SE	p[b]	β	SE	p[b]	β	SE	p[b]
Sleep duration									
SD_Total sleep time (min)									
Unadjusted	3.813	1.010	**<0.001**	6.300	1.865	**0.001**	1.683	1.109	0.13
Adjusted[c]	3.566	1.074	**0.001**	7.416	2.041	**<0.001**	0.795	1.207	0.51
SD_Total rest time (min)									
Unadjusted	4.425	1.138	**<0.001**	7.395	2.019	**<0.001**	1.719	1.294	0.19
Adjusted[c]	4.012	1.208	**0.001**	8.203	2.216	**<0.001**	0.522	1.395	0.71
Sleep quality									
SD_Sleep efficiency (%)									
Unadjusted	-9.1×10^{-3}	0.045	0.84	-0.024	0.074	0.75	-0.024	0.057	0.68
Adjusted[c]	0.012	0.048	0.79	-0.018	0.081	0.82	0.003	0.061	0.97
SD_Sleep onset latency (min)									
Unadjusted	0.009	0.019	0.65	0.030	0.027	0.27	-6.6×10^{-4}	0.027	0.98
Adjusted[c]	0.008	0.021	0.72	0.045	0.030	0.13	-0.010	0.030	0.74
SD_Number of awakenings (n)									
Unadjusted	0.129	0.071	0.07	0.254	0.120	**0.04**	-0.010	0.084	0.90
Adjusted[c]	0.069	0.073	0.34	0.196	0.128	0.13	-0.073	0.088	0.41
Sleep timing									
SD_Bedtime (min)									
Unadjusted	4.020	1.070	**<0.001**	6.160	2.210	**0.007**	1.760	0.913	0.06
Adjusted[c]	4.469	1.135	**<0.001**	7.795	2.400	**0.002**	1.478	1.011	0.15
SD_Rise time (min)									
Unadjusted	3.270	1.110	**0.003**	4.690	1.930	**0.02**	1.670	1.310	0.20
Adjusted[c]	2.453	1.149	**0.03**	5.573	2.086	**0.009**	0.151	1.403	0.91

SD = standard deviation; β = unstandardized regression coefficient; SE = standard error; min = minutes; n/N = number.
[a] Screen time (h/day) and night-to-night variations (as SDs) in sleep parameters for the entire week.
[b] *p*-value < 0.05 (bolded) was considered to show statistically significant relationship between screen time and outcome variables.
[c] Adjusted for physical activity, body fat percentage, and parental education.

additional 100 cpm/day of physical activity (ca. 5% of the average daily activity), there was a reduction in rest and sleep durations of 3.1 min and 2.5 min, respectively, as well as 0.3 fewer awakenings and 0.15 min earlier rise time.

Screen time and night-to-night variation in sleep parameters

The results of the linear regression analyses between screen time and night-to-night variations in sleep parameters are shown in Table 4. Total screen time was significantly related to night-to-night variations in total sleep time, total rest time, bedtime, and rise time (all $p < 0.005$). Significance persisted even after adjusting for body fat percentage, parental education, and physical activity (*p*-values from 0.0001 to 0.03). Standardized betas (see Additional File 1: Table S1) demonstrated that screen time was most strongly associated with variations in bedtime (0.254), followed by variability in total sleep (0.216) and rest times (0.215). Further adjustment for total sleep time and daylength did not meaningfully change the results of these analyses or any other regression analyses in the study. When regressions were performed separately by sex, the associations only remained significant for boys. With each additional hour in screen time, the nightly variation in rest and sleep duration of boys increased by 8.2 min and 7.4 min, respectively, and their nightly variation in bed and rise times increased by 7.8 min and 5.6 min, respectively. Boys in the 90th percentile of screen time, as compared to boys in the 10th percentile, had 43 min higher nightly variability in sleep duration, and their variability in bed and rise times was 46 min and 32 min higher, respectively. We did not observe significant associations between total screen time and variations in sleep quality parameters.

In analyses for subtypes of screen use (see Additional File 2: Table S2), game playing was associated with variability in all of the sleep parameters studied (*p*-values from <0.0001 to 0.04), except for that in sleep onset latency. Watching TV/DVD/internet material was associated with variability in rest and sleep durations (both $p < 0.005$), but spending time on the internet for web-browsing/Facebook/e-mail was associated with less variability in sleep efficiency ($p = 0.04$). When subtype regressions were stratified by sex, associations remained significant for boys but not girls (although the association for variability in sleep efficiency became nonsignificant for both sexes). In addition, we observed significant associations between internet use and variability in rest and sleep durations for boys (both $p = 0.03$), but not for girls or the total group.

Physical activity and night-to-night variation in sleep parameters

Results of the linear regression analyses between physical activity and night-to-night variations in sleep parameters are shown in Table 5. Physical activity was inversely related to night-to-night variations in the number of awakenings ($p < 0.0001$) and rise time ($p = 0.002$), even after adjusting for body fat percentage, parental education, and screen time ($p = 0.0001$ and 0.013, respectively). The association was stronger for variability in the number of awakenings than in rise time according to standardized beta values (−0.251 vs. −0.161, see Additional File 1: Table S1). When the analyses were performed for each sex separately, variation in the number of awakenings remained significantly associated with physical activity for both sexes, but variability in rise time was only significant for girls. With each additional 100 cpm/day in physical activity, the variability in the number of awakenings decreased by 0.14 and the variability in rise time decreased by 1.4 min (total group). Participants in the 90th percentile of physical activity, as compared to participants in the 10th percentile, had reduced variability in the number of awakenings of 1.7 and decreased variability in rise time of 17 min. We did not observe significant associations between physical activity and night-to-night variations in total sleep or rest times, sleep efficiency, sleep onset latency, or bedtime.

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Table 5
Linear relationships between physical activity and night-to-night variations in sleep parameters[a]

	All (N=247)			Boys (N=103)			Girls (N=144)		
	β	SE	p[b]	B	SE	p[b]	β	SE	p[b]
Sleep duration									
SD_Total sleep time (min)									
Unadjusted	-0.008	0.005	0.13	-0.006	0.010	0.58	-0.008	0.005	0.15
Adjusted[c]	-0.003	0.005	0.56	0.0038	0.010	0.71	-0.005	0.005	0.31
SD_Total rest time (min)									
Unadjusted	-0.012	0.006	**0.04**	-0.012	0.011	0.27	-0.010	0.006	0.10
Adjusted[c]	-0.007	0.006	0.24	-0.0015	0.011	0.89	-0.008	0.006	0.22
Sleep quality									
SD_Sleep efficiency (%)									
Unadjusted	$2.2x10^{-4}$	$2.2x10^{-4}$	0.32	$2.3x10^{-4}$	$3.7x10^{-4}$	0.54	$5.5x10^{-4}$	$2.6x10^{-4}$	**0.04**
Adjusted[c]	$1.8x10^{-4}$	$2.2x10^{-4}$	0.42	$-2.5x10^{-4}$	$4.0x10^{-4}$	0.53	$5.1x10^{-4}$	$2.7x10^{-4}$	0.06
SD_Sleep onset latency (min)									
Unadjusted	$1.6x10^{-5}$	$9.5x10^{-5}$	0.87	$1.7x10^{-4}$	$1.4x10^{-4}$	0.22	$9.0x10^{-5}$	$1.3x10^{-4}$	0.48
Adjusted[c]	$3.9x10^{-5}$	$9.8x10^{-5}$	0.69	$2.8x10^{-4}$	$1.5x10^{-4}$	0.06	$-8.5x10^{-5}$	$1.3x10^{-4}$	0.53
SD_Number of awakenings (n)									
Unadjusted	$-1.4x10^{-3}$	$3.3x10^{-4}$	**<0.001**	-0.002	$5.9x10^{-4}$	**0.003**	-0.001	$3.8x10^{-4}$	**0.006**
Adjusted[c]	$-1.4x10^{-3}$	$3.5x10^{-4}$	**<0.001**	-0.002	$6.3x10^{-4}$	**0.015**	-0.001	$3.9x10^{-4}$	**0.006**
Sleep timing									
SD_Bedtime (min)									
Unadjusted	$4.3x10^{-4}$	0.005	0.94	0.007	0.012	0.55	-0.001	0.004	0.80
Adjusted[c]	0.006	0.005	0.30	0.019	0.012	0.11	0.001	0.004	0.82
SD_Rise time (min)									
Unadjusted	-0.017	0.005	**0.002**	-0.015	0.010	0.14	-0.016	0.006	**0.008**
Adjusted[c]	-0.014	0.005	**0.013**	-0.010	0.010	0.32	-0.015	0.006	**0.016**

SD = standard deviation; β = unstandardized regression coefficient; SE = standard error; min = minutes; n/N = number.
[a] Physical activity (counts/min/day) and night-to-night variations (as SDs) in sleep parameters for the entire week.
[b] p-value < 0.05 (bolded) was considered to show statistically significant relationship between physical activity and outcome variables.
[c] Adjusted for screen time, body fat percentage and parental education.

