Online communication and adolescent health

Exploring adolescent mental and physical health and online communication in the early 21st century: Longitudinal and cross-sectional perspectives

Óttar Guðbjörn Birgisson

Dissertation towards the degree of Doctor of Philosophy

September 2025

School of Education

FACULTY OF HEALTH PROMOTION, SPORT & LEISURE STUDIES

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Thesis for the degree of Philosophiae Doctor

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Netsamskipti og heilsa ungmenna

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Ágrip

Þessi doktorsritgerð fer yfir þróun tengsla á milli netsamskipta, geðheilsu og líkamlegrar heilsu unglinga. Meginmarkmið var að meta hvernig netsamskipti tengjast geðheilsu (þunglyndi, kvíða, sjálfsáliti og líkamsímynd) og líkamlegri heilsu (þreki) við 15 ára aldur. Einnig var skoðað hvernig sambandið milli þessara þátta hefur breyst í upphafi 21. aldarinnar frá 2003 til 2017 þegar miklar breytingarnar í netsamskiptaleiðum áttu sér stað.

Rannsóknin byggir á þremur gagnasöfnum á íslenskum ungmennum: Hópi fæddum árið 1988 sem var metinn árið 2003 (n = 385) og hópi fæddum árið 1999 sem var metinn árið 2015 (n = 302) og fylgt eftir árið 2017 (n = 236). Mælingar innihéldu spurningar um netnotkun, gagnreynda spurningalista til að meta geðheilsu og hlutlægar mælingar á þreki. Félags- og efnahagsleg staða var metin út frá menntun foreldra og búsetufyrirkomulagi. Tölfræðigreiningar náðu yfir lýsandi tölfræði, fjölþátta aðhvarfsgreiningu, dreifigreiningu, formgerðargreiningu og marglaga líkanagerð.

Niðurstöður sýndu að þunglyndiseinkenni jukust hjá stúlkum á tímabilinu 2003 til 2015 en stóðu í stað hjá drengjum. Kvíðaeinkenni breyttust ekki marktækt hjá hvorugu kyninu og sjálfsálit var stöðugt yfir tímabilið. Líkamsímynd batnaði lítillega hjá drengjum en var óbreytt hjá stúlkum. Árið 2015 komu fram marktæk tengsl milli netsamskipta og aukinna þunglyndis- og kvíðaeinkenna hjá stúlkum, en slík tengsl voru ekki til staðar hjá drengjum. Þrek minnkaði frá 2003 til 2015 og samband fannst milli þreks og geðheilsu. Þrek versnaði einnig frá 2015 til 2017 frá 15 til 17 ára. Þá kom í ljós að netsamskipti höfðu neikvæð áhrif á geðheilsu og þrek við 15 ára aldur og hélst það samband fram til 17 ára aldurs óháð kyni og félagslegri stöðu.

Niðurstöður varpa ljósi á flókið samspil netsamskipta og heilsu ungmenna og að vaxandi vinsældir netsamskipta í upphafi 21. aldarinnar virðist vera að hafa neikvæð áhrif á heilsu ungmenna. Niðurstöðurnar benda sérstaklega til þess að aukin samskipti á netinu tengist verri geðheilsu og þá sérstaklega hjá stúlkum og mögulega í gegnum félagslegan samanburð. Minnkandi þrek og tengsl þess við geðheilsu undirstrikar nauðsyn þess að horfa á líkamlega heilsu og geðheilsu í samhengi. Þessar niðurstöður bæta skilning okkar á heilsu unglinga í stafrænum heimi og leggja grunn að frekari rannsóknum og markvissari inngripum.

Lykilorð:

Netsamskipti, Samfélagsmiðlar, Ungmenni, Geðheilsa, Þrek.

Abstract

In this thesis, I investigate the evolving relationship between online communication and adolescent mental and physical health, focusing on changes over time. The main aim was to assess how online communication relates to mental health outcomes (depression, anxiety, self-esteem, and body image) and physical health, measured as cardiorespiratory fitness (CRF). Additionally, how these relationships have changed in the early 21st century, during a period of significant transformations in online communication, was explored.

Three datasets collected from Icelandic adolescents were used. 1) A cohort born in 1988 assessed in 2003 at age 15 ($n = 385$), 2) a cohort born in 1999 assessed in 2015 at age 15 ($n = 302$), and 3) the cohort born in 1999 followed up in 2017 at age 17 ($n = 236$). Measurements included self-reported online communication frequency, validated questionnaires assessing mental health, and objective CRF measurements using a maximal cycle ergometer test. Socioeconomic status (SES) was estimated based on parental education and living arrangements. Statistical analyses included descriptive statistics, multiple regression, analysis of variance, structural equation modeling, and mixed-effects models.

Results showed that depressive symptoms increased among adolescent females between 2003 and 2015 while remaining stable for males. Anxiety levels and self-esteem did not change significantly for either sex. Body image improved slightly for males but was stable for females. By 2015, a significant relationship was found between online communication and an increase in depressive and anxiety symptoms in females but not in males. CRF declined from 2003 to 2015, and a negative association between CRF and mental health outcomes was observed. Lastly, online communication had a negative association with mental health and CRF at the age of 15, and that this relationship persisted until the age of 17, regardless of sex and SES.

The findings highlight the complex dynamics of online communication and its impact on adolescent mental and physical health. Increased online communication appears to be linked to poorer mental health outcomes particularly for females, possibly mediated by social comparison. Declining CRF underscores the importance of promoting physical fitness alongside mental health interventions. To address these challenges, interventions should integrate both digital literacy and physical activity strategies. This study contributes to a deeper understanding of adolescent well-being in the digital age and provides a foundation for targeted interventions.

Keywords:
Online communication, Social media, Adolescents, Mental health, Cardiorespiratory fitness.

Acknowledgements

This doctoral journey has been challenging yet one of the most rewarding experiences of my life, and I am deeply grateful to everyone who supported me along the way.

First and foremost, I would like to express my heartfelt gratitude to my supervisors, Dr. Erlingur Jóhannsson and Dr. Sunna Gestsdóttir. Their professional guidance, mentorship, and invaluable lessons in academia have shaped me as a researcher and scholar. I am incredibly fortunate to have had their support and encouragement throughout this process.

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I am deeply grateful to the School of Education at the University of Iceland for providing the resources and a nurturing academic environment to carry out this research. I also owe my thanks to everyone who was part of the *Heilsuhegðun ungra Íslendinga* project, whose work laid the foundation for this thesis. Special thanks go to Dr. Kristján Ketill Stefánsson for his invaluable assistance and thoughtful guidance during the analytical phases of this research.

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To my parents, thank you for instilling in me the values of perseverance, conscientiousness, and curiosity, which have carried me through this journey. To my wife, Dísa, and my children, Jökull, Lotta, and Orri, thank you for your unwavering love, patience, and understanding during the highs and lows of this journey. You are my greatest source of strength and inspiration.

Finally, I want to thank all the participants who contributed to this research. Your willingness to share your experiences has been vital to this work, and I hope the insights gained will contribute to bettering the lives of others. I dedicate this achievement to all of you.

Óttar Guðbjörn Birgisson
Kópavogur, 2025

Contents

List of Abbreviations

AOL = America Online

APA = American Psychiatric Association

BMI = Body Mass Index

CRF = Cardiorespiratory fitness

DSM = Diagnostic and Statistical Manual of Mental Disorders

IRC = Internet Relay Chat

MSN = Microsoft Messenger

OC = Online Communication

OECD = Organization for Economic Cooperation and Development

OSIQ = Offer Self-Image Questionnaire

PA = Physical Activity

PH = Physical Health

SCL = Symptom Checklist

SES = Socio-Economic Status

SMN = Social Media Network

$VO2_{max}$ = Maximal oxygen consumption

$VO2_{peak}$ = Highest amount of oxygen consumed at peak exercise

WHO = World Health Organization

W_{max} = Maximal work capacity

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List of Original Papers

This thesis is based on the following original publications, which are referred to in the text by their Roman numerals (I, II, III):

I. Birgisson, O., Hysing, M., Eriksen, H. R., Johannsson, E., & Gestsdottir, S. (2023). The relationship between online communication and adolescents' mental health: Long-term evaluation between genders. *Scandinavian Journal of Public Health, 52*(4). https://doi.org/10.1177/14034948231161382

II. Birgisson, O., Eriksen, H. R., Hysing, M., Johannsson, E., & Gestsdottir, S. (2024). Adolescent mental health and cardiorespiratory fitness: A comparison of two cohorts 12 years apart. *PLOS One*, *19*(5). https://doi.org/10.1371/journal.pone.0300810

III. Birgisson, O., Johannsson, E., Eriksen, H.R. Hysing, M., & Gestsdottir, S. (2025). The relationship between online communication and mental health and cardiorespiratory fitness from ages 15 to 17: A longitudinal cohort study. *BMC Public Health* 25, 587. https://doi.org/10.1186/s12889-025-21833-1

Declaration of Contribution

The initial idea for this PhD project originated from Dr. Erlingur Jóhannsson and Dr. Sunna Gestsdóttir. I independently applied to the PhD program and developed my own research plan, which was built upon their initial concept. Throughout the project, I worked closely with my supervisors, who provided guidance, but the majority of the effort and implementation was carried out by me.

This project utilized previously collected datasets from older studies by Dr. Erlingur Jóhannsson and Dr. Sunna Gestsdóttir and their colleagues. Although I was not involved in the data collection or initial verification, I was solely responsible for cleaning the data and combining the three datasets into one comprehensive database for these analyses. I received minimal assistance with this process, primarily through email communication with Hans Haraldsson from the Educational Research Institute at the School of Education, as well as from my supervisors.

I independently performed all statistical analyses for this project, consulting with Dr. Kristján Ketill Stefánsson, Assistant Professor at the School of Education, for specific methodological and analytical advice. I also led the interpretation of findings and drafted all manuscripts included in the thesis.

I have presented the results of this research at multiple conferences and in various media outlets, acting as the primary spokesperson for this study. While my supervisors, Dr. Jóhannsson and Dr. Gestsdóttir, provided initial guidance and oversight, the research planning, data management, analysis, interpretation, and dissemination were predominantly my responsibility.

1 Introduction

"The Web does not just connect machines, it connects people," proclaimed Sir Tim Berners-Lee, the inventor of the World Wide Web. These words capture the transformative power of the internet, a force that has reshaped the fabric of modern society and brought the world closer together than ever before. Today, the internet is not just a tool but a lifeline, enabling everything from instant communication to global commerce. Its profound impact on daily life is undeniable, with some even arguing that access to the internet should be recognized as a fundamental human right (Reglitz, 2020). However, as with most technological advancements, concerns have arisen regarding its impact on society, particularly on adolescents (Anderson et al., 2017; Montag & Diefenbach, 2018).

Such concerns are not new. Around 370 B.C.E., Socrates said that the written word was making young people forgetful (Jowett & Ballin, 2017). In the late 1800s, people believed that the telephone would make us lazy (Marvin, 1988, p.68), and in the 1970s and 1980s, researchers speculated that television was slowing the cognitive development in children and making them more aggressive (Hornik, 1978; Liebert, 1986). However, these concerns are often forgotten when new technologies become popular or when research disproves them. Nonetheless, the advent of the internet has sparked a new wave of such worries, and the jury is still out on whether it has a negative impact on adolescents.

The Internet has been available to the general public since the 1990s, and when the broadband connection became widely accessible around the year 2000 the Internet became part of most Western households (Gillett & Lehr, 1999). Therefore, today's adolescents and young adults are among the first generation (the generation Z, born approximately between 1995-2012) to grow up with the internet as a fundamental part of their lives. They have the option to do most daily tasks and activities through the internet which required more time and physical activity to complete before. These include shopping, banking, socializing, dating, and communicating in general, to name a few things (Seemiller & Grace, 2018). Furthermore, the development of smartphones and broadband cellular networks has made the internet even more accessible and always within reach.

Along with the advancement of the Internet, there has been evidence of declining mental health among adolescents and especially females (Bor et al., 2014; Parodi et al., 2022; Potrebny et al., 2024; Thapar et al., 2022; Twenge et al., 2019). Notably, depression rates among 12-17 year olds have increased from 8.3% to 12.9% between 2011 and 2016 (Twenge et al., 2019) which means it increased by 55.4% in a short

period. Physical health, too, seems to be getting worse in the 21st century, with a significant drop in cardiorespiratory fitness (CRF) among adolescents between 2000 and 2009 (Dyrstad et al., 2012), and a widespread increase in obesity rates across European countries (Nittari et al., 2020). In this thesis, I seek to explore the interplay between these trends of declining health and the evolving role of online communication.