Screen time and physical activity versus a weekend shift in sleep parameters

Average total screen time was associated with a weekend shift in bed and rise times after adjusting for physical activity, body fat percentage and parental education (Table 6; $p = 0.007$ and 0.03, respectively), with the shift in bedtime having the stronger association according to standardized beta values (0.174 vs. 0.140). Game playing was the only subtype of screen use significantly associated with a weekend shift in bed and rise times (Additional File 3: Table S3; $p = 0.0002$ and $p = 0.002$, respectively). When performed separately by sex, these associations were only significant for boys (all $p < 0.05$). With each additional hour in screen time, the weekend shift in bed and rise times of boys increased by 8.8 min and 8.6 min, respectively. Both these weekend shifts were around 50 min greater for boys in the 90th versus the 10th percentile of screen time.

Physical activity was negatively associated with a weekend shift in sleep time, rest time, and the number of awakenings (all $p < 0.05$) after adjusting for screen time, body fat percentage, and parental education, with all relationships showing a similar strength of

Table 6
Linear relationships between weekend shifts in sleep parameters and screen time/physical activity

	β	SE	p[c]
Screen time (h/day)[a]			
TST NSchD – SchD (min)	-0.024	0.037	0.51
TRT NSchD – SchD (min)	-1.92	2.60	0.46
BT NSchD – SchD (min)	4.90 (boys: 8.78; girls: 2.16)	1.87 (boys: 3.74; girls: 1.87)	**0.007 (boys: 0.02**; girls: 0.24)
RT NSchD – SchD (min)	4.90 (boys: 8.64; girls: 1.37)	2.30 (boys: 3.89; girls: 2.88)	**0.03 (boys: 0.03**; girls: 0.64)
NOA NSchD – SchD (N)	-0.09	0.20	0.64
SLE NSchD – SchD (%)	$-3.7x10^{-4}$	0.12	1.00
SOL NSchD – SchD (min)	0.07	0.04	0.12
Physical activity (cpm/day)[b]			
TST NSchD – SchD (min)	-0.023 (boys: $-7.2x10^{-4}$; girls: $-2.5 x10^{-4}$)	0.011 (boys: $3.5x10^{-4}$; girls: $1.9 x10^{-4}$)	**0.03 (boys: 0.04**; girls: 0.18)
TRT NSchD – SchD (min)	-0.027 (boys: -0.045; girls: -0.019)	0.012 (boys: 0.025; girls: 0.013)	**0.03** (boys: 0.08; girls: 0.15)
BT NSchD – SchD (min)	$6.9x10^{-3}$	$8.6x10^{-3}$	0.42
RT NSchD – SchD (min)	-0.019	0.011	0.09
NOA NSchD – SchD (N)	$-2.0x10^{-3}$ (boys: $-1.1x10^{-3}$; girls: $-2.1x10^{-3}$)	$9.4x10^{-4}$ (boys: $1.8x10^{-3}$; girls: $1.0x10^{-3}$)	**0.04** (boys: 0.53; **girls: 0.05)**
SLE NSchD – SchD (%)	$1.5x10^{-4}$	$5.6x10^{-4}$	0.79
SOL NSchD – SchD (min)	$-6.2x10^{-5}$	$2.1x10^{-4}$	0.77

TST = total sleep time; TRT = total rest time; SLE = sleep efficiency; SOL = Sleep onset latency; NOA = number of awakenings; BT = bedtime; RT = rise time; NSchD = nonschool days; SchD = school days; h = hours; min = minutes; cpm = counts per minute; N = number; β = unstandardized regression coefficient; SE = standard error.
[a] Adjusted for physical activity, body fat percentage and parental education.
[b] Adjusted for screen time, body fat percentage and parental education.
[c] p-value < 0.05 (bolded) was considered to show statistically significant relationship between screen time/physical activity and outcome variables.

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association (standardized beta = -0.14). When performed separately by sex, physical activity was only significantly associated with a weekend shift in sleep time for boys ($p = 0.04$) and in the number of awakenings for girls ($p = 0.05$). With each additional 100 cpm/day in physical activity, there was a reduction in the weekend shift in the number of awakenings by 0.2 and in the weekend shift in rest and sleep duration by 2.7 min and 2.3 min, respectively (total group). Participants in the 90th percentile of physical activity, as compared to participants in the 10th percentile, had around 30 min less weekend shifts in rest and sleep duration, and less shift in the number of awakenings of 2.4.

Discussion

We found that more irregular sleep patterns were associated with greater screen time and less physical activity among mid-teen adolescents, especially among boys. Screen time was most strongly associated with variability in bedtime, and physical activity with variation in the number of awakenings. To the best of our knowledge, this is the first study to examine the relationship between intra-individual variations in sleep parameters and screen time and physical activity with objective measures in adolescents.

Greater screen time, especially game playing, was associated with greater night-to-night variations in bedtime, rise time, rest duration and sleep duration, and greater weekend shifts in bed and rise times (game playing was furthermore associated with higher variability in the number of awakenings and sleep efficiency). Screen time was also associated with later bedtime and less rest and sleep durations. Additionally, we found that the increase in reported screen time on nonschool days was correlated with the shift toward later bedtime on nonschool days (Beta = 0.195; $p = 0.002$). Collectively, these findings support a growing body of research that suggests that screen time disrupts bedtime routine and sleep duration,[23,24] and also previous findings based on self-report that adolescents with more screen/computer use experience greater nightly variation in sleep duration,[25] and greater weekend shift in bedtime.[26] Although mechanisms for sleep disruption by screen usage remain uncertain, factors, such as direct displacement of sleep by screen time, screen-light altering peak melatonin release, and arousal from screen usage are all thought to contribute.[23,24,36]

Higher levels of physical activity have been associated with better sleep quality in adolescents,[8,26,37] but studies of its association with adolescent sleep duration have yielded mixed results.[26,38,39] In this study, we observed that physical activity was associated with less sleep and rest durations and earlier rise time, possibly due to direct displacement of sleep by physical activity. Prior studies exploring the relationship between physical activity and sleep variability in adolescents and children have also produced inconsistent results.[26,40] However, these studies were limited to self- or parent-report and focused only on weekend shifts in sleep. Our results, obtained using objective measures, suggest that physical activity contributes to both better and more consistent sleep quality since physical activity was inversely associated with the mean value, night-to-night variation, and weekend shift in awakenings. We also found that greater physical activity was associated with less nightly variation in rise time and smaller weekend shifts in sleep and rest durations, indicating that it may also promote more consistent sleep patterns. These results, taken together, suggest that physically active students have more consistent sleep quality and routine across the week and less need for catch-up sleep on weekends than their more sedentary counterparts. These findings are consistent with the idea that some of the physiological effects of physical activity, including enhanced body temperature control and melatonin production, may be favorable to sleep regulation.[41]

Our sex-specific linear regression analyses showed that associations between screen time and variability in sleep were significant for boys but not girls. Since boys had higher levels of screen time, and more profound nightly variation in sleep and weekend shifts in sleep timing, stronger associations between screen time and sleep variations for boys were not surprising. Among the subtypes of screen use, game playing was most often associated with variability and weekend shift in sleep parameters. A higher percentage of boys than girls reported this type of screen use in our study, which may further explain the sex differences in our results. Conversely, we found that the relationship between physical activity and night-to-night variation in rise time was significant for girls but not boys. This discrepancy may be due to insufficient power in our sex-specific analyses, which should be interpreted with caution due to our limited sample size.

Although the observed increases in the variability in sleep parameters among boys with each additional hour of screen time were modest (ranging from 5.6 to 8.8 min), the cumulative effect of screen use on the stability of sleep parameters may have public health relevance. The same applies to decreases in the variability of sleep parameters with increasing physical activity. Boys in the 90th percentile of screen time, as compared to boys in the 10th percentile, had considerably higher nightly variability in sleep duration, bed and rise times, as well as a substantially greater weekend shift in bed and rise times. This higher variability (28-59% of the average variability/shift in the corresponding sleep parameters among boys) may negatively affect the health, functionality, and well-being of individuals with the highest screen time.[4] Participants (total group) in the 90th percentile of physical activity, as compared to participants in the 10th percentile, had considerably less variability and weekend shift in the number of awakenings, decreased variability in rise time, and less weekend shift in rest and sleep durations. Again, these are substantial differences (17-56% of the average variability/shift in the corresponding sleep parameters), supporting the notion that by promoting stable sleep patterns, being physically active may have definite and positive effects on health and well-being.

The results of the current study contribute to the limited data on the relationship of screen time and physical activity with the regularity of sleep among adolescents. A strength of our study was the use of objective rather than self-reported measures for sleep, physical activity, and body composition. The participation rate (79%) was also quite high, and the study sample represents a relatively large portion of the total number (4,254 individuals) of 15-year-old Icelandic adolescents,[42] and the results are, therefore, likely to be representative for the Icelandic youth population. The generalizability to other adolescent populations is less clear as objective measurements of sleep patterns are scarce. The northern latitude and homogeneous racial and ethnic composition of Iceland may limit the generalizability of the findings.