2 Background

2.1 Adolescence

Understanding adolescence is crucial, yet often overlooked in research (Patton & Temmerman, 2016). Adolescence is a pivotal developmental stage marking the transition from childhood to adulthood, typically occurring between the ages of 10 and 19 (World Health Organization, n.d.) with 14-15 being the middle of the range. This period is characterized by significant physical, psychological, and social changes and marked by developmental milestones such as the onset of puberty, increased independence, and identity formation. Cognitively, adolescents begin to develop more advanced abstract thinking, problem-solving skills, and moral reasoning (Eccles et al., 2003; Steinberg, 2005). Furthermore, since the prefrontal cortex and other structures in the brain are still developing, the adolescent is not as rational as an adult (Dumontheil, 2016) which often clashes with the increased autonomy that goes with adolescence. Socially, peer relationships take on greater importance, influencing behavior, self-esteem, and identity (DuBois et al., 2002; Tarrant et al., 2001). While this stage is full of opportunities for growth and development, it also presents various risks. Emotional volatility, risk-taking behaviors, and susceptibility to external influences like peer pressure can make adolescents more vulnerable to issues such as substance abuse, mental health disorders, and academic challenges (Steinberg, 2004; Zarrett & Eccles, 2006). There are worries that this period is going to be especially challenging for generation Z (born around 1995 to around 2012) mostly because of a hyperconnected world and the rapid development of digital technology (Elmore & McPeak, 2019; Haidt, 2024; Seemiller & Grace, 2018; Twenge, 2017).

Adolescence manifests differently in males and females, not just physically but also emotionally and socially (Peper et al., 2020). For instance, females often enter puberty earlier than males and may experience emotional and social changes sooner than males as a result. Males tend to engage in more physical risk-taking behaviors, while females are more likely to experience emotional turbulence and body image issues (Perry & Pauletti, 2011). Understanding these differences is essential for a more nuanced approach to adolescent education, healthcare, and social services, acknowledging that the experiences of adolescent males and females can diverge in significant ways. Therefore, studies on adolescents should factor in sex differences.

Adolescent education is slightly different in Iceland than in other European countries. Compulsory education in Iceland ends after the 10th grade, typically when students are between 15 and 16 years old. Following this, most adolescents choose to attend upper

secondary school, which is optional. Secondary schools generally require 3–4 years to complete, culminating in a matriculation diploma (*stúdentspróf* in Icelandic). This diploma qualifies students for university admission, where they can pursue bachelor's degrees and beyond. Alternatively, some adolescents opt for vocational education after compulsory schooling. These programs also last 3–4 years and conclude with an apprenticeship and a journeyman's examination in their chosen field. However, vocational qualifications do not meet the minimum requirements for university admission, unlike the matriculation diploma (Stefansson & Karlsdottir, 2007).

2.2 Online communication

Online communication is a big part of most people's daily life. According to data from 2022 from countries in the European Union, people mostly use the internet for communication purposes (Eurostat, 2022). Online communication is mostly attained through social media networks (SMN) such as Facebook, Instagram, Discord, and related platforms. However, it is not exclusive to those platforms. Other means of online communication are emails, instant messengers, chatrooms, and online forums. In this thesis, online communication is defined as *all means of sending and receiving information between two or more people, synchronous or asynchronous, exclusively using the internet*. A good way to get a feel for what is meant by online communication is by going through the history of online communications and starting at the beginning (see Figure 1).

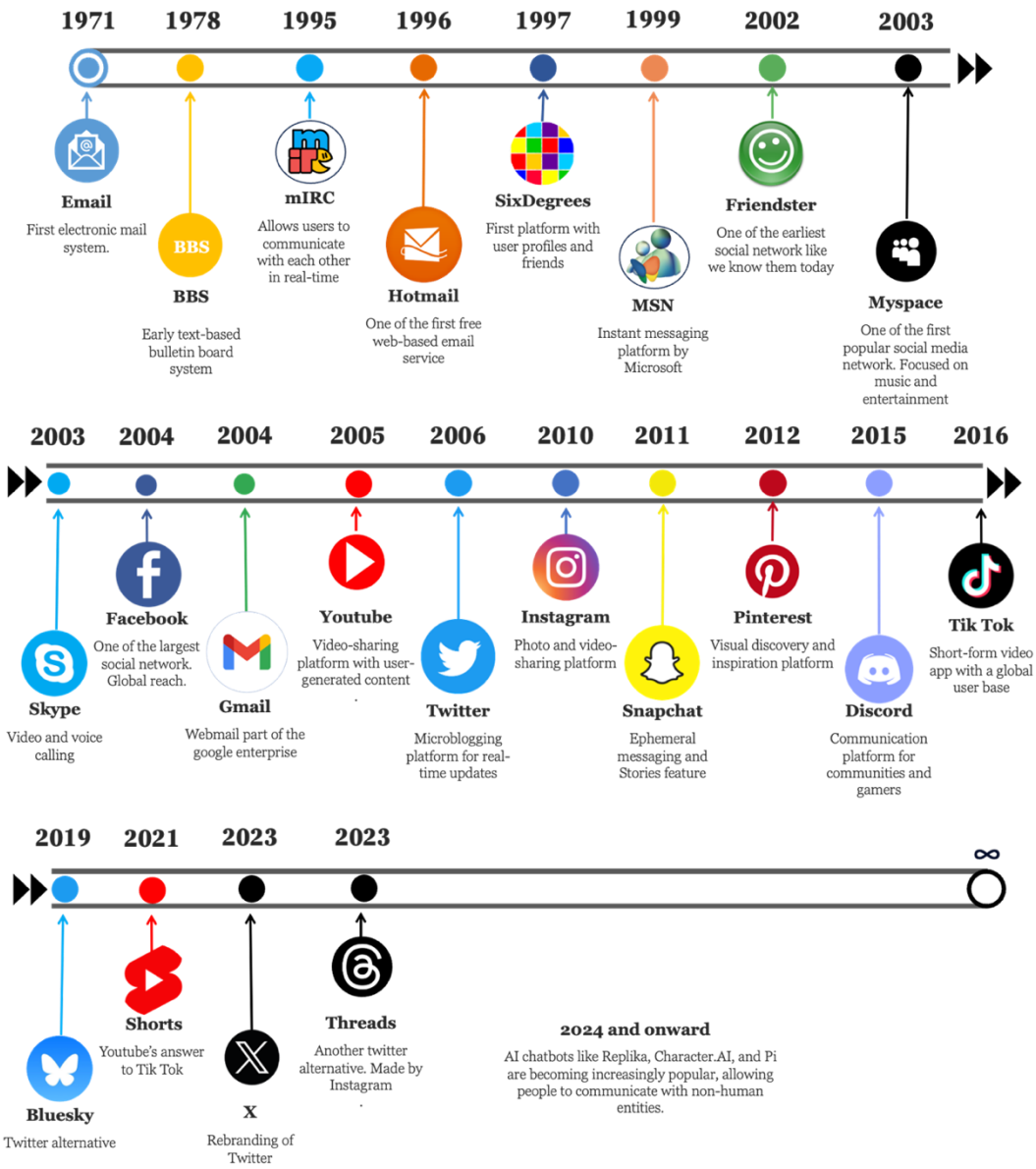

Figure 1. Timeline of the main advancements in online communication from 1971 to 2024.

BBS = Bulletin Board System, mIRC = Microsoft Internet Relay Chat, MSN = Microsoft Network Messenger.

2.2.1 History of online communication

Although the history of the internet can be traced at least back to the 1950s and the first email being sent in the 1970s, it did not have a significant impact on how people communicated until the early 1990s when ordinary people could access the internet through their personal computers using the existing telephone wires to access it (Leiner et al., 2009). During that time, communication between the general population could for the first time happen through personal emails, online forums, and Internet relay chat (IRC). Later instant messengers such as AOL and MSN became common and at the beginning of the 21st century, social networks became an inseparable part of most people's lives, especially after the invention of the smartphone in the later part of the first decade and onward (Dainow, 2017). Haidt (2024) has argued that one of the biggest and most important changes to social media occurred around 2010 when social media became a lot more algorithmically driven and able to tailor the content more efficiently to the user and keep him more engaged. However, in a review of the rising prevalence of internalizing conditions among adolescents, Keyes and Platt conclude that while social media and digital technology are often cited as contributing factors, the evidence remains inconclusive, warranting further research to clarify their role (Keyes & Platt, 2024).

Looking ahead, the rise of AI-driven chatbots such as Replika, Character.AI, and PI represents a possible paradigm shift in online communication. These technologies represent a change in how social interaction can occur online. Unlike traditional social networks that facilitate communication between humans, these chatbots introduce the possibility of engaging in meaningful, dynamic conversations entirely with non-human entities. This development redefines "social networking" by enabling individuals to seek connection, companionship, or even emotional support in solitude, engaging with algorithms that are increasingly capable of mimicking human-like interaction. As this trend gains traction, it raises critical questions about its implications for human relationships, mental health, and the very nature of socialization in the digital age.

2.2.2 Online communication trends among adolescents

Adolescence is marked by significant developmental changes, such as identity formation, emotional regulation, and the growing influence of peer relationships (Eccles et al., 2003; Steinberg, 2005). In this context, the considerable time adolescents spend online has raised concerns about how the Internet may affect these processes (Surgeon General, 2023). For instance, online communication might amplify the influence of peers because they are always just one click away from your phone or computer. Additionally, the emotional volatility and risk-taking behaviors typical of this stage (Steinberg, 2004; Zarrett & Eccles, 2006) may be amplified in digital environments, potentially impacting mental health and social development.

Internet use amongst 15-year-olds in the OECD countries increased from 2012 to 2015

from 21 hours per week to 29 hours per week (Echazarra, 2018). That is around 4.1 hours per day online or around one-fourth of their waking hours. Furthermore, total screen time for teens in 2018 was 7-8 hours per day (Common Sense Media, 2019). Although most adolescents today are familiar with online communication (Tsitsika et al., 2014), this was not always the case. In 2003, general computer use was common, with 91% of American children and adolescents using computers daily. However, only 59% reported using the Internet, and a mere 36% used it for online communication, such as emails or instant messaging (DeBell & Chapman, 2006). However, in 2015, at least 71% used the internet for online communication (Lenhart, 2015). In 2003, there were many platforms to communicate online, though social media networks were not common. That year in Iceland, a hobby-based website (Hugi.is) similar to today's Reddit.com, was popular with 25.000 active users a week (Fréttablaðið, 2003). Other popular online communication tools in Iceland were mIRC, MSN, and emails. Ten years later, in 2013, around 64% of Icelandic 15-year-olds had their own smartphone and 39% used smartphones to access social media (SAFT, 2013). In 2016, over 90% of Icelandic adolescents used social media every day (Guðmundsdóttir et al., 2016).

2.2.2.1 Differences in online communication between sexes

Female adolescents are more likely to use the Internet for social networking, while male adolescents are more likely to engage in online gaming (Dufour et al., 2016). However, it is important to note that many online games incorporate social elements, often blurring the lines between gaming and social networking. For example, platforms like Roblox are classified as both games and social media networks. With advances in virtual reality, this overlap between gaming and social media is becoming even more pronounced (Han et al., 2023). Sex differences also emerge when examining internet addiction. Female adolescents tend to attribute their addiction to social media, whereas male adolescents are more likely to attribute theirs to pornography (Rehbein & Mößle, 2013). Additionally, female adolescents are more likely to experience cyberbullying compared to their male peers (Beckman et al., 2013). A recent qualitative study sheds further light on how adolescents use social media differently based on sex (de Felice et al., 2022). In the study, both sexes reported using social media for communication and sharing information or images. However, their motivations differed: males often used social media to meet potential romantic partners, while females primarily sought emotional support and connection. Furthermore, female adolescents expressed concerns about constant exposure to idealized versions of femininity, which they described as frustrating and damaging to self-esteem (de Felice et al., 2022).

2.3 Mental health

According to the American Psychological Association (APA) dictionary, mental health is defined as: "a state of mind characterized by emotional well-being, good behavioral adjustment, relative freedom from anxiety and disabling symptoms, and a capacity to

establish constructive relationships and cope with the ordinary demands and stresses of life". Conversely, a mental disorder is defined as "any condition characterized by cognitive and emotional disturbances, abnormal behaviors, impaired functioning, or any combination of these. Such disorders cannot be accounted for solely by environmental circumstances and may involve physiological, genetic, chemical, social, and other factors" (*APA Dictionary of Psychology*, n.d.).

In this dissertation, mental health is defined as the subjective experience that participants report, relying on instruments with known good psychometric properties for common mental health issues among adolescents, such as depression, anxiety, low self-esteem, and negative body image (See Figure 2). Furthermore, these concepts will be referred to as *problems, issues* and/or *symptoms* depending on the context, instead of *disorders*, as the measurements only assess the symptoms experienced by the participants, rather than a diagnosis.

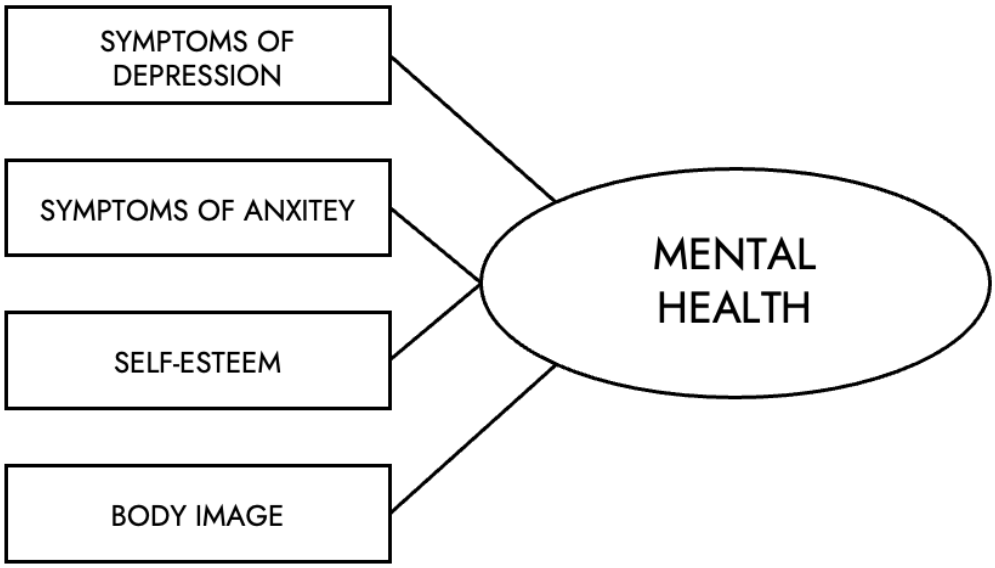

Figure 2. The mental health variables in the thesis

2.3.1 Depression

Depression is a complex mental health disorder characterized by persistent feelings of sadness, hopelessness, and a lack of interest or pleasure in activities that were once enjoyable. In addition to these main symptoms, it often includes a range of emotional, cognitive, and physical symptoms, such as changes in appetite or sleep patterns, difficulty concentrating, and feelings of worthlessness or guilt (American Psychiatric Association, 2013). Depression can significantly impair daily functioning and quality of life, and it is a leading cause of disability worldwide (Depression and Other Common Mental Disorders: Global Health Estimates, 2017). The Diagnostic and Statistical Manual of mental disorders (DSM-5) recognizes that children and adolescents, like adults, can be diagnosed with depression, but with few caveats: Children and adolescents can show the symptoms of depression or low mood as irritability. Furthermore, they can show symptom number 3 (weight gain/loss) as a failure to follow normal developmental weight gain (American Psychiatric Association, 2013).

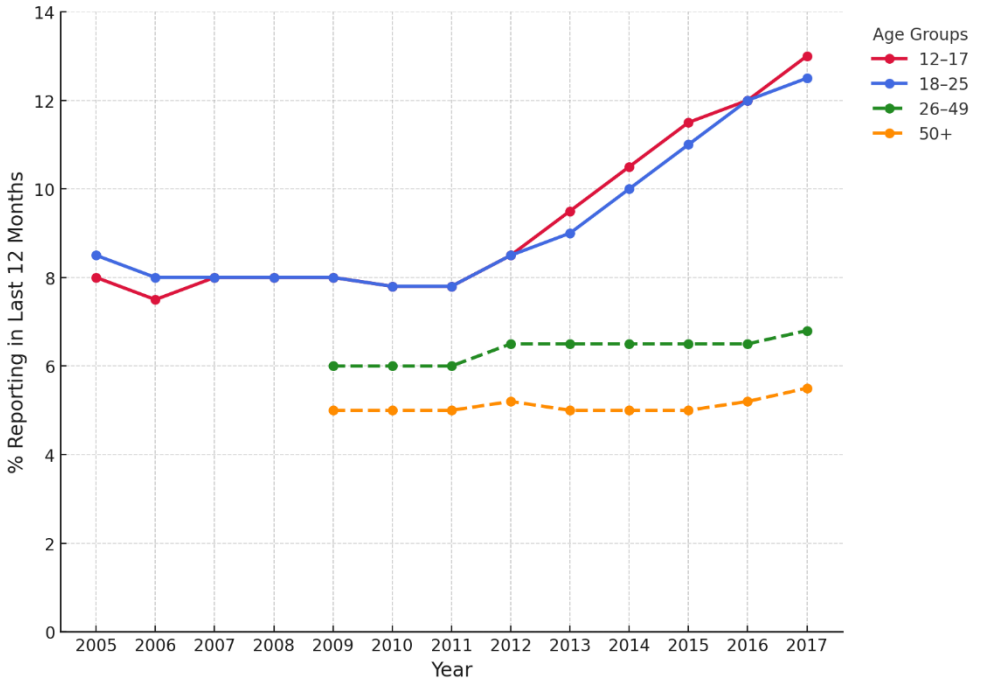

Figure 3. The 12-month prevalence for depression for four age groups from 2005 to 2017.

This figure is adapted from Haidt, J., & Twenge, J. (Ongoing). Social media and mental health: A collaborative review. New York University. Adaptation is made under the principles of fair use, with modifications to reflect the specific context of this work. Proper attribution is given to the original authors.

The Twelve-month prevalence for depression in the United States of America is usually cited as around 7% but varies between age groups (American Psychiatric Association, 2013). For example, between 2011 and 2016 depression rose from 8.3% to 12.9% for 12-17 year olds (*Young People's Well-Being in the UK - Office for National Statistics*, n.d.). Interestingly, as Figure 3 shows, the prevalence of depressive episodes for 26 years old and older has remained relatively stable in the 21st century while for ages 12-25, it has risen sharply since 2011 (Twenge et al., 2019). Furthermore, a recent systematic review and meta-analysis showed that for self-reported depressive symptoms from 2001 to 2020, the prevalence was 34% globally (Shorey et al., 2022).

2.3.2 Anxiety

Anxiety is a universal feeling everyone experiences but is often used synonymously with anxiety disorders. Anxiety disorders are a multifaceted group of mental health disorders that significantly affect the lives of millions worldwide and can affect all age groups. According to DSM-5, anxiety disorders are characterized by excessive worry, fear, and apprehension, often accompanied by physical symptoms like a racing heart, trembling, and sweating. These disorders encompass a range of specific conditions, including generalized anxiety disorder, social anxiety disorder, panic disorder, specific phobias and more, each with its unique set of symptoms and diagnostic criteria. Yet, they all share the common thread of overwhelming anxiety and distress, impacting various aspects of an individual's life (American Psychiatric Association, 2013). According to the DSM-5, even young individuals can experience anxiety disorders, although the presentation may differ from that of adults. Instead of classic symptoms of excessive worry, adolescents may exhibit signs of irritability or physical complaints like stomachaches or headaches (American Psychiatric Association, 2013). The prevalence of anxiety disorders varies among age groups and specific disorders and can fluctuate over time and it is estimated that the 12-month prevalence varies greatly from 2.4% and 29.8% (Baxter et al., 2013). In Europe, it is the most common mental health disorder for children and adolescents with a pooled prevalence rate of 5.1% to 11.8% (Sacco et al., 2024). The trend is similar for Icelandic adolescents. The proportion reporting high anxiety symptoms among 14- to 15-year-olds increased by 1.3% for boys and 8.6% for girls between 2006 and 2016 (Thorisdottir et al., 2017).

Females are more prone than males to experience anxiety disorders, such as agoraphobia, panic disorder, separation anxiety, specific phobias, social anxiety disorder, generalized anxiety disorder, obsessive-compulsive disorder, and both acute and post-traumatic stress disorders (Christiansen, 2015). This difference has also been observed among adolescents (Lewinsohn et al., 1998).

2.3.3 Body image

During adolescence, the body goes through an immense transformation. As a result, it is understandable that a focus on the body is heightened. Body image has been

defined as: "the mental picture one forms of one's body as a whole, including its physical characteristics (body percept) and one's attitudes toward these characteristics" (*APA Dictionary of Psychology*, n.d.). It is common to talk about negative body image, but negative body image is not classified as a mental disorder in the DSM-5, it is however, a crucial element of our mental health and overall self-perception (American Psychiatric Association, 2013). Studies repeatedly show it has a strong association with mental health (Allen & Celestino, 2018; Gillen, 2015; Soltani et al., 2017) and self-esteem (O'Dea, 2012). Furthermore, negative body image is associated with worse quality of life (Nayir et al., 2016). Recent evidence also suggests that physical activity may serve as a protective mediator in the relationship between negative body image and low mood (Melo et al., 2025). Similarly, sport participation has been linked to better body image (Riddervold et al., 2024).

Since negative body image is not a mental health disorder with specific cutoffs on measurements like depression and anxiety, it is hard to estimate how common it is. However, large sample studies have indicated that around half of adolescents report some body image distortions (Yun, 2018) though data from 2017-2022 does not show evidence that it is getting worse over time for college students (Jiménez-Limas et al., 2022) and data from 2010-2015 shows it is relatively stable for both males and females in all age groups (Hockey et al., 2021). This could be related to the body positivity movement that started to emerge on social media around 2012 (Cwynar-Horta, 2016; Lazuka et al., 2020).

Finally, it has been extensively documented that body image concerns are more commonly reported among females than males (Karazsia et al., 2017). This can be because the societal pressure on females to adhere to certain standards of beauty is pervasive and can lead to a multitude of body image-related issues (Merino et al., 2024). However, males also experience body image concerns, albeit often differently than females (Voges et al., 2019). Despite the higher incidence in females, the complexity surrounding male´s body image issues should not be underestimated. The intricate nature of these concerns for males may be influenced by factors such as muscularity, body composition, and societal ideals of masculinity (Bergstrom & Neighbors, 2006).

2.3.4 Self-esteem

Self-esteem, much like depression and anxiety, is a complex part of people's mental health. However, like body image issues and unlike depression and anxiety, self-esteem is not classified as a mental disorder in the DSM-5. Nevertheless, it remains a crucial aspect of mental health and has a profound impact on an individual's thoughts, feelings, and behaviors. Self-esteem is an individual's overall sense of self-worth and self-acceptance, often referred to as global self-esteem. It differs from specific self-esteem, which reflects self-evaluations in particular areas such as academics or

appearance. While global self-esteem represents a broad, general evaluation of oneself, specific self-esteem focuses on confidence in distinct aspects of life (Rosenberg, 1965b). Self-esteem (global) can therefore be defined as the measure of how positively one perceives one's self-concept, including physical self-image, achievements, values, and how others see and react to them (Rosenberg, 1965b). Higher self-esteem results from a more positive view of these qualities, which is crucial for mental health, while low self-esteem often accompanies depressive symptoms (*APA Dictionary of Psychology*, n.d.). Self-esteem is furthermore positively associated with body image (Siegel et al., 1999).

Self-esteem can manifest in various emotional, cognitive, and behavioral ways. Individuals with healthy self-esteem tend to display confidence in their decisions, assertiveness in their communication, and adaptability when facing obstacles (Baumeister et al., 2003). Conversely, those with low self-esteem may exhibit self-criticism, feelings of inadequacy, and avoidance of situations that challenge their self-worth (Rosenberg, 1965b).

Since low self-esteem is not a disorder it does not have a specific prevalence rate. Nevertheless, low self-esteem has been estimated to have a prevalence of 20% for US adolescents (McClure et al., 2010). Furthermore, the frequency of self-esteem issues can vary significantly among age groups and across cultures. Birth cohort effects explain between 7% and 40% of the variance in self-esteem scores and self-esteem scores have varied systematically among different age groups, with larger effects observed for birth cohort differences than for developmental age differences (Twenge & Campbell, 2001). Self-esteem tends to fluctuate and is usually at its lowest around puberty (Robins et al., 2002) when individuals grapple with identity development and peer influence. However, low self-esteem is not limited to any specific age group and can affect people throughout their lives (Orth & Robins, 2014).

Males tend to have slightly better self-esteem than females (Kling et al., 1999). However, though males display higher self-esteem across their lifespan, with a significant spike during adolescence, it is usually in global self-esteem (Gestsdottir et al., 2015). When it comes to domain-specific self-esteem, such as in academic areas, males show levels comparable to females (Zeigler-Hill & Myers, 2012). Furthermore, males often report lower self-esteem in moral-ethical areas, contrasting with higher self-esteem in fields like athletics (Zeigler-Hill & Myers, 2012). This suggests that while overall self-esteem trends may favor males, the variation across different domains presents a more complex picture (Zeigler-Hill & Myers, 2012).

2.3.5 Adolescents and mental health

The most common age for the onset of mental health problems is at the age of 14.5 (Solmi et al., 2021) which is in the middle of the adolescent age range. During this period, individuals experience rapid changes in their bodies and brains, alongside new

social and academic pressures (Zarrett & Eccles, 2006). These changes can make adolescents particularly susceptible to mental health issues such as anxiety, depression, low self-esteem, and negative body image.

2.4 Physical health

Health is usually defined as: "... a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." (World Health Organization, 1948). There are many ways to measure physical health.