The cross-sectional study design does not allow us to determine causal relationships between the study variables. Reverse causality cannot be ruled out; participants with irregular sleep patterns may spend more time in screen-based activities and less time in physical activity than their peers. Longitudinal and laboratory-based studies are needed to further clarify the causality of screen time and physical activity with sleep patterns. Another limitation of the present study is the use of self-report for screen time, which may be subject to recall and reporting biases. Employing time-use diaries and/or using discrete time periods to report on may help in minimizing such biases, but it also increases subject burden, which may reduce compliance.[43] Our questionnaire included separate questions for time spent on individual screen-based activities, which were combined for the total screen time used in our analyses. This may have resulted in an overestimation of the total screen time, as multitasking on different screens, such as watching TV and using a smart-phone at the same

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time, is quite prevalent in youth.[15] We adjusted for several potential confounders in our analyses, but residual confounding may be present. Finally, although we have no evidence to suggest that the non-participants (N = 96) differed from the general student population in terms of socioeconomic status, lifestyle habits (including physical activity and screen time) and/or sleep habits, we cannot rule out the possibility of selection bias.

Conclusions

We found that less screen time and more physical activity were both associated with less variable sleep patterns among mid-teen Icelandic adolescents, especially among boys. The cumulative effect of screen time and physical activity was substantial and may impact the health, functionality, and well-being of participants. Our results suggest that encouraging youngsters to lead an active lifestyle and limit their screen use may be important to achieve recommendations for a more consistent sleep schedule.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

Conceptualization: SMH, SLG, SAA. Data curation: SMH, RJB, VR. Formal analysis: SMH. Funding acquisition: EJ, SAA. Investigation: SMH, VR, SLG. Methodology: SMH, SLG, SAA, RJB. Project administration: EJ, SAA. Resources: RJB, KYC, EJ. Software: RJB. Supervision: SLG, SAA. Writing – original draft: SMH. Writing – review & editing: SMH, RJB, VR, KYC, EJ, SLG, SAA. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The research project was approved by the Icelandic Data Protection Authority, the National Bioethics Committee (VSNb2015020013/13.07), and the Icelandic Radiation Safety Authority. Written informed consent was obtained from all participants and their guardians.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleh.2020.02.005.

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Paper III

Screen time and body image – a longitudinal cohort study in Icelandic adolescents

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Abstract

Background: Studies of adolescent body image and screen use are mostly limited to girls and longitudinal data are scarce. We examined cross-sectional and longitudinal associations between these variables in mid-adolescent boys and girls.

Methods: Data was collected when participants were at age 15 and 17, by questionnaire and objective measurements (n=152 had complete data). Sex-specific linear regression was used to explore associations of screen use and body image, adjusting for vigorous physical activity, symptoms of depression, and body composition.

Results: Screen time was negatively associated with body image at both timepoints, although more strongly at age 15, and for girls only. Girls with above median screen time at both ages had 14% lower body image score at age 17 than girls with below median screen time at both timepoints.

Conclusion: Limiting screen time may help to mitigate body dissatisfaction in adolescent girls.

Introduction

Body image can be defined as a person’s perceptions, thoughts, and feelings about his/her body (Grogan, 2008). Body dissatisfaction occurs when feelings towards one´s body are negative and disparate from one’s concept of the ideal body (Grogan, 2008). Negative effects of television use and print media on body image are well documented (López-Guimerà, Levine, Sánchez-carracedo, & Fauquet, 2010; Holland & Tiggemann, 2016). The impact of newer media sources is less known, but emerging evidence suggests that internet usage, especially social media use and networking, may have adverse effects on perceptions of one´s physical appearance (Holland & Tiggemann, 2016; Dumas & Desroches, 2019). This is of special concern for adolescents, as their internet usage has increased exponentially in recent years, largely through smartphones (Saul & Rodgers, 2018).

Screen time may affect health and wellbeing via psychosocial and psychological effects (Suchert, Hanewinkel, & Isensee, 2015). Social media, television and other screen-based material provides adolescents with diverse opportunities to compare their physical appearance to that of others, elevating the potential for body dissatisfaction (Suchert et al., 2015). Girls may be more vulnerable than boys since media extensively promotes an unrealistic thin-beauty ideal for women that is unattainable for most females (Calado, Lameiras, Sepulveda, Rodriguez, & Carrera, 2011; Suchert et al., 2015; Swami et al., 2010). Screen time is also typically sedentary and higher levels of sedentary behavior are associated with greater adiposity (Ekelund, Hildebrand, & Collings, 2014; Suchert, Hanewinkel, & Isensee, 2016; Tremblay et al., 2011b) and lower fitness (Tremblay et al., 2011b), both of which may result in body image dissatisfaction (Gao et al., 2016). Negative feelings towards one´s body may promote unhealthy weight-control behaviours and eating disorders (López-Guimerà et al., 2010) and have also been linked to depression (Stice & Whitenton, 2002) and lower self-esteem (Tiggemann, 2005; van den Berg, Mond, Eisenberg, Ackard, & Neumark-Sztainer, 2010). Adolescents may be especially vulnerable due to the major physical and psychological changes they undergo during puberty (Smolak & Thompson, 2009), and their extensive use of social media (Rodgers & Melioli, 2016).

The type of screen-based activity preferred by adolescents has been found to differ across sex (Rideout, 2015). Boys tend to favor computer gaming, whereas girls are more likely to use the internet for communicating via social media. Thus, it is important to determine the effects of specific screen use subtypes on body image in a sex-specific manner (Bucksch, Inchley, Hamrik, Finne, & Kolip, 2014; Straker, Smith, Hands, Olds, & Abbott, 2013). Most research on screen time and body image has focused on girls (Anez et al., 2018; Sladek, Engeln, & Miller, 2014) and composite screen time, and longitudinal data are scarce.

The aim of this study was to examine the relationship between screen time and body image in Icelandic adolescents, both cross-sectionally at ages 15 and 17, and longitudinally between these timepoints. We sought to identify differential effects of sex and screen-based activity type on body image. We hypothesized that more screen time across the two year study period would result in less favorable body image at age 17.

Methods

Sample and data collection

Four hundred and eleven tenth-grade students (age 15-16 years, 47% boys and 53% girls) from six compulsory schools in metropolitan Reykjavik, Iceland, were invited in the spring of 2015 to participate in the study; 315 (79%) agreed and 244 had complete data for the variables of interest. Two years later, in the spring of 2017, 168 of the 244 agreed to repeat the measurements. Non-participation in the follow up study was largely due to schedule conflicts, relocation, lack of interest, or because the subjects could not be located. Data are presented for 152 participants (95 girls) with complete data at both timepoints. Participants provided information regarding their socioeconomic background, health, and lifestyle by answering a tablet-based questionnaire provided by the research team. Objective measurements of body composition were also performed. Written informed consent was attained from all participants and their guardians, and strict procedures were followed to ensure confidentiality. The study was approved by the Icelandic Data Protection Authority, the National Bioethics Committee (VSNb2015020013/13.07), and the Icelandic Radiation Safety Authority.

Measures

Self-reported screen time. Participants reported average daily weekday and weekend hours spent playing computer games, watching TV/DVD/internet material, using the internet for web-browsing/Facebook/e-mail, and using a computer for "other" activities. Each screen time category had the following response options: 1 = "none", 2 = "about ½ h", 3 = "1 up to 2 h", 4 = "2 up to 3 h", 5 = "3 up to 4 h", 6 = "4 to 5 h" and 7 = "more than 5 h". Weekly averages (h/day) for each screen-based activity were computed using the midpoint for each scoring category (5.5 h/day for category 7) and weighted averages for weekdays and weekends. All screen-based activities were then summed for total daily screen time on all days, weekdays, and weekends. These questions were used previously to evaluate adolescent screen time in the Icelandic population (Hrafnkelsdottir et al., 2018).

Self-reported vigorous physical activity. Participants were asked: “How often, per week, do you perform physical activity that makes you breathe more rapidly or sweat?”, and given the following response options: 1 = “never”, 2 = “less than once a week”, 3 = “once a week”, 4 = “2-3 times a week”, 5 = “4-5 times a week”, 6 = “almost every day”. This question was previously used to quantify adolescent vigorous physical activity in the Icelandic population (Hrafnkelsdottir et al., 2018; Rognvaldsdottir et al., 2018).

Depression. A 10-item subscale of the Symptom Checklist 90 (SCL-90) (Derogatis, 1971) was used to assess how often participants experienced symptoms of depression during the preceding week. Each item included the following response options: 1 = “almost never”, 2 = “seldom”, 3 = “sometimes”, 4 = “often” and 5 = “almost always”, yielding a total score between 10-50 points. This subscale of the SCL-90 was previously employed in studies on mental well-being among Icelandic adolescents (Gestsdottir et al., 2015; Hrafnkelsdottir et al., 2018).

Global self-esteem. Global self-esteem was assessed using the Rosenberg Self-Esteem Scale (Rosenberg, 1965). The scale consists of 10 statements, each rated as positive or negative, with four response options: 0 = “strongly agree“, 1 = “somewhat agree“, 2 = “somewhat disagree“ and 3 = “strongly disagree“, yielding a total score between 0-30 points. The Rosenberg scale has been widely used for evaluating self-esteem of young people, and its reliability and validity are well documented (Kling, Hyde, Showers, & Buswell, 1999).

Body image. Body image was evaluated with five items from the Body and Self-Image subscale of the Offer Self-Image Questionnaire (OSIQ) (Offer, 1992), which were translated into Icelandic. Participants rated how well the following statements described them: “When I think about how I will look in the future, I am happy”, “I frequently feel ugly and unattractive", "I am proud of my body", "I am happy with the way my body has changed in recent years", and "I feel strong and healthy". A four-point scale was used for all statements, ranging from 1 = "describes me very well" to 4 = "doesn´t describe me at all". If necessary, responses were recoded such that higher scores reflected more positive body image, yielding a total score between 5-20. The internal consistency of the scale was satisfactory at both baseline and follow-up (Cronbach's alphas = 0.83 and 0.82, respectively). This 5 item scale has been verified for validity and reliability (Bjarnason & Thorlindsson, 1993) and used in previous studies on Icelandic adolescents (Eidsdottir, Kristjansson, Sigfusdottir, Garber, & Allegrante, 2014; Gestsdottir et al., 2015; Ingolfsdottir, Asgeirsdottir, Gunnarsdottir, & Bjornsson, 2014; Vilhjalmsson, Kristjansdottir, & S. Ward, 2011).

Body composition: Body mass index (BMI, kg/m^2) was calculated from standing height (m) measured to the nearest mm with a stadiometer (Seca model 217, Seca Ltd., Birmingham, UK) and body weight (kg) measured to the nearest 0.1 kg on a calibrated scale (Seca model 813, Seca Ltd., Birmingham, UK) with participants wearing light clothing. Measurements were performed at individual schools at age 15 and at the Icelandic Heart Association at age 17. Body fat percentage was derived from whole-body dual energy X-ray absorptiometry (DXA) scans performed on a GE Lunar bone densitometer (GE Healthcare, Madison, Wisconsin USA) by a certified radiologist at the Icelandic Heart Association in Kopavogur, Iceland.

Statistical analysis

Descriptive summaries are presented as means and standard deviations for continuous variables and frequencies and percentages for categorical variables, for boys and girls separately. Sex differences were evaluated by unpaired t-tests for continuous variables and chi-square tests for categorical variables. Measures at ages 15 and 17 were compared using paired t-tests. Cross-sectional associations between body image and screen time were assessed using linear regression, with both unadjusted models and models adjusted for body fat percentage, depression score, and vigorous physical activity. Covariates were selected based on prior research (Gao et al., 2016; Hrafnkelsdottir et al., 2018; Kelly, Bulik, & Mazzeo, 2011; Stice & Whitenton, 2002; Tremblay et al., 2011b; Vilhjalmsson et al., 2011) and bivariate correlation analysis. Screen time variables included total screen time, game playing, watching TV/DVD/internet material, and internet use (Facebook/web-browsing/e-mail) on all days, and total screen time on weekdays and weekend days. We tested for an interaction between screen time and vigorous physical activity, with respect to body image. Separate regressions were run for boys and girls at ages 15 and 17. Participants were then categorized by total screen use relative to the median at ages 15 and 17 (5.1 h/day and 6.0 h/day, respectively), yielding the following longitudinal groups: above median screen use at both ages (High-High, HH), above the median at 15 and below at 17 (High-Low, HL), below the median at 15 and above at 17 (Low-High, LH), and below median screen use at both ages (Low-Low, LL). Longitudinal regression analysis assessed the relationship between longitudinal screen use and body image at age 17, with LL as the reference group and baseline values (age 15) for all covariates. Cross-sectional regression results are presented as standardized betas and adjusted R^2 coefficients to indicate relative strength of associations and percentage of explained variance in body image, respectively. Longitudinal regression results are presented as unstandardized betas. An $\alpha < 0.05$ was set as the significance threshold in all analyses. SAS statistical software (v9.4, SAS Institute Inc., Cary, NC; www.sas.com) was used for all statistical work.

Results

Characteristics of participants

Screen time, physical activity and characteristics of participants with complete data are presented in Tables 1a (cross-sectional data) and 1b (longitudinal data for screen time).

Screen time: Median value for total daily screen time (total sample) was 5.1 h at age 15 and 6.0 h at age 17. Average total daily screen time was somewhat higher for boys than girls in 2015 (6.0 vs. 5.4 h, $p = 0.14$), but had become equal for the sexes in 2017 (6.4 h), due to a significant increase between timepoints for girls. Both sexes had higher screen time on weekends than weekdays at age 15 (1.4 h difference, both $p < 0.0001$), this difference was smaller at age 17 (1.0 h for boys and 0.8 h for girls (both $p \leq 0.001$)). Girls spent most of their screen time on the internet in 2015, whereas boys preferred game playing. The pattern of activities changed significantly between 2015 and 2017 among boys, they spent more time on the internet and less time playing computer games in 2017. Girls spent similar time in the various screen time activities at both timepoints, except that there was a significant increase in "other" activities between 2015 and 2017. As is shown in Table 1b, about 37% of boys and 28% of girls remained above the median screen time from age 15 to 17 (HH group), while 30% of boys and 33% of girls were below median screen time at both ages (LL group). About 19% of boys and 18% of girls went from above median screen time at age 15 to below at 17 (HL group), while 14% of boys and 21% of girls showed the opposite trend (LH group).

Body image: Average body image score was significantly higher for boys, both at age 15 and 17 (~16.5 for boys vs. ~14.5 for girls, $p < 0.0001$). The score did not change significantly between timepoints, for either sex. The average body image score was significantly lower for girls reporting total screen time above the median value at ages 15 and 17 (HH group) compared to girls with total screen time below the median value at both timepoints (LL group), 13.4 vs.15.5, or 14% lower for HH girls. For boys, the body image score did not differ between the HH and LL groups.

Covariates: Both sexes reported participating less frequently in vigorous physical activity at age 17 compared to 15, but the decrease was significant for boys only. However, boys reported more physical activity than girls at both timepoints (although marginal at age 17). Mean depression score was higher for girls than boys at both timepoints (both $p < 0.01$), but there was a significant increase in the score for boys between age 15 and 17. Girls had higher body fat percentage than boys at both timepoints ($p < 0.0001$), and there was a significant increase in this parameter for girls only, between age 15 and 17.

Global self-esteem: Boys had higher average self-esteem score at age 17 than girls ($p = 0.03$) and borderline higher score at age 15 ($p = 0.07$). The score did not change significantly between timepoints, for either sex.

Association of screen time with body image

Linear regression analyses demonstrate that screen time variables were only significantly associated with body image score for girls, both cross-sectionally at ages 15 and 17 (Table 2), and longitudinally between timepoints (Table 3).

Cross-sectional association at age 15: Total daily screen time (all days, weekends and weekdays), time spent in game playing and time watching TV/DVD/internet material were all negatively associated with body image score for girls (all $p < 0.001$, Table 2). Associations remained significant, except for total screen time on weekdays, when the data were adjusted for body fat percentage, depression, and vigorous physical activity (all $p < 0.05$). Using the internet for Facebook/e-mail/web-browsing was borderline significant for girls (p =

0.06) in the unadjusted model and non-significant in the adjusted model. We did not find a significant interaction between screen time and vigorous physical activity, for either sex. Total screen time, body fat percentage and depression score were all significantly related to body image score in the fully adjusted model (model 4), explaining 40% of the variance in body image score (Table S1).

Cross-sectional association at age 17: As is shown in Table 2, total daily screen time (all days and weekends), game playing, internet use (Facebook/web-browsing/e-mail), and watching TV/DVD/internet material, were all negatively associated with body image score for girls (p = 0.03 to 0.0002). Associations became non-significant when the data were adjusted for body fat percentage, depression, and vigorous physical activity. Whereas screen time on weekends had the strongest association with body image score, screen time on weekdays was not associated with this outcome. We did not find a significant interaction between screen time and vigorous physical activity, for either sex. Vigorous physical activity and depression score were significantly related to body image score in the fully adjusted model (model 4), explaining 31% of the observed variance in body image score (Table S1).

Longitudinal association, at age 15 to 17: As is shown in Table 3, having screen time above the median value at both timepoints (all days), as compared with having screen time below the median both years (group HH vs. group LL), was negatively associated with body image score at age 17 among girls (p = 0.005). The association remained significant after adjustment for baseline (age 15) body fat percentage, depression score, and vigorous physical activity (p = 0.03). This negative association was stronger for screen time on weekends (p = 0.0002 for unadjusted model and p = 0.002 for adjusted model), but was not observed for screen time on weekdays. We also found a negative association between screen time on weekends and body image for the LH group compared to the LL group (p = 0.03 for both unadjusted and adjusted models).

Discussion

As smartphones and social networking become nearly ubiquitous in modern culture, a growing body of research continues to find additional adverse impacts of excessive screen time on well-being. Our results add to this literature, confirming a negative association between screen time and body image for adolescent girls and further demonstrating that girls with consistently higher than median screen time over a two-year period rated their body image lower than girls with below median screen time. We also show that greater time spent in gaming and TV/DVD/internet watching was more strongly associated with lower body image than internet use for social media, and that the strength of the association between body image and screen time varied dramatically by gender, age and type of day (weekdays vs. weekends).