Physical health (See Figure 4 for the components of physical health), as a crucial component of overall well-being, is influenced by multiple interrelated factors, including physical fitness, body composition, and levels of physical activity. Maintaining good physical health reduces the risk of chronic diseases, enhances longevity, and improves quality of life (Warburton et al., 2006). It is often assessed through markers such as cardiorespiratory fitness (CRF), muscular strength, endurance, and metabolic health (Caspersen, Powell, & Christenson, 1985). While body mass index (BMI) is also widely used as a marker for health, research has highlighted its limitations in distinguishing between fat and muscle mass, leading to debates about its effectiveness as a sole health indicator. For instance, Bhaskaran et al (2018) found associations between BMI and mortality risks in a large-scale UK cohort, further fueling discussions about its role in health assessment. Other, more appropriate markers for physical health are physical activity (PA) and physical fitness (Sharpe et al., 2004; Simbolon & Firdausi, 2019). The latter is a broad concept that encompasses multiple facets of health, such as CRF, muscular strength and endurance, flexibility, and body composition (McArdle et al., 2006). Among these, CRF is particularly significant, as low levels are strongly associated with an increased risk of numerous chronic diseases, including cardiovascular disease, type 2 diabetes, and certain cancers (Kodama et al., 2009; Lee et al., 2010). In contrast, high CRF has been shown to be one of the most protective factors against all-cause mortality and morbidity, often outweighing traditional risk factors such as obesity or hypertension (Blair et al., 1989; Ross et al., 2016). Furthermore, physical inactivity, a major contributor to low CRF, has been identified as a leading modifiable risk factor for premature death, comparable to smoking and poor diet (Booth et al., 2012) (Booth, Roberts, & Laye, 2012) In this thesis CRF is used as a marker for overall physical health.

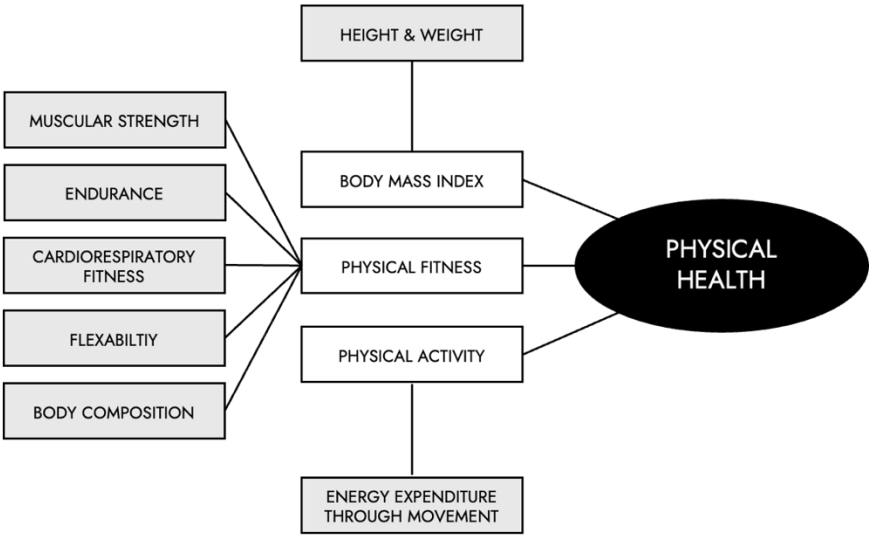

Figure 4. Composition of physical health

2.4.1 Cardiorespiratory fitness

CRF (often used interchangeably with aerobic fitness) is a measure of the efficiency of the circulatory and respiratory systems in delivering oxygen to muscles during continuous physical exertion (Raghuveer et al., 2020). Essentially, it gauges the coordination of the heart, lungs, and blood vessels in providing oxygen to muscles and eliminating waste products. While CRF holds significance in physical fitness, it is just one component of fitness, and exercise regimens should aim to enhance overall fitness across various domains (Ortega et al., 2008). However, high levels of CRF have been associated with better metabolic profiles in adolescents (Mesa et al., 2006), better overall health (Lang et al., 2018), and even better math achievement through greater cognitive processes to execute arithmetic faster (McGowan et al., 2021). Studies have shown that CRF can predict longevity (Strasser & Burtscher, 2018), with recent meta-analytic evidence highlighting its association with lower mortality risk, independent of body mass index (Weeldreyer et al., 2025). CRF has furthermore been shown to be a protective factor against stress related health hazards and burnout for adults (Gerber et al., 2013, 2016).° Additionally, CRF has been positively associated with quality of life (Bermejo-Cantarero et al., 2021; Evaristo et al., 2019).

There is an indication that CRF is getting worse for adolescents. A Norwegian study (Dyrstad et al., 2012) indicated that between 2000 and 2009, 16- to 18-year-old males and females exhibited a decline in aerobic fitness performance compared to previous decades (see Figure 5).

Recent international data support the notion that CRF among children and adolescents has declined in recent decades where trends show consistent declines over 35 years (Leone et al., 2023).

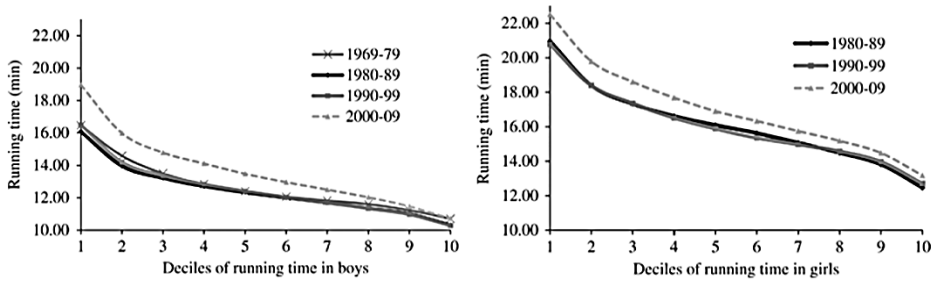

Figure 5. Aerobic fitness performance (running time) across deciles for from 1969 to 2009.

This figure is adapted from Dyrstad, S. M., Berg, T., & Tjelta, L. I. (2012). *Secular trends in aerobic fitness performance in a cohort of Norwegian adolescents*. Scandinavian Journal of Medicine & Science in Sports, 22(6), 822–827. Adaptation is made under the principles of fair use in accordance with Wiley's Terms of Use, with proper attribution to the original authors.

2.4.2 Physical activity

Physical activity (PA) is the collective term for any movement generated by skeletal muscles that leads to the consumption of energy (Caspersen et al., 1985). Exercise, a closely related concept, is "a subset of physical activity that is planned, structured, and repetitive and has as a final or an intermediate objective the improvement or maintenance of physical fitness." (Caspersen et al., 1985). Sedentary behavior is often thought of as the opposite of physical activity since it generally refers to activities that involve sitting or lying down with little energy expenditure, while awake (Tremblay et al., 2017). However, the relationship between PA and sedentary behavior is a little bit more complicated. Physical inactivity refers to when people are not doing enough of the recommended PA and is defined as engaging in less than 150 minutes of moderate-intensity PA per week (Bull, 2003). Sedentary behavior, on the other hand, refers to time spent sitting or lying down (Tremblay et al., 2017). Therefore, even if an individual engages in sufficient PA to meet recommended guidelines, they may still be categorized as sedentary if a significant portion of their day is spent sitting or reclining at work, home, during study, travel, or leisure (Knight, 2012). It has been shown that PA is a useful measure when it comes to health in general (Rödjer et al., 2012) and prescribing PA can be a useful way to increase PA (Onerup et al., 2019). Furthermore, monitoring individuals' self-reported engagement in regular physical activity may even be more relevant than assessing fitness levels when evaluating the potential mental health benefits of physical activity (Lindwall et al., 2012).

The World Health Organization (WHO) guidelines from 2020 (World Health Organization, 2020) recommend that children and adolescents aged 5-17 years should engage in a daily average of 60 minutes of moderate-to-vigorous intensity physical activity which is essential for maintaining overall well-being. The activity should be predominantly focused on aerobic exercises (to increase CRF) and should be distributed throughout the week. Additionally, it's crucial to integrate vigorous-intensity aerobic activities, along with muscle and bone-strengthening exercises, into the routine at least three days a week. Moreover, it is important to monitor and limit sedentary behavior, especially recreational screen time (such as online communications), to ensure a healthy and active lifestyle (Xu et al., 2015). These guidelines collectively promote physical fitness, cardiovascular health, muscle strength, and overall vitality, laying the foundation for a fulfilling and enduring quality of life. When people meet their recommended daily amount of physical activity it does not automatically lead to better health if all other waking hours are spent sedentary. Therefore, the 2020 WHO guidelines distinguish between physical inactivity and sedentary behavior, reflecting the evidence that these are separate constructs that require distinct guidelines (Chaput et al., 2020).

While the guidelines emphasize the importance of PA for cardiovascular and muscular health, it is equally important to consider the practical context of adherence. Studies suggest that a significant proportion of adolescents fail to meet these recommendations. For example, data from the Global Matrix 3.0 on Physical Activity among Children and Adolescents indicate that only a minority of 15-year-olds achieve the daily average of 60 minutes of moderate-to-vigorous PA (Aubert et al., 2018). In Iceland, under 50% of 15-year-olds report meeting the minimum recommendation for PA (Rognvaldsdottir et al., 2018).

These findings align with studies from 40 HBSC countries that demonstrate marked differences in adolescent activity levels based on socioeconomic and family-related factors (Haug et al., 2024; Jørgensen et al., 2025).

2.4.3 Adolescents and physical health

Adolescence is a critical period for establishing lifelong health behaviors, as patterns of physical activity and sedentary behavior formed during this stage often persist into adulthood (Sawyer et al., 2012). Physical inactivity and obesity in adolescents are serious health concerns in the world today (Ebbeling et al., 2002; Guthold et al., 2020; Johannsson et al., 2006; Wang & Lim, 2012). Adolescent obesity has risen in 27 European countries from 1980 to 2016, with some countries experiencing over fivefold increases and others, such as the UK, France, and Spain, witnessing near tripling rate (Nittari et al., 2020). Newer reports show that in 2022, one in four adolescents in Europe was overweight or obese (WHO Regional Office for Europe, 2022). Obesity rates among Icelandic schoolchildren increased from 5% to 7% over the

past decade, with a sharper rise in rural areas (6.5% to 10%) compared to the capital region (4% to 6%) (Starfshópur um offitu, 2024). A key contributor to this trend is physical inactivity, defined as engaging in less than 150 minutes of moderate-intensity physical activity per week (Bull, 2003). Additionally, sedentary behavior, prolonged sitting or reclining during activities such as studying, screen time, and commuting, is an independent risk factor for poor health outcomes, even in those who meet physical activity guidelines (Knight, 2012; Tremblay et al., 2017). Adolescents today spend more time in sedentary activities, which contributes to weight gain, metabolic issues, and declining CRF (Ng et al., 2021). Not surprisingly, obese and overweight adolescents have worse CRF than those with normal weight (Davison et al., 2010; Ortega et al., 2019; Pate et al., 2006). CRF is one of the best marker for current health and a predictor for future health (Lang et al., 2018) and thus important for adolescents.

2.5 Social well-being

Social well-being is one of the cornerstones of overall health along with physical health and mental health. It encompasses individuals' access to social resources, their ability to form and maintain meaningful relationships, and their participation in society. It is shaped by both structural and subjective factors, such as income, education, and perceived social standing, which collectively influence individuals' quality of life (Berkman et al., 2000; Keyes, 1998). Because these factors (income, education, and social standing) are also core components of socioeconomic status (SES) (Adler & Ostrove, 1999), examining SES provides a useful way to gauge social well-being.

SES is a multidimensional construct encompassing social and economic factors such as income, education, and occupational status (Adler & Ostrove, 1999). Extensive research underscores its critical role in shaping health outcomes across the lifespan. Persistent low SES has been linked to a higher prevalence of mental health disorders, such as depression and anxiety, due to chronic exposure to stress, limited access to resources, and social disadvantages (Adler & Ostrove, 1999; Kim et al., 2018). SES-related disparities in mental health are part of broader social inequalities in health, where individuals with lower SES systematically experience poorer health outcomes across various domains, including physical and mental health (Marmot, 2005). Among adolescents, SES has been identified as a significant predictor of mental health issues, with studies consistently finding that low SES is associated with increased risk (McLaughlin et al., 2012). A systematic review of 55 studies found that persistent or declining SES strongly predicts mental health problems in children and adolescents (Reiss, 2013). Adolescents from lower SES families were more likely to engage in unhealthy behaviors such as lower physical activity, higher screen time, and smoking (Jørgensen et al., 2025). Moreover, SES interacts with other demographic variables, such as sex, to influence mental health outcomes. For instance, females often report poorer mental health than males, and these differences could partially be explained by stressors and disadvantages associated with SES, such as financial strain, limited access

to resources, or social inequities (Sjögren & Kristenson, 2006). A research on Norwegian youth populations supports this, showing that SES-related stressors contribute to mental health disparities between the sexes, particularly among adolescents (Bøe et al., 2017).

Measuring SES poses challenges due to its multifaceted nature. It includes both objective factors, such as income and educational attainment, and subjective factors, such as perceived social status. Subjective assessments, which reflect individuals' perceptions of their SES relative to others, are often more predictive of mental health outcomes than objective measures (McLaughlin et al., 2012). However, researchers frequently use single proxies, such as parental education, to represent SES in studies (Aarø et al., 2009).

Given the link between SES and health, and its potential as a confounding variable, it is critical to account for SES in studies that aim to predict mental health. Research indicates that individuals with lower SES are more likely to encounter negative experiences on social media platforms, potentially exacerbating mental health issues (Odgers, 2022). Additionally, lower SES is consistently linked to a higher prevalence of mental health disorders, including depression and anxiety, due to factors such as chronic stress and limited access to resources (Reiss, 2013). By including SES, for example, as a control variable or a moderator, researchers can better isolate the effects of other variables on health outcomes and mental well-being, and enhance the robustness of their analyses (Marmot, 2005; Reiss, 2013). This allows for improved generalizability of the results.

2.6 The relationship between online communication and mental and physical health

Since physical and mental health seem to be declining rapidly for adolescents in the 21st century (Bor et al., 2014; Dyrstad et al., 2012; Haidt & Twenge, Ongoing; Nittari et al., 2020; Slee et al., 2021; WHO Regional Office for Europe, 2022) it is of interest to try to understand what could be causing it or playing a part in it. Longitudinal studies suggest that these trends are not merely a product of increased reporting but reflect genuine declines in mental health (Keyes et al., 2019; Twenge et al., 2021).

Many theories exist on why adolescents´ mental health is getting worse. Reasons have ranged from increased academic pressure (Rudolf & Bethmann, 2023), less religion and spirituality (Cotton et al., 2006), increased drug use (Johnson et al., 2015), overuse of antidepressants (Miller et al., 2014), and increased use of oral contraceptives (de Wit et al., 2020) to name a few, but most of these theories have only weak evidence. For example, while academic stress has increased over time (Organisation for Economic Co-operation and Development, 2019), its direct causal link to mental health deterioration remains debated (Wang et al., 2022). Similarly, a decline in religiosity has been observed in Western countries, but its association with

worsening adolescent mental health is inconsistent across studies (Francis & Robbins, 2019; O'Connor et al., 2003). Oral contraceptive use has been linked to mood changes in some studies (Skovlund et al., 2016), but large-scale reviews indicate that this relationship is complex and dependent on individual factors (Zethraeus et al., 2017). Screen time is more often thought to be a culprit for those negative trends but Orben and Przybylski (2019) have convincingly shown that digital technology in general is not affecting adolescents' well-being. However, other studies have found that excessive social media use, particularly among adolescent girls, is associated with increased depressive symptoms and anxiety (Keles et al., 2020; Kelly et al., 2018). Similarly, a recent study on Canadian adolescents showed that intense social media use was negatively associated with good mental health and particularly females while no such relationship was found if the engagement was in moderation (Clayborne et al., 2025). This relationship coincides with the trends of worse mental health for adolescents, especially females. The trend seems to be occurring not only in the UK and the USA but also in Australia, Canada, New Zealand, and other countries (Boyle et al., 2014; Clark et al., 2023; Haidt & Twenge, Ongoing; Hall et al., 2020).

Studies on the relationship between online communication and depression revealed mixed findings. Ivie et al. (2020) conducted a meta-analysis of 12 studies on adolescents aged 11 to 18, finding a small but statistically significant association between social media use and depressive symptoms. Similarly, McCrae et al. (2017) reviewed 11 studies with a combined sample of 12,646 children and adolescents, reporting a small but significant correlation between social media use and depression. Another more recent umbrella review which included 102 meta-analyses showed a small but significant and negative association between social media and depression. However, methodological differences and the prevalence of cross-sectional designs limit causal interpretations. Overall, these findings suggest a weak to moderate association, warranting further investigation into potential moderating factors (Ivie et al., 2020; McCrae et al., 2017; Sanders et al., 2024).

One possible moderating factor, as noted by Valkenburg et al. (2022), is the participants' sex. When sex is included, findings suggest that online communication has a larger effect on adolescent females than males (Valkenburg et al., 2022). For instance, a large cohort study from the United Kingdom found that the relationship between social media use and depression was strongest when adolescent females spent over five hours per day online (Kelly et al., 2018). That study also identified associations with worse sleep, worse body image, and increased bullying for both male and female adolescents. Additionally, a study by Twenge et al. (2018) indicated that adolescents spending more time communicating online were more likely to report negative perceptions of their mental well-being. While heightened discussions about mental health on social media may normalize these issues and increase reporting, the study also highlighted objective indicators such as suicidal behavior, which rose significantly between 2010 and 2015—a period coinciding with the rapid rise of social media use

among adolescents. This is further supported by Nilesen et al. (2024) that showed that the increase in depressive symptoms can not only be explained by changes in how adolescents report mental health problems.

Studies on the relationship between online communication and anxiety symptoms are less abundant. However, a systematic review revealed that previous studies on adolescents demonstrated a correlation between anxiety symptoms and general internet use, though many of these studies had methodological limitations (Keles et al., 2020). Another study found that problematic social media use, characterized by addictive-like behavior, was strongly associated with anxiety, although the relationship was not linear for time spent on social media (Mojtabai, 2024). Additionally, social media appears to be linked with social anxiety, as individuals with social anxiety tend to use social media passively to compensate for reduced real-life social interaction (O'Day & Heimberg, 2021).

Furthermore, social media can shape how adolescents see themselves by promoting unrealistic appearance ideals (Meier & Gray, 2014; Tiggemann & Slater, 2013). The more time adolescents spend online, the more vulnerable they become to internalizing these ideals and evaluating their bodies negatively (Twenge et al., 2018). This risk affects both boys and girls, highlighting how social media use can undermine body image across the sexes (Kelly et al., 2018).

The impact of online communication on self-esteem is less extensively studied but is still noteworthy. One study found that adolescents who received more positive feedback on social media experienced higher self-esteem, while those subjected to negative feedback saw a decline (Valkenburg & Peter, 2011). Individuals with low self-esteem may use social media in ways that perpetuate their negative self-concept, such as sharing negative self-disclosures that often receive indifferent or unsupportive responses (Forest & Wood, 2012).

As for physical health, there seems to be no clear evidence that online communication is directly affecting the physical health of adolescents. However, social media and other screen time are related to more sedentary behavior (Alley et al., 2017; Pate et al., 2011; X. Wang et al., 2019) and sedentary behavior has been shown to be associated with worse mental health (Hoare et al., 2016; Suchert et al., 2015). A recent study on screentime and PA has confirmed these findings (Haug, 2024). However, other research suggests a U shaped relationship, where both very low and problematic social media use are linked to lower activity levels, while moderate to intense but nonproblematic use may not be detrimental (Morningstar et al., 2023). Additionally and notably, physical health is associated with mental health (Noetel et al., 2024; Peng et al., 2022; White et al., 2024).

2.6.1 Theories and possible mechanisms behind the relationship between online communication and mental and physical health

In this thesis, social comparison theory (Festinger, 1954) is used as the theoretical framework to explore how online communication impacts adolescent mental and physical health. Festinger's social comparison theory suggests that people have an innate drive to evaluate themselves, often in comparison to others, to assess their abilities and opinions. When objective measures are unavailable, individuals compare themselves to others who are similar to them. This process helps them form accurate self-evaluations but can also influence self-esteem and motivation depending on whether the comparison is upward (to someone better) or downward (to someone worse). Online platforms often present idealized portrayals, fostering upward social comparisons that can negatively affect mental health, including depression, anxiety, low self-esteem, and poor body image (Vogel et al., 2014; McCarthy & Morina, 2020). Furthermore, online communication may replace face-to-face interactions, leading to misjudgments and social difficulties (Hjetland et al., 2022). Finally, according to a qualitative study, social comparison is one of the motivational factors behind using social media (Throuvala et al., 2019).

The conceptual framework for this thesis (see Figure 6) represents a theoretical draft synthesizing key background variables and proposed mechanisms rather than a formal theory or a hypothesis to be directly tested. It outlines how online communication may influence mental and physical health outcomes. Online communication increases social comparison, negatively influencing mental health, while replacing offline interactions, which may lead to less effective communication and more social misjudgments. Additionally, increased online activity often results in more sedentary behavior, contributing to poorer physical health (Santos et al., 2014). Mental and physical health are interconnected (Noetel et al., 2024; Peng et al., 2022; White et al., 2024), with negative outcomes in one domain reinforcing challenges in the other.

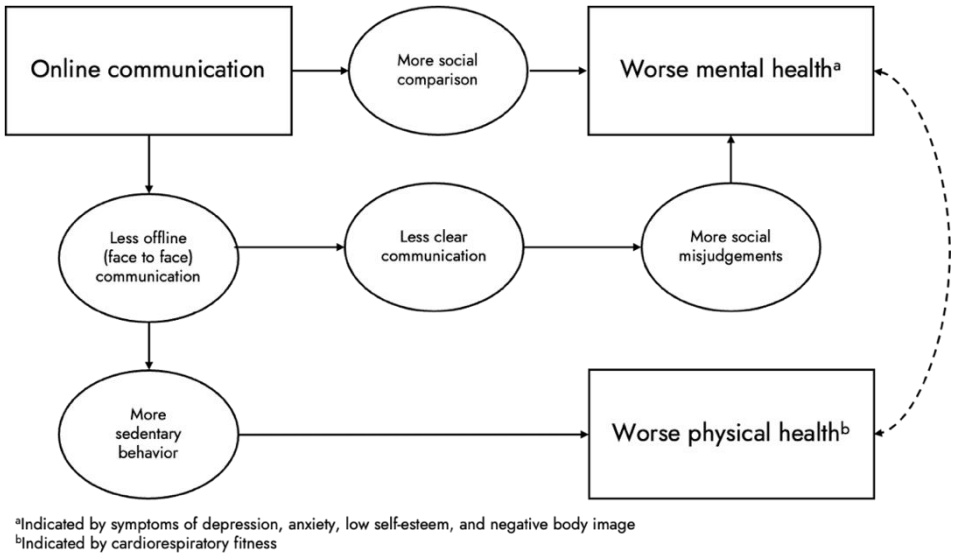

Figure 6. Theoretical framework informing the thesis

2.7 Background summary

Adolescence is a critical period marked by significant developmental changes and heightened susceptibility to mental and physical health challenges (Eccles et al., 2003; Steinberg, 2004, 2005). Against this backdrop, the rise of online communication, particularly through social media, has introduced new complexities into adolescent development. While online communication is not inherently detrimental (Craig et al., 2021; Escobar-Viera et al., 2018; Keles et al., 2020; Orben & Przybylski, 2019), it might foster a unique risk that could explain why mental health and physical health seem to be getting worse in the 21st century. Building on these findings, the current state of research highlights the multifaceted ways in which online communication shapes adolescent mental health. Studies suggest that the curated and idealized portrayals on social media amplify social comparison, while the displacement of offline interactions may lead to social misjudgments and a decline in meaningful connections (Choukas-Bradley et al., 2020; Hjetland et al., 2022; McCarthy & Morina, 2020; Nesi & Prinstein, 2015; Vogel et al., 2014). Furthermore, prolonged screen time has been linked to reduced physical activity and an increase in sedentary behavior, both of which have well-documented negative effects on physical health (Santos et al., 2014). This growing body of literature provides the foundation for examining the nuanced and interconnected effects of online communication on adolescent mental and physical health.

2.8 Knowledge gaps and novelty of the thesis

Most studies on the relationship between online communication and adolescent mental health are cross-sectional. Although cross-sectional studies are important and insightful, they limit the interpretation of possible causality and directions of effects. This thesis uses cross-sectional design along with longitudinal design to add to the knowledge we have on possible causality. Furthermore, it has been argued that it is important to account for the sex of participants in similar studies (see Valkenburg et al., 2022 for an overview). Therefore, in this study, the sex of the participants is taken into account for all analyses when possible. Another way this study addresses a knowledge gap is by comparing the relationship between online communication and mental health across two markedly different periods in the 21st century: the early 2000s (2003), when social media use was still rare, and the mid-2010s (2015 and 2017) when social media had become widespread. To my knowledge, no previous studies have examined how this relationship may have shifted across these contrasting digital contexts. Finally, this study is the first I know of that looks at the relationship between online communication and CRF.

3 Aims

The main aim of this thesis is to explore how online communication relates to adolescent mental and physical health, focusing on the changes over time, sex differences, and the interaction between mental and physical health. This aim is addressed by answering the following specific research questions, each corresponding to a research paper:

1. How has the relationship between online communication and mental health (depression, anxiety, body image, and self-esteem) evolved among 15-year-old Icelandic adolescents born in 1988 and 1999, and how has this relationship changed from 2003 to 2015 in relation to sex (Paper I).

2. How have key indicators of physical health (cardiorespiratory fitness and physical activity) changed among 15-year-olds at the beginning of the 21st century (between 2003 and 2015)? Furthermore, what is the relationship between cardiorespiratory fitness and mental health? (Paper II).

3. How does online communication relate to mental health and physical health (cardiorespiratory fitness) at ages 15 and 17 (cohort born in 1999), and how do these relationships change over time? Additionally, do these associations differ by sex and socioeconomic status? (Paper III).