We found a consistent, negative cross-sectional relationship between body image score and total screen time and time spent on various screen activities for girls at ages 15 and 17. These results were supported by the longitudinal observation that girls with higher-than-average total screen time at both ages had lower body image scores at age 17 than girls with below average screen time at both ages, even after adjusting for potential confounders. Our results broadly agree with previous cross-sectional studies on the association of media and body image (Dumas & Desroches, 2019; Holland & Tiggemann, 2016; López-Guimerà et al., 2010) and with the few longitudinal studies on this subject that have in most cases found time spent on social network sites (Holland & Tiggemann, 2016), and reading magazines and watching TV (López-Guimerà et al., 2010; Schooler & Trinh, 2011) being predictive of body dissatisfaction. Taken together, these findings suggest that media use may play a causal role in the development of body dissatisfaction.

We observed striking sex differences in this study, with no significant associations between screen time and body image for boys, but consistent negative cross-sectional and longitudinal relationship between these variables for girls. Results of the few prior studies that have analysed this topic in both sexes have been mixed. Studies on total screen use (Suchert et al., 2015), computer use in leisure time (Anez et al., 2018), TV watching (Schooler & Trinh, 2011) and Facebook use (Thompson & Lougheed, 2012) have found an association between screen time and body dissatisfaction in girls but not boys. However, as reviewed by Holland and Tiggeman (Holland & Tiggemann, 2016), a few studies on social media use and body image have not observed gender differences.

The influence of media on body image may be stronger for girls than boys due to the extensive promotion of an unrealistic thin-beauty ideal for women by the media and objectification of the female body in Western societies (Calado et al., 2011; Swami et al., 2010). This may result in greater self-monitoring of appearance among girls, leading to higher levels of body dissatisfaction in females than males (Holland & Tiggemann, 2016). Adolescent girls also tend to have lower self-esteem (Aslund, Starrin, & Nilsson, 2010; Kling et al., 1999) and more depressive symptoms (Patton & Viner, 2007) than adolescent boys, which may make them more vulnerable to the negative effects of mass media (Ahadzadeh, Sharif, & Ong, 2017; Suchert et al., 2015). In addition, quality of social relationships have been found to be positively associated with screen use among boys (Finne, Bucksch, Lampert, & Kolip, 2014), which may have beneficial influences on their overall mental well-being (Suchert et al., 2015). In our study, girls had lower average body image score and higher depression score than boys at both age 15 and 17, and lower self-esteem score at age 17.

Screen time, both total time and time spent in subcategories, was more strongly associated with body image score at age 15 than 17. This was despite an increase in screen time between age 15 and 17 for girls, whereas body image score remained similar between these ages. It can be speculated that greater publicity and awareness of the negative effects of unrealistic body standards presented by the media and increased maturity with age could have contributed to this finding. Results from a recent study on adolescent girls suggest that both parental involvement and school environment may play crucial roles in protecting them from the detrimental effects that social media use may have on their body image (Burnette, Kwitowski, & Mazzeo, 2017). Positive mother-adolescent relationship may be especially beneficial in this respect (de Vries, Vossen, & van der Kolk-van der Boom, 2019).

Total screen time on weekends was more strongly related to body image than total screen time on weekdays, more so at age 17. A possible explanation may be the higher average screen time observed on weekends, and likely longer continuous periods of screen use on these days. This could be especially relevant at age 17, as parental supervision may have decreased between ages 15 and 17. These results agree with a study on Spanish adolescents, that found computer use in leisure time on weekends, but not weekdays, to be associated with body dissatisfaction among girls (Anez et al., 2018).

Game playing was most strongly associated with body image score at both ages, followed closely by wathing TV/DVD/internet material, but internet use (Facebook/e-mail/web-browsing) was only associated with body image at age 17. Prior research has focused on the cross-sectional relationship between TV use and body image, and has found inverse association between these variables, explained by the exposure to thin-ideal images and self-objectification (Levine & Murnen, 2009; López-Guimerà et al., 2010; Schneider et al., 2013). According to a recent systematic review female characters in video games are typically objectified and hypersexualized with disproportionate body parts, which may lead to self-objectification in female players (Gestos, Smith-Merry, & Campbell, 2018), more so than television use (Karsay, Knoll, & Matthes, 2018). Most prior research has found social media use negatively associated with body image (Dumas & Desroches, 2018; Fardouly & Vartanian, 2016; Holland & Tiggemann, 2016), with a few exceptions (Fardouly, Diedrichs, Vartanian, & Halliwell, 2015; Schneider et al., 2013). Thus, the lack of association between internet use and body image at age 15 came as a surprise but may be due to the phrasing of our question on internet use, which included Facebook but not other social media sites that later became increasingly popular. In addition, the distinction between internet use and watching internet material may have been unclear and perhaps resulted in the former being misclassified as the latter.

We adjusted for depression, body composition, and vigorous physical activity in our analyses. It is, however, up for debate whether some or all of these variables are confounders or intermediates in a causal pathway between screen time and body image dissatisfaction. Depression may also be the result of body dissatisfaction (Eidsdottir et al., 2014; Holland & Tiggemann, 2016). Regardless, total screen time was a significant explanatory variable for body image in girls at age 15, independent of these covariates. This effect of screen time was not observed, however, at age 17, where depression and vigorous physical activity were the only variables significantly associated with body image in the fully adjusted model. Altogether, these results are consistent with screen time having both direct effects on body image and indirect effects via depression and vigorous physical activity.

A limitation of the present study is the use of self-report for screen time and vigorous physical activity, which may be subject to recall and reporting biases (Chinapaw, Mokkink, van Poppel, van Mechelen, & Terwee, 2010). Further, our questionnaire included separate questions for screen use in four categories, which were summed for total screen time. While this format can provide more detailed information on screen use, summing the answers may have resulted in an over-estimation of the total screen time, as multi-tasking on different screens, such as watching TV and using a smart-phone at the same time, has been reported to be quite prevalent in youth (Rideout, 2015). On the other hand, we did not specifically ask about smart-phone use and our question on internet use only included Facebook and lacked other social media platforms at age 15, which may have led to under reporting of internet use and total screen time at that age. As previously mentioned, misclassification of social media use as watching material via the internet may also be present.

The major strength of this study is the longitudinal design that enabled us to evaluate the effects of screen time on body image, across the two year period from age 15 to 17. The cross-sectional and longitudinal results agree, strengthening the credibility of our findings. Our follow-up time of 2 years is, furthermore, longer than that used in the majority of previous studies in this field. Another strength is that analyses were performed separately by sex, which adds to the limited data on sex-based difference in the relationship between screen time and body image. Still another advantage is the available information on the subtypes of screen use and screen time on weekends as well as on weekdays. Finally, the use of DXA measurements yielded accurate information on body composition in terms of body fat percentage, and we therefore did not have to rely on the more crude measure, BMI.

In summary, we found that screen time was associated with lower body image score among girls, both cross-sectionally at age 15 and 17 and longitudinally between these ages. Our results support the notion that screen use plays a role in the development of body dissatisfaction among girls. Limiting screen time may help to mitigate body dissatisfaction in this group.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The research project was approved by the Icelandic Data Protection Authority, the National Bioethics Committee (VSNb2015020013/13.07) and the Icelandic Radiation Safety Authority. Written informed consent was obtained from all participants and their guardians.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Table 1a. Characteristics of the study subjects (57 boys and 95 girls) at age 15 and 17

	15y		p*	17y		p*
	Boys	Girls		Boys	Girls	
Screen time, h/day, mean (SD)						
Days						
All days	6.0 (2.3)	5.4 (2.4)[a]	0.14	6.4 (2.7)	6.4 (2.7)[a]	0.91
Weekdays	5.6 (2.2)[b]	5.0 (2.5)[a,b]	0.17	6.1 (2.8)[c]	6.2 (2.9)[a,c]	0.80
Weekends	7.0 (2.7)[b]	6.4 (3.0)[b]	0.20	7.1 (3.0)[c]	7.0 (2.9)[c]	0.79
Activities						
Games	1.9 (1.2)[a]	0.3 (0.8)	**<0.0001**	1.4 (1.2)[a]	0.4 (1.0)	**<0.0001**
Internet	1.7 (0.9)[a]	2.6 (1.4)	**<0.0001**	2.3 (1.3)[a]	2.8 (1.2)	**0.03**
Viewing	1.7 (0.9)	1.8 (1.0)	0.46	1.8 (1.0)	1.9 (1.1)	0.33
Other	0.7 (0.8)	0.7 (0.9)[a]	0.70	0.8 (0.9)	1.3 (1.3)[a]	**0.01**
Vigorous PA, times/week, mean (SD)	5.1 (1.1)[a]	4.6 (1.4)	**0.02**	4.8 (1.3)[a]	4.4 (1.4)	0.06
Body fat, %, mean (SD)	17.1 (6.2)	30.1 (6.7)[a]	**<0.0001**	17.6 (6.5)	31.2 (7.3)[a]	**<0.0001**
BMI, mean (SD)	21.3 (2.8)[a]	22.3 (3.4)[a]	0.05	22.4 (3.1)[a]	23.0 (4.6)[a]	0.35
Body image score, mean (SD)	16.4 (2.7)	14.3 (3.1)	**<0.0001**	16.5 (2.4)	14.6 (3.1)	**<0.0001**
Depression score, mean (SD)	14.6 (6.9)[a]	20.4 (10.4)	**<0.0001**	16.3 (7.3)[a]	20.3 (9.2)	**0.006**
Self esteem score, mean (SD)	22.2 (6.3)	20.1 (6.6)	0.07	23.2 (6.1)	20.7 (7.0)	**0.03**