4 Materials and Methods

4.1 Study design and subjects

Three pre-collected datasets were analyzed in this thesis. The earliest dataset, from a study called Lifestyle of 15-year-old Icelanders: Exercise, health, diet, and social factors (*Lífsstíll 15 ára Íslendinga: Hreyfing, heilsufar, mataræði og félagslegir þættir*), was compiled from August 2003 to January 2004 and included 385 fifteen-year-old participants (born in 1988) (190 females and 195 males) (see Figure 7). The next two datasets came from a study called The Health Behavior of the Icelandic youth (*Heilsuhegðun ungra Íslendinga)*. The first wave, amassing data in April to September 2015, included 302 fifteen-year-olds (born in 1999) (182 females and 120 males). The second wave, collected from February to April 2017, followed up with the same cohort born in 1999 and then at age 17, featuring a cohort size of 236 (149 females and 87 males). The datasets are collectively represented in Figure 7. The initial phase of this research, outlined in the first two papers, adopted a cross-sectional design, drawing on data from two cohorts born in 1988 and 1999 gathered in 2003 and 2015. The third paper uses mixed longitudinal and cross-sectional design, examining the 1999 cohort at two time points, in 2015 and 2017 when the participants were aged 15 and then 17.

The data from 2003 on the cohort born in 1988 consisted of participants from 18 schools in Iceland where 65% were from the capital area, 30% from other urban areas of Iceland, and 5% from rural areas, and those proportions are the same as the population distribution in Iceland. In total 661 got an invitation to participate and of that 58% participated and had usable data. The data from 2015 on the cohort born in 1999 had participants from six schools in the capital area of Iceland where 65% of the population lives. In total, 411 participants got an invitation to join the study and 73% agreed to participate and had usable data. The same participants that participated in 2015 were asked again to participate again in 2017 and of them, 78% agreed and had usable data (see Figure 7).

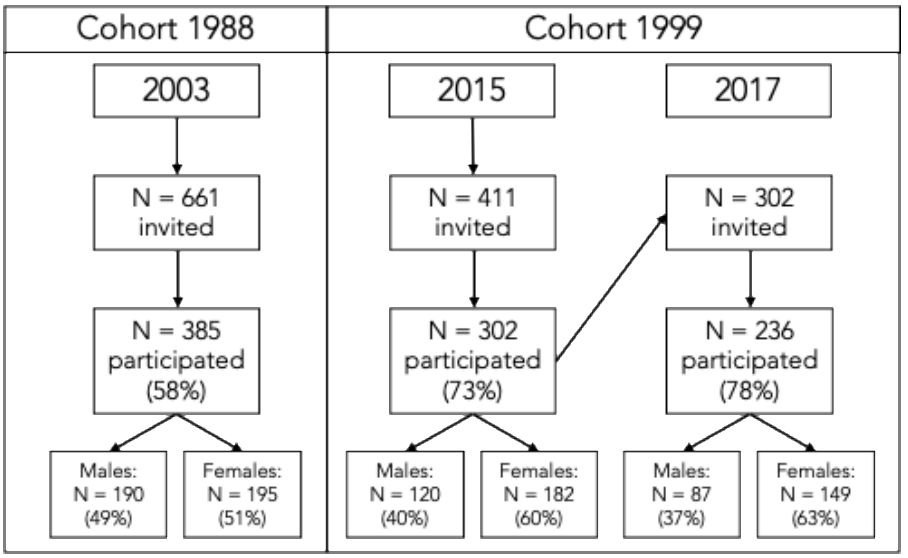

Figure 8. Recruitment of participants with attrition rates.

The data used in each study varies but is overall categorized into background, mental, and physical variables along with questions about online communication. An overview of the variables used in all the studies can be found in Figure 8 and describes in detail in the next section. Furthermore, Figure 9 shows the full context between the study variables where the measured variables are marked with red.

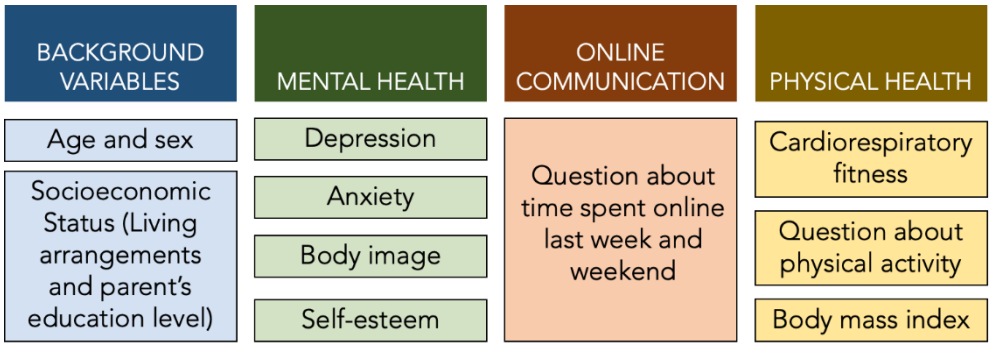

Figure 7. List of all variables used in the thesis.

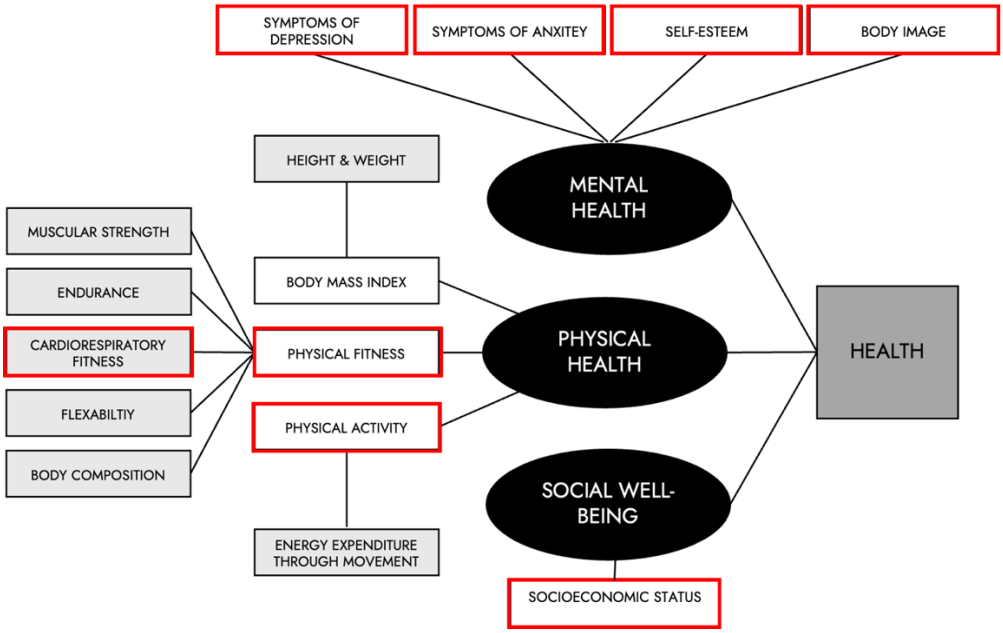

Figure 9. The context between measured variables

Note. This figure illustrates the relationships between mental health, physical health, and social well-being. The large dark gray rectangle represents overall health, while black ovals indicate key domains of health according to the World Health Organization. Light gray boxes depict specific health-related factors within each domain. Red-bordered boxes highlight the variables used in the study. Solid black lines indicate conceptual groupings within each health domain.

4.2 Ethics

This dissertation is based on results from a database that has been available for more than two decades and the initial studies had approval from the Icelandic Data Protection Authority according to the Icelandic Act on Processing of Personal Data, and the Icelandic Bioethics Committee (VSNb200605002/03 for 2003, VSNb2015020013/13.07 for 2015, and VSNa2003060014/03-12/BH/– for 2017).

4.3 Measurements

All measures had validated sources and were in the original datasets aligned with the "Health Behavior in School-aged Children (HBSC)" (Roberts et al., 2009) and by incorporating several measures from the European Youth Heart Study (EYHS) (Riddoch et al., 2005) and the Icelandic HBSC questionnaires. Online communication, depression, anxiety, self-esteem, body image, socio-economic status, and physical activity are all measured subjectively with a questionnaire. Cardiorespiratory fitness was measured objectively. For all three data collections (years 2003, 2015, and 2017), the following measurements were conducted:

4.3.1 Online communication

Questions on online communication came from a subsection about screen time in the original questionnaire (Jóhannsson et al., 2022). It was based on two questions that gauged how many hours per day the participant spent on average online communicating. The question gave examples of Facebook and writing and reading emails. One question asked about use over weekdays and the other over weekends. Options ranged from 1-7 where 1 = no use, 2 = around ½ hour, 3 = 1-2 hours, 4 = 2-3 hours, 5 = 3-4 hours, 6 = 4-5 hours, and 7 = more than 5 hours.

4.3.2 Depression

Depression was measured with a ten-item Subscale of Symptom Checklist 90 (SCL-90; Derogatis et al., 2000). It was scored on a five-point Likert scale rated from 1 (almost never) to 5 (almost always), asking about feelings of depression like "*Did you feel that the future is hopeless*", in the preceding week. Higher scores indicate a higher level of depression. Cronbach's alpha for the full scale was used to evaluate internal consistency, which was $\alpha = 0.88$ for the 1988 cohort and $\alpha = 0.94$ for the 1999 cohort. Older studies have confirmed the discriminant validity of SCL-90 between anxiety and depression (Morgan et al., 1998).

4.3.3 Anxiety

Anxiety was measured with a four-item Subscale of Symptom Checklist 90 (SCL-90)(Derogatis et al., 2000). It was scored on a five-point Likert scale rated from 1 (almost never) to 5 (almost always), asking about feelings like "Suddenly scared for no reason" in the preceding week. Higher scores indicate a higher level of anxiety. Cronbach's alpha was used to evaluate internal consistency, which was $\alpha = 0.74$ for the 1988 cohort and $\alpha = 0.88$ for the 1999 cohort. Older studies have confirmed the discriminant validity of SCL-90 between anxiety and depression (Morgan et al., 1998).

4.3.4 Self-esteem

Global self-esteem was assessed, using the Rosenberg Self-Esteem Scale (Rosenberg, 1965a; Rosenberg et al., 1995). The scale consists of ten statements like "I feel I do not have much to be proud of", each rated as negative or positive, with four response options ranging from "strongly agree" (3) to "strongly disagree" (0). Higher scores (15 points or higher) reflect a higher level of self-esteem. The Rosenberg scale has been widely used in measuring self-esteem in young people, and its reliability and validity are well documented (Kling et al., 1999; Schmitt & Allik, 2005). Higher scores indicate a higher level of self-esteem. Cronbach's alpha was used to evaluate the internal consistency of the scale, which was $\alpha = 0.87$ for the 1988 cohort and $\alpha = 0.91$ for the 1999 cohort.

4.3.5 Body image

Body image_was assessed with five items from the *Body and Self-Image subscale of the Offer Self-Image Questionnaire* (Offer, 1992). Participants were asked how well they agreed with five statements e.g. "*I'm satisfied when I think about how my body will look in the future*". All items were rated on a four-point response scale, where *1 = Not at all true of me,* and *4 = True of me*. Higher scores indicate higher levels of body image (i.e. more positive body image). Cronbach's alpha for the scale was used to evaluate internal consistency, which was $\alpha = 0.70$ for the 1988 cohort and $\alpha = 0.85$ for the 1999 cohort. Although the reliability is good former research on validity has only shown weak to moderate validity (Conti et al., 2011; Laukkanen, 2000; Lindfors et al., 2005; W. Patton & Noller, 1994).

4.3.6 Cardiorespiratory fitness

The most reliable and valid way to measure CRF involves conducting assessments in a laboratory setting. In adults, cardiorespiratory fitness is commonly expressed as maximal oxygen uptake (VO_{2max}) where milliliters of oxygen used in one minute is divided by bodyweight (mL/kg/min), while for adolescents, it is sometimes referred to as peak oxygen uptake (VO_{2peak}; Lang et al., 2018). However, it has also been validated that CRF can be measured less invasively by using the maximal cycle ergometer test on a stationary bike where maximal mechanical power (W_{max}) produced, is used, after being dived by bodyweight, as an indirect measure of VO_{2max} (Andersen, 1995). The test has been validated in adolescents and predicted oxygen uptake from this test correlates well with measured oxygen uptake (Arngrimsson et al., 2008; Eisenmann, 2007). Furthermore, CRF can be denoted ordinally as a level of fitness where the VO_{2max} is categorized into low, medium, and high levels of fitness. Low levels of 42 mL/kg/min for adolescent males and 35 mL/kg/min for adolescent females should be the cutoff point to intervene to reduce risk for cardiovascular diseases (Ruiz et al., 2016).

VO_{2max} in healthy, untrained subjects across the USA, Canada, and seven European countries reveal that VO_{2max} generally increases from childhood to adolescence in both males and females, before declining with age (Shvartz & Reibold, 1990). When it comes to sex differences males tend to have better CRF (Ekelund et al., 2007) and that has been attributed to blood factors that determine how oxygen delivery is different between sexes (Diaz-Canestro et al., 2022).

In this thesis, CRF was assessed objectively using the maximal cycle ergometer test on a Monark stationary bike (Hansen et al., 1989) where maximal mechanical power (W_{max}) was used, after being dived by the participants' weight, to assume the VO_2 max.

4.3.7 Physical activity

The physical activity was assessed with the question "How often, per week, do you perform physical activity that makes you breathe more rapidly or sweat?". Response options were six ranging from 1 = never to 6 = almost every day.

4.3.8 Socio-economic status

To estimate participants' SES, parents' education and their living arrangements were used. Parents' education was measured by questions about their education level, e.g., if they had finished primary school, secondary school, apprenticeship, or university. Participants also answered questions about whom they lived with, e.g., with both parents, with either mother or father, with grandparents, or other living arrangements. To simplify multiple regression analysis, a single SES variable was created: 3 for participants with both parents having a university education and living with both parents, 2 for those with one parent having a university education or living with both parents, and 1 for those with neither (Amato & Keith, 1991; Manning & Lichter, 1996; Ravanera & Rajulton, 2010).

4.4 Statistics

All statistical analyses were conducted in Rstudio (RStudio Team, 2020) and Jamovi (The Jamovi Project, 2021) after raw data was organized first in Microsoft Excel (Microsoft Corporation, 2018) with further work in Rstudio. The data wrangling mainly consisted of turning the raw data into well-structured data frames using comprehensible variable names that are the same across all datasets and that all variables were coded and classified correctly. All data was inspected prior to each analysis. The inspection included checking assumptions for each statistical test used. These assumptions included checking for minimum sample size, linearity, normality, multicollinearity, auto-correlation, homoscedasticity, and missing data analysis. If assumptions were violated, appropriate actions were taken.

Descriptive statistics (means, standard deviations, frequencies, and percentages) were calculated for all variables to summarize the data. Group comparisons across years (2003, 2015, and 2017) and sexes were conducted using independent t-tests or Welch's t-tests, depending on whether variances were equal. Chi-squared tests were used to assess categorical changes in variables such as online communication frequency over time. Factorial analysis of variance (FANOVA) was employed to evaluate interactions between sex, year, and mental health outcomes (depression, anxiety, body image, and self-esteem). Post hoc Tukey tests were applied to examine significant interactions further and identify differences across groups.

4.4.1 Paper I

To answer if the relationship between online communication and mental health changed for 15-year-old adolescents from 2003 to 2015, Structural Equation Modeling (SEM) was conducted. Its purpose was to assess the relationship between online communication and mental health outcomes (depression and anxiety) across years. Online communication was treated as an exogenous variable, while depression and anxiety were modeled as endogenous latent variables. Latent variables were constructed using raw scores from the relevant questionnaire items as indicators, and covariance between latent variables was included. To address non-normality, Diagonally Weighted Least Squares (DWLS) estimation was used, and the Satorra-Bentler method was applied to scale chi-square statistics. Model fit was evaluated using the Comparative Fit Index (CFI), Tucker Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA), with thresholds for acceptable and good fit as outlined by Hu and Bentler (1999). Two models were compared: one with constrained intercepts and regression coefficients across groups and another where these parameters were free to vary. Chi-squared difference tests were used to determine significant differences between models.

4.4.2 Paper II

To answer if CRF is getting worse at the beginning of the 21st century and if there is a relationship between mental health, both t-tests and multiple regression analysis were used. In the multiple linear regression analyses, the goal was to investigate the association between CRF and mental health outcomes, while controlling for SES as a covariate. The models were structured with mental health outcomes (body image, depressive symptoms, anxiety symptoms, and self-esteem) as the dependent variables (Y), and CRF (W_{max}/kg) as the primary independent variable (X1). SES (parental education and living arrangement) was included as an additional independent variable (X2). Adjusted R-squared values were reported to indicate the proportion of variance in mental health outcomes explained by the models after accounting for SES. CRF was further categorized into three groups using tertiles: Low (<2.65), Medium (2.65–3.39), and High (>3.39). An analysis of variance (ANOVA) was then conducted to examine differences in body image, depressive symptoms, anxiety symptoms, and self-esteem across the three CRF levels, stratified by sex and cohort.

4.4.3 Paper III

To explore how online communication relates to mental health and physical health (CRF), the relationship between online communication and these outcomes was analyzed. A longitudinal approach was used to examine changes in these outcomes from age 15 to 17, and whether these relationships varied by sex and SES. Five linear mixed-effects models were employed to assess the associations between online communication and mental health outcomes (depression, anxiety, body image, and self-

esteem) as well as CRF, while adjusting for year, participant sex, and SES. The models accounted for both main effects and interactions among these variables as fixed effects. Participant-specific intercepts were included as random effects to control for individual baseline variability, recognizing that each participant may have a distinct starting point. Wald tests were used to evaluate the significance of fixed effects, and random effect variance components were estimated to capture variability attributable to individual differences beyond the fixed effects. Marginal and conditional R-squared values were calculated to measure the proportion of variance explained by the fixed effects alone and by the entire model, respectively. Linear mixed-effects models were chosen for their ability to handle unbalanced data effectively. This approach allowed for the inclusion of all participants, accounting for individual changes over time and providing more precise estimates. By handling missing data under the assumption of data missing at random (MAR), this method avoided the need for data imputation while ensuring robust results.

4.5 Methodological considerations

There were some specific methodological considerations in this current study. First, the question regarding time spent online communicating differed between 2003 on the one hand and 2015 and 2017 on the other, and it was ordinal instead of continuous divided into two parts (time spent on weekdays and time spent on weekends). In 2003, the possible answers were as follows (translated from Icelandic) with the appropriate scores shown under:

Almost none	0.5-1 hours	Around 1 hour	Around 2 hours	Around 3 hours	Around 4 hours	Around 5 hours	6 hours or more
1	2	3	4	5	6	7	8

In 2015 and 2017 the possible answers were almost the same, but the maximum score was 7 for "More than 5 hours". Because of discrepancies in the scales between 2003 and 2015 in paper I, the scale in 2003 was transformed. The transformation was rationalized with the idea that subjects answering the scale might be using the response alternative as a comparison for their answer instead of the actual meaning of *hours* in the options (Schwarz et al., 1985). That is, it is common for participants to view the score as a continuum from low to high, rather than meaningful categories. The transformation was executed so that the value of 8 from 2003 was transformed to 7 before running the analysis for paper I. So instead of meaning "6 or more hours" it meant "5 or more hours". Table 1 shows the effect the transformation had on the mean. The mean lowered by only .05 for both females and males which can be considered minimal.

Table 1. Comparison of the raw score of online communication for 2003 and the transformed score.

Score	Year	Sex	*n*	Mean	*SD*	Min.	Max.
Raw (1-8)	2003	Males	195	3.25	1.87	1	8
		Females	190	3.21	1.89	1	8
Transformed (1-7)	2003	Males	195	3.20	1.77	1	7
		Females	190	3.16	1.79	1	7

In papers I and III, the weighted average (weekend*0.29 + weekdays*0.71) was taken between weekdays and weekends to generate a single variable measuring the amount of weekly online communication. This step changed the two ordinal variables for time online communicating to one continuous ratio variable (Norman, 2010; Sullivan & Artino, 2013).

Another consideration is related to how online communication was defined. Most similar studies simply talk about *social media* instead of *online communication*. The reason that this current study uses *online communication* is because the data goes back to 2003 when the term *social media* was not widely used. The questionnaire hence does not use the word *social media* but asks for time spent online with examples of sending emails, using chatrooms and such. Related to this definition, online games are often considered as online communication (Bhroin et al., 2024). However, in this thesis, games were omitted for the following three reasons:

1. In the original questionnaire, there was a separate question asking about time spent playing video games, which could affect how participants answered the other question about the time spent communicating online.

2. In the oldest dataset from 2003, games were usually not that communicative. If communication was involved it was usually face-to-face via split screen on a single console or computer, or by linking computers together with a local area network (LAN) in one physical location.

3. Even though games *can* include communication they don't always do. So, if the questions about games (see point 1) had been added to the analysis it could introduce a possible bias.

It can be seen as a methodological flaw that in 2003, the data was gathered across Iceland, proportionally representing the population distribution, whereas in 2015, data collection was confined solely to the capital area. This inconsistency in data collection

methods across different regions and times potentially compromises the comparability and reliability of the data between these two years.

However, the Icelandic population is very homogenous and around 65% of the population lives in the capital area. Nonetheless, to address the concern further, the data from 2003 was split into two groups prior to analysis to assess the validity: Group 1 from the capital area and Group 2 from regions outside the capital. Analysis of the key variables in our study revealed no significant differences between participants from these two groups (Table 2).

Table 2. Comparison of the key variables used in the thesis depending on the location of participants in 2003.

	Capital area		**Outside capital area**				
	n	***M (SD)***	***n***	***M (SD)***	***DF***	***t***	***p***
OC	197	3.15 (1.93)	190	3.33 (1.83)	375	-0.95	0.343
CRF	113	3.37 (0.61)	100	3.49 (0.60)	209	-1.38	0.169
Body Image	198	10.4 (3.20)	180	10.5 (3.21)	373	-0.34	0.734
Self-Esteem	199	19.4 (6.68)	174	18.1 (6.07)	370	1.95	0.052
Depression	198	16.2 (6.30)	176	15.7 (6.84)	358	0.72	0.46

Note. OC = Online communication. CRF = Cardiorespiratory Fitness.

Moreover, we compared the educational background of mothers as a proxy for socio-economic status in paper II, specifically looking at the proportion holding university degrees in both regions. Our findings indicate no significant difference between maternal education between regions, χ^2 (df = 5, N = 247) = 5.2434, p = 0.3869.

5 Results

5.1 Online communication and mental health from 2003–2015 (Paper I)

5.1.1 Changes in online communication

Results showed a significant increase in online communication between 2003 and 2015 (see Figure 10). In 2003 (cohort born in 1988), 15-year-old adolescents spent significantly less time online communicating compared to 2015 (cohort born in 1999), with mean scores of 3.19 (*SD* = 1.79) in 2003 and 3.83 (*SD* = 1.38) in 2015 (Welch's $t(682.03) = -4.81$, $p < .001$, $d = -0.36$).

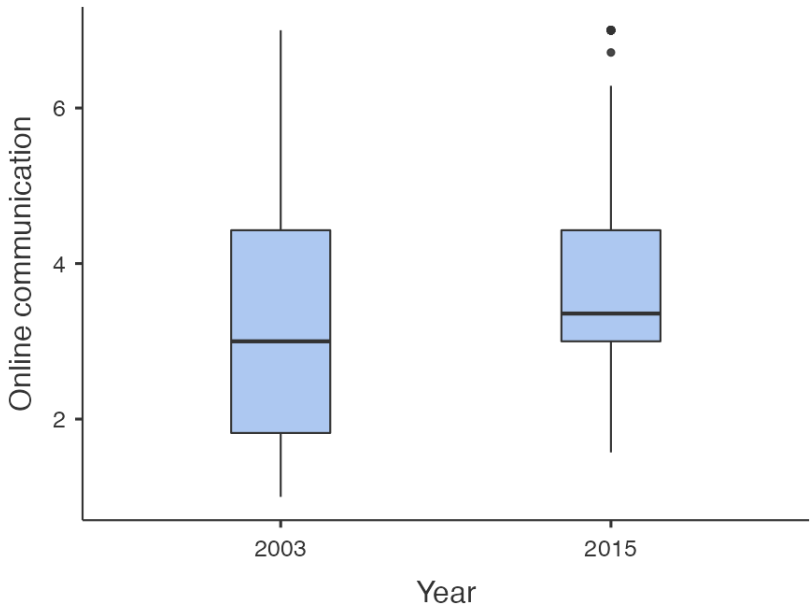

Figure 10. Changes in online communication between 2003 and 2015.
Online communication is shown with the raw scores from the questionnaire where 0 means no online communication in the last week and 7 shows the maximum score. The whiskers show the smallest and largest values within 1.5 × interquartile range.

There were no sex differences regarding time spent online communicating in 2003 ($t(383) = .23$, p=.818.), where males scored 3.20 (approximately 70 minutes per day on average) and females 3.16 (approximately 70 minutes) (Table 3). In 2015, females

compared to males, spent on average, almost an hour longer online communicating, scoring 4.21 and males 3.31 (approximately 130 minutes and 80 minutes, respectively, $t(300) = 5.89$, $p<.001$). Time communicating online for males did not change between 2003 and 2015. The time females spent online communicating increased significantly by approximately an hour from 2003 to 2015 ($t(363) = 5.61$, $p<.001$).

Table 3. Descriptive statistics for scores on online communication in 2003 and 2015 by sex.

Year	Sex	*n*	*M*	*SD*	Min.	Max.
2003	Males	195	3.2	1.75	1.0	7.0
	Females	190	3.16	1.79	1.0	7.0
	Total	385	3.19	1.79	1.0	7.0
2015	Males	127	3.31	1.05	1.71	7.0
	Females	175	4.21	1.47	1.58	7.0
	Total	302	3.83	1.38	1.57	7.0

Note. Means shown as the ordinal scale from the questionnaire (not the hours spent).