PA = physical activity

[*] p-value < 0.05 (bolded) between sexes at 15y or 17y
[a] p < 0.05 between 15y and 17y
[b] p < 0.0001 between weekdays and weekends at 15y
[c] p ≤ 0.001 between weekdays and weekends at 17y

Table 1b. Participants´ distribution in categories of daily screen time at 15y to 17y

	Boys		Girls	
	N	**%**	**N**	**%**
Total screen time – all days				
HH	21	36.8	27	28.4
HL	11	19.3	17	17.9
LH	8	14.1	20	21.1
LL	17	29.8	31	32.6
Total screen time – weekends				
HH	20	35.1	26	27.4
HL	11	19.3	17	17.9
LH	11	19.3	23	24.2
LL	15	26.3	29	30.5
Total screen time – weekdays				
HH	22	38.6	24	25.3
HL	10	17.5	19	20.0
LH	7	12.3	19	20.0
LL	18	31.6	33	34.7

HH: above median screen time at 15y and 17y
HL: above median screen time at 15y but below median screen time at 17y
LH: below median screen time at 15y but above median screen time at 17y
LL: below median screen time at 15y and 17y

Table 2. Linear relationships between hours of average daily screen time and body image score

	15 y (2015)				17y (2017)			
	Boys		Girls		Boys		Girls	
	β	p[1]	β	p[1]	β	p[1]	β	p[1]
Total screen time[2] – all days[3]								
Unadjusted	-0.174	0.20	-0.424	**<.0001**	0.067	0.62	-0.257	**0.01**
Adjusted[4]	-0.029	0.81	-0.201	**0.03**	0.088	0.49	-0.032	0.74
Total screen time[2] - weekends								
Unadjusted	-0.135	0.32	-0.400	**<.0001**	0.024	0.86	-0.378	**0.0002**
Adjusted[4]	0.041	0.73	-0.210	**0.02**	0.044	0.73	-0.171	0.07
Total screen time[2] - weekdays								
Unadjusted	-0.182	0.18	-0.378	**0.0002**	0.080	0.55	-0.186	0.07
Adjusted[4]	-0.060	0.61	-0.158	0.08	0.099	0.43	0.024	0.80
Game playing[3]								
Unadjusted	-0.158	0.24	-0.396	**<.0001**	-0.002	0.99	-0.227	**0.03**
Adjusted[4]	-0.109	0.37	-0.211	**0.02**	-0.043	0.75	-0.129	0.14
Watching TV/DVD/internet material[3]								
Unadjusted	-0.112	0.40	-0.338	**0.0008**	0.098	0.47	-0.225	**0.03**
Adjusted[4]	-0.026	0.83	-0.204	**0.03**	0.064	0.62	0.023	0.81
Internet use (Facebook/email/web-browsing)[3]								
Unadjusted	0.062	0.65	-0.192	0.06	0.137	0.31	-0.223	**0.03**
Adjusted[4]	0.070	0.54	-0.016	0.86	0.128	0.33	-0.055	0.55

β = standardized regression coefficient
[1]p-value < 0.05 (bolded) for body image vs. screen time variables
[2]Total screen time (h/day) = game playing + watching TV/DVD/internet material + internet use (Facebook/e-mail/web-browsing)
[3]weighted average for weekends and weekdays
[4]adjusted for body fat percentage, depression score, and vigorous physical activity

Table 3. Categorical total daily screen time from age 15 to 17 versus age 17 body image

	Boys		Girls	
	β	**p[1]**	**β**	**p[1]**
All days				
Unadjusted				
HH	0.168	0.83	-2.141	**0.005**
HL	0.791	0.38	-0.607	0.49
LH	0.882	0.38	-0.948	0.26
LL	Ref.		Ref.	
Adjusted[2]				
HH	-0.060	0.94	-1.705	**0.03**
HL	0.297	0.75	0.058	0.95
LH	0.309	0.77	-0.893	0.28
LL	Ref.		Ref.	
Weekdays				
Unadjusted				
HH	0.086	0.91	-1.269	0.13
HL	0.322	0.74	0.097	0.91
LH	0.722	0.51	-0.640	0.47
LL	Ref.		Ref.	
Adjusted[2]				
HH	-0.179	0.82	-0.694	0.41
HL	-0.138	0.89	1.156	0.22
LH	0.179	0.88	-0.279	0.76
LL	Ref.		Ref.	
Weekends				
Unadjusted				
HH	-0.233	0.78	-2.984	**0.0002**
HL	1.048	0.27	-1.491	0.09
LH	1.048	0.27	-1.747	**0.03**
LL	Ref.		Ref.	
Adjusted[2]				
HH	-0.599	0.48	-2.568	**0.002**
HL	0.610	0.53	-1.363	0.13
LH	0.452	0.66	-1.797	**0.03**
LL	Ref.		Ref.	

β = unstandardized regression coefficient
[1]p-value < 0.05 (bolded) for body image vs. screen time category
HH: above median screen time at 15y and 17y; 21 boys (36.8%) , 27 girls (28.4%)
HL: above median screen time at 15y but below median screen time at 17y; 11 boys (19.3%), 17 girls (17.9%)
LH: below median screen time at 15y but above median screen time at 17y; 8 boys (14.1%), 20 girls (21.1%)
LL: below median screen time at 15y and 17y; 17 boys (29.8%), 31 girls (32.6%)
[2]Adjusted for body fat percentage, depression score and vigorous physical activity

Appendix A: Questionnaire

Questions used in the study:

Q2 Ertu karl eða kona?

- ❍ Karl (1)
- ❍ Kona (2)

Q3 Hvaða ár ertu fæddur?

- ❍ 1998 (2)
- ❍ 1999 (3)
- ❍ 2000 (4)

Q5 Hver er/var menntun föður þíns? Merktu við allt sem við á

- ❑ Grunnskólapróf (2)
- ❑ Stúdentspróf (3)
- ❑ Iðnréttindi/starfsréttindi (4)
- ❑ Háskólapróf (5)
- ❑ Önnur (6)
- ❑ Veit það ekki (7)
- ❑ Ég vil ekki svara (8)

Q8 Hver er/var menntun móður þinnar? Merktu við allt sem við á

- ❑ Grunnskólapróf (1)
- ❑ Stúdentspróf (2)
- ❑ Iðnréttindi/starfsréttindi (3)
- ❑ Háskólapróf (4)
- ❑ Önnur (5)
- ❑ Veit það ekki (6)
- ❑ Ég vil ekki svara (7)

Q9 Hversu margar klukkustundir á dag gerir þú eftirtalið að jafnaði á virkum dögum?

	Ekkert (1)	Um ½ klst. (2)	1-2 klst. (3)	2-3 klst. (4)	3-4 klst. (5)	4-5 klst. (6)	Meira en 5 klst. (7)
Spilar tölvuleiki (t.d. á netinu, heimilistölvu, Playstation) (1)	❍	❍	❍	❍	❍	❍	❍
Horfir á sjónvarp, DVD eða myndefni af netinu (2)	❍	❍	❍	❍	❍	❍	❍
Ert á netinu (t.d. skoða vefsíður, Facebook eða lesa/skrifa tölvupóst) (3)	❍	❍	❍	❍	❍	❍	❍
Hlustar á tónlist í útvarpi, af diski eða af netinu (4)	❍	❍	❍	❍	❍	❍	❍
Lest bækur, tímarit, dagblöð eða annað prentað efni (5)	❍	❍	❍	❍	❍	❍	❍
Notar tölvu í annað en að vera á netinu eða spila tölvuleiki (6)	❍	❍	❍	❍	❍	❍	❍

Q11 Hversu margar klukkustundir á dag gerir þú eftirtalið að jafnaði um helgar?

	Ekkert (1)	Um ½ klst. (2)	1-2 klst. (3)	2-3 klst. (4)	3-4 klst. (5)	4-5 klst. (6)	Meira en 5 klst. (7)
Spilar tölvuleiki (t.d. á netinu, heimilistölvu, Playstation) (1)	❍	❍	❍	❍	❍	❍	❍
Horfir á sjónvarp, DVD eða myndefni af netinu (2)	❍	❍	❍	❍	❍	❍	❍
Ert á netinu (t.d. skoða vefsíður, Facebook eða lesa/skrifa tölvupóst) (3)	❍	❍	❍	❍	❍	❍	❍
Hlustar á tónlist í útvarpi, af diski eða af netinu (4)	❍	❍	❍	❍	❍	❍	❍
Lest bækur, tímarit, dagblöð eða annað prentað efni (5)	❍	❍	❍	❍	❍	❍	❍
Notar tölvu í annað en að vera á netinu eða spila tölvuleiki (6)	❍	❍	❍	❍	❍	❍	❍

Q14 Eftirfarandi spurningar eru um íþróttir og líkamsrækt.

	Aldrei (1)	Sjaldnar en einu sinni í viku (2)	1 sinni í viku (3)	2-3 sinnum í viku (4)	4-5 sinnum í viku (5)	Svo til á hverjum degi (6)
Hve oft stundar þú íþróttir (æfir eða keppir) með íþróttafélagi? (1)	❍	❍	❍	❍	❍	❍
Hversu oft stundar þú íþróttir eða æfingar sem ekki eru á vegum íþróttafélags? (2)	❍	❍	❍	❍	❍	❍
Hversu oft reynir þú á þig líkamlega þannig að þú mæðist verulega eða svitnir? (3)*	❍	❍	❍	❍	❍	❍

*Liður (3) var einungis notaður

Q31 Hversu vel eiga eftirfarandi fullyrðingar við um þig?

	Á mjög vel við um mig (1)	Á frekar vel við um mig (2)	Á frekar illa við um mig (3)	Á mjög illa við um mig (4)
Þegar ég hugsa um hvernig ég muni líta út í framtíðinni er ég ánægð(ur) (1)	❍	❍	❍	❍
Mér finnst ég oftast vera ófríð(ur) og óaðlaðandi (2)	❍	❍	❍	❍
Ég er ánægð(ur) með líkama minn (3)	❍	❍	❍	❍
Ég er ánægð(ur) með þær líkamlegu breytingar sem hafa átt sér stað hjá mér undanfarin ár (4)	❍	❍	❍	❍
Mér finnst ég vera sterk(ur) og hraust(ur) (5)	❍	❍	❍	❍

Q33 Hversu oft varðst þú var/vör við eftirfarandi vanlíðan eða óþægindi síðastliðna viku?

	Nær aldrei (1)	Sjaldan (2)	Stundum (3)	Oft (4)	Nær alltaf (5)
Höfuðverk (1)	❍	❍	❍	❍	❍
Svima (2)	❍	❍	❍	❍	❍
Verk í baki (3)	❍	❍	❍	❍	❍
Ógleði eða ólgu í maga (4)	❍	❍	❍	❍	❍
Doða eða sting einhvers staðar í líkamanum (5)	❍	❍	❍	❍	❍
Verk í maga (6)	❍	❍	❍	❍	❍
Liðverki (7)	❍	❍	❍	❍	❍
Skjálfta (8)	❍	❍	❍	❍	❍
Verki í höndum eða fótum (9)	❍	❍	❍	❍	❍
Taugaóstyrk (10)	❍	❍	❍	❍	❍
Skyndilegrar hræðslu án nokkurrar ástæðu (11)	❍	❍	❍	❍	❍
Þú varst uppspennt/uppspenntur (12)	❍	❍	❍	❍	❍
Þú varst leið/leiður eða hafðir lítinn áhuga á því að gera hluti (13)	❍	❍	❍	❍	❍
Þú hafðir litla matarlyst (14)	❍	❍	❍	❍	❍
Þér fannst þú einmana (15)	❍	❍	❍	❍	❍
Þú grést auðveldlega eða langaði til að gráta (16)	❍	❍	❍	❍	❍
Þú áttir erfitt með að sofa eða sofna (17)	❍	❍	❍	❍	❍
Þú varst niðurdregin/niðurdreginn eða döpur/dapur (18)	❍	❍	❍	❍	❍
Þú varst ekki spennt/spenntur fyrir að gera neitt (19)	❍	❍	❍	❍	❍
Þér fannst þú hægfara eða hafa lítinn mátt (20)	❍	❍	❍	❍	❍
Þér fannst framtíðin vonlaus (21)	❍	❍	❍	❍	❍
Þú hugsaðir um að fyrirfara þér (22)	❍	❍	❍	❍	❍

Q40 Hér fyrir neðan eru ýmsar staðhæfingar um hvað þér finnst um sjálfa/sjálfan þig

	Mjög sammála (1)	Frekar sammála (2)	Frekar ósammála (3)	Mjög ósammála (4)
Ég er almennt ánægð/ur með sjálfa/sjálfan mig (1)	❍	❍	❍	❍
Stundum finnst mér ég einskis virði (2)	❍	❍	❍	❍
Mér finnst ég hafa marga góða eiginleika (3)	❍	❍	❍	❍
Ég get gert margt jafn vel og flestir aðrir (4)	❍	❍	❍	❍
Mér finnst ég ekki geta verið stolt/stoltur af mörgu (5)	❍	❍	❍	❍
Stundum finnst mér ég sannarlega vera gagnslaus (6)	❍	❍	❍	❍
Mér finnst ég vera a.m.k. jafn mikils virði og aðrir (7)	❍	❍	❍	❍
Ég vildi að ég gæti borðið meiri virðingu fyrir sjálfum/sjálfri mér (8)	❍	❍	❍	❍
Allt í allt finnst mér ég vera misheppnaður/misheppnuð (9)	❍	❍	❍	❍
Ég hef jákvæða afstöðu til sjálfs/sjálfrar mín (10)	❍	❍	❍	❍

Q42 Hversu sammála eða ósammála ert þú eftirfarandi fullyrðingum?

	Mjög ósammála (1)	Ósammála (2)	Frekar ósammála (3)	Hvorki né (4)	Frekar sammála (5)	Sammála (6)	Mjög sammála (7)
Líf mitt er að flestu leyti nálægt því sem ég óska mér (1)	❍	❍	❍	❍	❍	❍	❍
Aðstæður lífs míns eru frábærar (2)	❍	❍	❍	❍	❍	❍	❍
Ég er ánægð/ánægður með lífið (3)	❍	❍	❍	❍	❍	❍	❍
Hingað til hef ég fengið það mikilvægasta sem ég vil í lífinu (4)	❍	❍	❍	❍	❍	❍	❍
Ef ég gæti lifað lífi mínu upp á nýtt myndi ég næstum engu breyta (5)	❍	❍	❍	❍	❍	❍	❍

Appendix B: Supplementary tables

Supplementary table 1. Pearson Correlation Coefficients for Mental Health scores vs. averages in Sleep parameters

	TRT	TST	BT	RT	NOA	SLE	SOL
Anxiety	-0.10157	-0.09257	0.10259	0.01245	-0.08686	-0.01404	0.01841
Depression	-0.07661	-0.05891	**0.14127***	0.07301	-0.10525	0.00745	-0.01199
Somatic complaints	0.00205	0.00802	0.10371	0.10633	-0.09257	-0.00459	-0.02316
Self-esteem	**0.15609***	0.11756	-0.08572	0.03896	0.12283	-0.05303	0.04834
Life satisfaction	0.10366	0.08553	-0.12382	-0.06114	0.04092	-0.00772	0.01900

TST = total sleep time, TRT = total rest time, BT = bed time, RT = rise time, NOA = number of awakenings, SLE = sleep efficiency, SOL = Sleep onset latency

*p-value < 0.05 (bolded) was considered to show statistically significant relationship between variables

Supplementary table 2. Pearson Correlation Coefficients for Mental Health scores vs. night-to-night variability in Sleep parameters

	SD_TRT	SD_TST	SD_BT	SD_RT	SD_NOA	SD_SLE	SD_SOL
Anxiety	0.02763	0.06647	0.04424	0.00748	-0.05629	-0.06167	0.00714
Depression	0.07626	0.12244	0.09907	0.09746	-0.08006	-0.06485	-0.02017
Somatic complaints	0.10733	**0.14282***	0.01708	0.05418	-0.00905	0.00488	0.03241
Self-esteem	0.00310	-0.01635	-0.07150	-0.02528	0.08518	0.00249	0.04305
Life satisfaction	-0.05725	-0.09075	-0.10000	-0.06713	-0.00742	0.00748	0.00666

SD = standard deviation, TST = total sleep time, TRT = total rest time, BT = bed time, RT = rise time, NOA = number of awakenings, SLE = sleep efficiency, SOL = Sleep onset latency

*p-value < 0.05 (bolded) was considered to show statistically significant relationship between variables

Supplementary table 3. Pearson correlation coefficients for mental health scores vs. weekend shift in sleep parameters

	WS_TRT	WS_TST	WS_BT	WS_RT	WS_NOA	WS_SLE	WS_SOL
Anxiety	-0.01720	0.02123	0.06565	0.03506	-0.06601	0.11173	-0.03327
Depression	0.04519	0.09211	**0.13489***	**0.13649***	-0.03643	**0.14003***	0.04695
Somatic complaints	0.06099	0.10157	0.03608	0.06566	-0.02709	0.11334	-0.01318
Self-esteem	0.00776	-0.01572	-0.10236	-0.07946	0.07181	-0.05136	-0.09140
Life satisfaction	0.02273	-0.00914	-0.09823	-0.06638	0.05014	-0.10854	-0.03103

WS = weekend shift (difference between non-school days and school days), TST = total sleep time, TRT = total rest time, BT = bed time, RT = rise time, NOA = number of awakenings, SLE = sleep efficiency, SOL = Sleep onset latency

*p-value < 0.05 (bolded) was considered to show statistically significant relationship between variables

Supplementary table 4. Pearson correlation coefficients for mental health variables*

	Depression	Anxiety	Somatic complaints	Life satisfaction	Self-esteem	Body Image
Depression	1.000	0.794	0.684	-0.463	-0.620	-0.54110
Anxiety		1.000	0.677	-0.341	-0.520	-0.42528
Somatic complaints			1.000	-0.277	-0.405	-0.35919
Life satisfaction				1.000	0.498	0.42547
Self-esteem					1.000	0.58035
Body Image						1.000

*Statistically significant relationship was found between all pairs of variables (all $p < 0.0001$)

Supplementary table 5. **Comparison of participants with complete vs. incomplete data at baseline**

	Complete data (N=247)	**Incomplete data (N=54)**	**p-value[3]**
Age, years, mean (SD)	15.8 (0.3)	15.8 (0.3)	0.98
Males, n (%)	102 (41.3)	20 (37.0)	0.65
BMI, kg/m^2, mean (SD)	21.9 (3.0)	22.2 (3.7)	0.60
Body fat, %, mean (SD)	25.3 (8.9)	25.8 (8.3)	0.70
Vigorous PA[1], times/week, mean (SD)	4.7 (1.3)	4.4 (1.4)	0.17
Total PA[1], cpm/day, mean (SD)	2043 (475)	1939 (383)	0.19
Screen time[2], h/day, mean (SD)	6.0 (2.9)	5.8 (3.0)	0.73
Depression score, mean (SD)	17.6 (8.9)	19.0 (10.0)	0.37
Anxiety score, mean (SD)	6.7 (3.6)	6.7 (3.7)	0.88
Somatic complaints score, mean (SD)	15.7 (6.6)	17.9 (7.6)	0.04
Self-esteem score, mean (SD)	21.2 (6.8)	21.7 (6.5)	0.66
Life satisfaction score, mean (SD)	26.1 (7.1)	24.4 (8.5)	0.14
Body image score, mean (SD)	15.3 (3.2)	15.4 (3.6)	0.78
Total sleep time, h/night, mean (SD)	6.6 (0.7)	6.5 (1.0)	0.45
Total rest time, h/night, mean (SD)	7.5 (0.7)	7.4 (1.1)	0.49
Bed time, o´clock, mean (SD (min))	00:48 (52)	00:40 (68)	0.44
Rise time, o´clock, mean (SD (min))	8:22 (43)	8:18 (65)	0.60
Number of awakenings, n, mean (SD)	20.0 (5.5)	21.0 (5.9)	0.23
Night-to-night variability			
Total sleep time, min, mean (SD)	75.7 (37.2)	88.4 (58.8)	0.15
Total rest time, min, mean (SD)	85.6 (41.9)	99.0 (64.3)	0.17
Bed time, min, mean (SD)	68.8 (39.8)	65.9 (34.4)	0.63
Rise time, min, mean (SD)	99.7 (40.4)	97.4 (53.8)	0.78
Number of awakenings, n, mean (SD)	6.3 (2.6)	6.4 (3.1)	0.83
Parent with university degree, %	80.3	57.1	0.001

BMI = body mass index, PA = physical activity, SD = standard deviation, cpm = counts per minute, h = hour, n = number
[1]Total PA, by actigraphy, mean of total vector magnitude activity/wear time; Vigorous PA by self-report
[2]weighted average for the week (5 weekdays and 2 weekend-days), by self-report
[3]p-value < 0.05, for differences between follow-up repeaters and non-repeaters, was considered statistically significant

Supplementary table 6. **Baseline characteristics, follow-up participants vs. dropouts**

	Participants (n=152)	Dropouts (n=92)	p-value[3]
Age, years, mean (SD)	15.9 (0.3)	15.9 (0.3)	0.98
BMI, kg/m^2, mean (SD)	22.0 (3.2)	21.9 (2.9)	0.91
Body fat, %, mean (SD)	25.0 (9.1)	25.6 (8.7)	0.58
Vigorous PA, subjective, n (%)			0.07
Less (< 4x/week)	47 (31.0)	39 (42.4)	
More (≥ 4x/week)	105 (69.0)	53 (57.6)	
Total PA[1], objective, cpm/day, mean (SD)	2063 (490)	2003 (444)	0.33
Screen time[2], h/day, mean (SD)	5.7 (2.5)	5.8 (2.6)	0.86
Depression score, mean (SD)	17.7 (9.2)	17.3 (8.5)	0.76
Anxiety score, mean (SD)	6.6 (3.6)	6.7 (3.7)	0.87
Somatic complaints score, mean (SD)	15.8 (6.7)	15.3 (6.5)	0.53
Self-esteem score, mean (SD)	21.1 (6.7)	21.5 (7.0)	0.63
Life satisfaction score, mean (SD)	26.5 (6.5)	25.5 (7.9)	0.32
Body image score, mean (SD)	15.2 (3.1)	15.4 (3.4)	0.62
Total sleep time, h/night, mean (SD)	6.6 (0.7)	6.6 (0.6)	0.28
Total rest time, h/night, mean (SD)	7.5 (0.7)	7.5 (0.7)	0.97
Bed time, o´clock, mean (SD (min))	00:48 (50)	00:46 (55)	0.77
Rise time, o´clock, mean (SD (min))	8:24 (40)	8:19 (48)	0.44
Number of awakenings, n, mean (SD)	19.3 (5.8)	20.8 (5.1)	0.04
Night-to-night variability			
Total sleep time, min, mean (SD)	78.2 (40.0)	72.4 (32.8)	0.22
Total rest time, min, mean (SD)	88.3 (45.0)	81.4 (37.2)	0.19
Bed time, min, mean (SD)	68.9 (44.4)	68.2 (32.4)	0.90
Rise time, min, mean (SD)	99.0 (39.3)	100.9 (42.5)	0.73
Number of awakenings, n, mean (SD)	6.0 (2.4)	6.6 (2.7)	0.06
Parent with university degree, %	83.0	75.6	0.20

BMI = body mass index, PA = physical activity, SD = standard deviation, cpm = counts per minute, h = hour, n = number
[1]mean of total vector magnitude activity/wear time
[2]weighted average for the week (5 weekdays and 2 weekend-days)
[3]p-value < 0.05, for differences between follow-up repeaters and non-repeaters, was considered statistically significant

Supplementary table 7.

Standardized Betas for significant linear relationships between screen time and sleep variability at age 15, with models further adjusted for total sleep time and daylength[a,b]

	All (N=247)			Boys (N=103)			Girls (N=144)		
	Std. β	**SE**	**p[c]**	**Std. β**	**SE**	**p[c]**	**Std. β**	**SE**	**p[c]**
SD_Total sleep time	0.216	1.088	**0.0012**	0.375	2.049	**0.0004**	0.055	1.241	0.55
SD_Total rest time	0.208	1.222	**0.0017**	0.379	2.227	**0.0003**	0.015	1.428	0.87
SD_Bed time	0.239	1.145	**0.0003**	0.337	2.409	**0.0015**	0.100	1.026	0.27
Shift[d]_Bed time	0.164	0.0013	**0.012**	0.249	0.0026	**0.02**	0.081	0.0013	0.38
SD_Rise time	0.135	1.161	**0.0384**	0.271	2.080	**0.01**	-0.011	1.438	0.90
Shift[d]_Rise time	0.136	0.0016	**0.04**	0.232	0.0027	**0.03**	0.006	0.002	0.95

ST = screen time, SD = standard deviation, β = standardized regression coefficient, SE = standard error, n/N = number

[a]Values for screen time and night-to-night variations (as SDs) in sleep parameters are for the entire week

[b]Models were adjusted for body fat percentage, parental education, physical activity , total sleep time and daylength

[c]p-value < 0.05 (bolded) was considered to show statistically significant relationship between screen time and outcome variable

[d]Shift = weekend shift, the difference between non-school days and school days.

Supplementary table 8.

Standardized Betas for significant linear relationships between physical activity and sleep variability, with models further adjusted for total sleep time and daylength[a,b]

	All (N=247)			Boys (N=103)			Girls (N=144)		
	Std. β	**SE**	**p[c]**	**Std. β**	**SE**	**p[c]**	**Std. β**	**SE**	**p[c]**
Shift[d]_Total sleep time	-0.111	0.011	0.11	-0.185	0.022	0.09	-0.081	0.012	0.39
Shift[d]_Total rest time	-0.121	0.013	0.08	-0.156	0.026	0.16	-0.113	0.014	0.23
SD_Rise time	-0.187	0.006	**0.0067**	-0.131	0.011	0.22	-0.226	0.007	**0.0161**
SD_Number of awakenings	-0.291	3.7x10^{-4}	**<0.0001**	-0.270	6.6x10^{-4}	**0.013**	-0.287	4.1x10^{-4}	**0.001**
Shift[d]_Number of awakenings	-0.143	0.001	**0.042**	-0.037	0.002	0.73	-0.196	0.001	**0.03**

PA = physical activity, SD = standard deviation, β = standardized regression coefficient, SE = standard error, n/N = number

[a]Values for physical activity and night-to-night variations (as SDs) in sleep parameters are for the entire week

[b]Models were adjusted for body fat percentage, parental education, screen time, total sleep time and daylength

[c]p-value < 0.05 (bolded) was considered to show statistically significant relationship between physical activity and outcome variable

[d]Shift = weekend shift, the difference between non-school days and school days.