5.1.2 Changes in mental health

The descriptive statistics for depression, anxiety, body image, and self-esteem can be seen in Table 4.

Table 4. Descriptive statistics for mental health variables in 2003 and 2015 by sex.

Variables	Year	Sex	*n*	Mean	*SD*	Min	Max
Depression	2003	M	195	14.51	5.8	10	50
		F	190	17.31	6.94	10	43
	2015	M	127	14.51	6.19	10	41
		F	175	20.38	10.23	10	50
Anxiety	2003	M	195	5.7	2.33	4	20
		F	190	7.05	2.99	4	16
	2015	M	127	5.35	2.48	4	17
		F	175	7.69	4.01	4	20
Body Image	2003	M	188	15.44	2.78	5	20
		F	185	14.05	2.87	4	20
	2015	M	125	16.5	2.83	7	20
		F	173	14.49	3.29	7	20
Self-Esteem	2003	M	190	22.15	5.72	0	30
		F	181	20.75	6.01	3	30
	2015	M	125	22.42	6.91	0	30
		F	171	20.54	6.66	1	30

The FANOVA for depression revealed a statistically significant interaction between year and sex on depression ($F(1,1) = 6.960$, $p = .009$), with significant main effects for both years ($p = .008$) and sex ($p < .001$; Figure 11a). The post hoc Tukey test for depression showed that females had significantly higher scores on depression both in 2003 and 2015. Additionally, the Tukey test indicated a statistically significant difference in depression scores for females between 2003 and 2015.

For anxiety, the FANOVA revealed a statistically significant interaction between year and sex on anxiety ($F(1,1) = 4.519$, $p = .033$). A simple main effect for sex was also significant ($p < .001$), showing that females scored higher on anxiety compared to males (Figure 11b). Year alone did not have a main effect ($p = .541$). The post hoc Tukey test for anxiety indicated that females had more anxiety symptoms than males in both 2003 and 2015.

The FANOVA for body image revealed a statistically significant main effect for year ($F(1,667) = 10.40$, $p = .001$) and sex ($F(1,667) = 53.81$, $p < .001$; Figure 11c), but the interaction between year and sex on body image was not statistically significant ($F(1,667) = 1.85$, $p = .175$). Post hoc Tukey tests showed that males had significantly better body image scores compared to females across both years ($p < .001$).

The FANOVA for self-esteem revealed a statistically significant main effect for sex ($F(1,663) = 11.03$, $p < .001$; Figure 11d), with males scoring higher on self-esteem than females. However, there was no significant main effect for year ($F(1,663) = 0.00$, $p = .955$) or interaction between year and sex ($F(1,663) = 0.23$, $p = .633$).

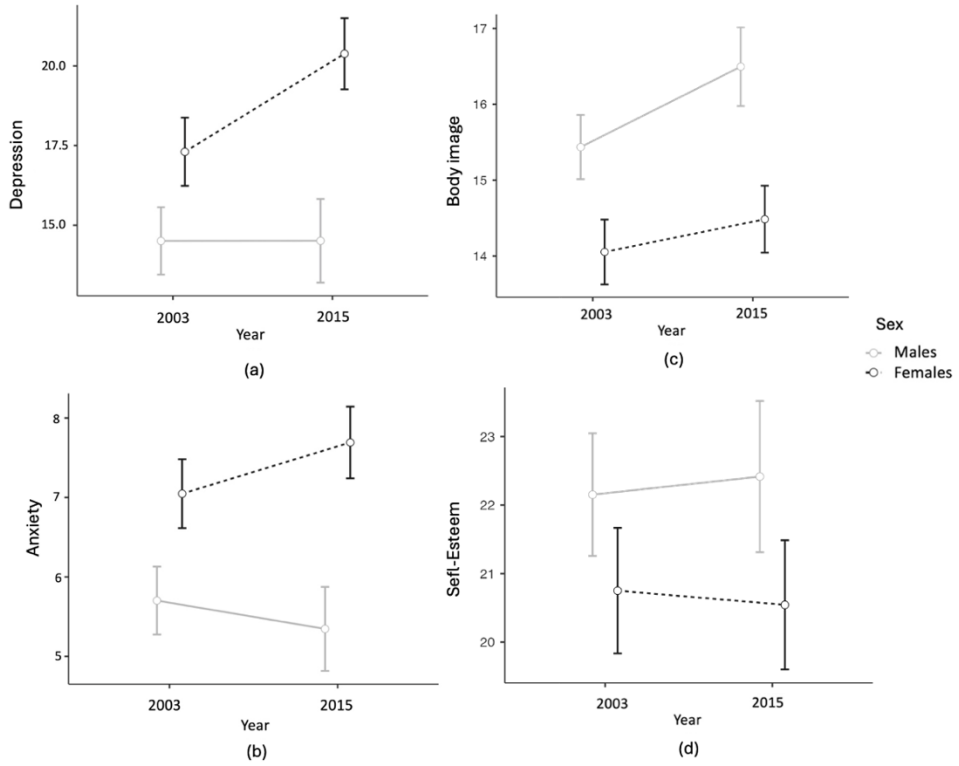

Figure 11. Changes in mental health scores among 15-year-old adolescents from 2003 to 2015 by sex.

The y-axis show the scores from the relevant measure where a) and b) are subscales of SCL-90, c) is the score from OSIQ, and d) is the score from the Rosenberg Self-Esteem Scale. The error bars show the standard error of the mean.

5.1.3 The relationships between online communication, anxiety, and depression among males and females in 2003 and 2015

The results from the structural equation model (Figure 12) show that there was no significant relationship between time spent online communicating and anxiety or depression, except for females in 2015, where anxiety increased significantly by .14 standard deviations and depression by .21 standard deviations for each increase in the score for time online communicating. The fit for the constrained model was χ^2 (394, n = 687) = 1007, p < .001 (scaling correction factor = .312), TLI = .90, CFI = .91, RMSEA = .10. The model fit with all parameters freely estimated for all groups, was χ^2 (352, n = 687) = 526, p < .001 (scaling correction factor = .240), TLI = .99, CFI = .99, RMSEA = .05. All indicators for latent variables for all groups in both models were acceptable, suggesting construct validity of depression and anxiety (see Appendix A). The Chi-squared difference test between model fits indicated a significant difference (p < .001), rationalizing the use of the model with the better fit, which was the one where the parameters were not constrained between groups, thus indicating valid differences between groups.

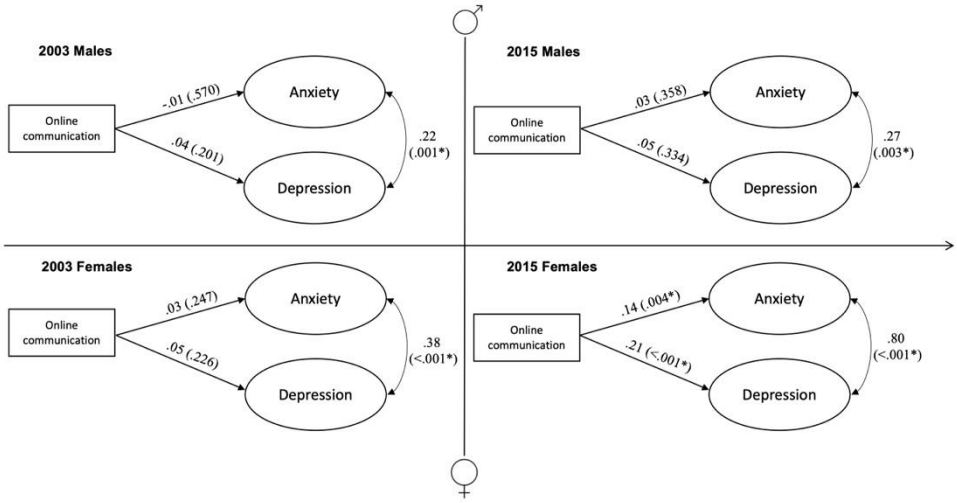

Figure 12. Models showing the relationships between online communication, anxiety, and depression for males and females in 2003 and 2015.

5.2 Physical health in 2003 and 2015 and its link to mental health (Paper II)

5.2.1 Changes in physical health (CRF and PA)

The results showed that CRF was significantly different between males and females in both 2003 (cohort born in 1988) and 2015 (cohort born in 1999). In 2003, males had a significantly higher mean CRF compared to females, with a large effect size. This trend persisted in 2015, where males again had higher CRF scores compared to females, although the effect size decreased slightly (see Table 5 for details).

Table 5. Sex differences in cardiorespiratory fitness scores in 2003 and 2015.

Variable	Year	Male	Female	*t*	*df*	*p*	*d*	95% CI (Lower)	95% CI (Upper)
CRF	2003	3.78	3.03	11.34	222	<.001	1.47	0.62	0.88
	2015	3.09	2.21	8.38	291	<.001	0.99	0.67	1.09

Note. CRF=Cardiorespiratory fitness

In 2003, more males (36.6 %) than females (19.6%) reported that they engaged in PA almost every day (see Table 6 for details). Females, on the other hand, reported lower activity levels, with 27% exercising 2-3 times per week compared to 17.5% of males. A similar sex difference was found in 2015, where 39.5% of males reported exercising almost every day, compared to 28.9% of females. The proportion of individuals who reported "never" exercising was low for both sexes and decreased over time, with no males reporting "never" in 2015 compared to 4.1% in 2003. Females showed a slight increase in this category, from 2.1% in 2003 to 3.5% in 2015. Additionally, those who reported exercising less than once a week or only once a week declined over time for both sexes, while the proportions of individuals exercising 2-3 times a week remained relatively stable.

Table 6. Self-reported physical activity frequency by sex and year.

	2003		2015	
	Male	**Female**	**Male**	**Female**
Never	8 (4.1%)	4 (2.1%)	0 (0.0%)	6 (3.5%)
Less than 1x a week	8 (4.1%)	15 (7.9%)	5 (4%)	11 (5.4%)
1x a week	13 (6.7%)	22 (11.6%)	9 (7.3%)	17 (9.8%)
2-3x a week	34 (17.5%)	51 (27%)	24 (19.4%)	42 (24.3%)
4-5x a week	60 (30.9%)	60 (31.7%)	37 (29.8%)	47 (27.2%)
Almost every day	71 (36.6%)	37 (19.6%)	49 (39.5%)	50 (28.9%)
Total	194 (100%)	189 (100%)	124 (100%)	173 (100%)

5.2.2 The relationship between cardiorespiratory fitness and mental health

The relationship between CRF and mental health indicators (depression, anxiety, body image, and self-esteem) varied by sex and year, with females showing stronger associations. Significant associations were observed between CRF and symptoms of depression for both males and females, with stronger associations found in 2003 compared to 2015. Similarly, for symptoms of anxiety, significant associations were identified only among females in both 2003 and 2015.

For body image, CRF was significantly associated with higher scores among both males and females in 2003. However, in 2015, the relationship persisted only for females. Finally, CRF showed a significant positive relationship with self-esteem exclusively for females in both years, with no significant findings for males. These results highlight the nuanced and sex-specific relationships between CRF and mental health outcomes across time (see Table 7 for details).

Table 7. Associations between cardiorespiratory fitness and mental health by sex and year.

	Year	Sex	R^2	*B*	*SE*	*p*
CRF-> Depression	2003	Male	0.24	-3.83	1.42	0.009**
	2015	Male	0.10	-1.23	0.59	0.039*
	2003	Female	0.09	-4.87	1.92	0.014*
	2015	Female	0.06	-2.27	-1.99	0.049*
CRF-> Anxiety	2003	Male	0.04	-0.62	0.51	0.224
	2015	Male	0.09	-0.41	0.22	0.071
	2003	Female	0.06	-1.77	0.85	0.042*
	2015	Female	0.06	-1.14	0.46	0.014*
CRF-> Body Image	2003	Male	0.16	2.03	0.68	0.004**
	2015	Male	0.03	0.33	0.27	0.227
	2003	Female	0.14	2.39	0.75	0.002**
	2015	Female	0.06	0.92	0.36	0.012*
CRF-> Self-Esteem	2003	Male	0.12	2.24	1.28	0.087
	2015	Male	0.02	0.84	0.68	0.217
	2003	Female	0.10	3.87	1.65	0.022*
	2015	Female	0.06	1.41	0.97	0.019*

The results consistently demonstrated a significant main effect of CRF levels on mental health outcomes across all variables. Specifically, there was a significant reduction in depression ($F(2, 459) = 29.254$, $p < 0.001$) and anxiety scores ($F(2, 461) = 20.000$, $p < 0.001$), along with increases in body image ($F(2, 458) = 26.113$, $p < 0.001$) and self-esteem ($F(2, 454) = 12.061$, $p < 0.001$) associated with higher CRF levels. These effects were consistent across both the 2003 and 2015 measures, as depicted in Figure 13. No significant interaction effects between CRF levels and sex or year were found, indicating the relationship between CRF and mental health outcomes was stable irrespective of these variables.

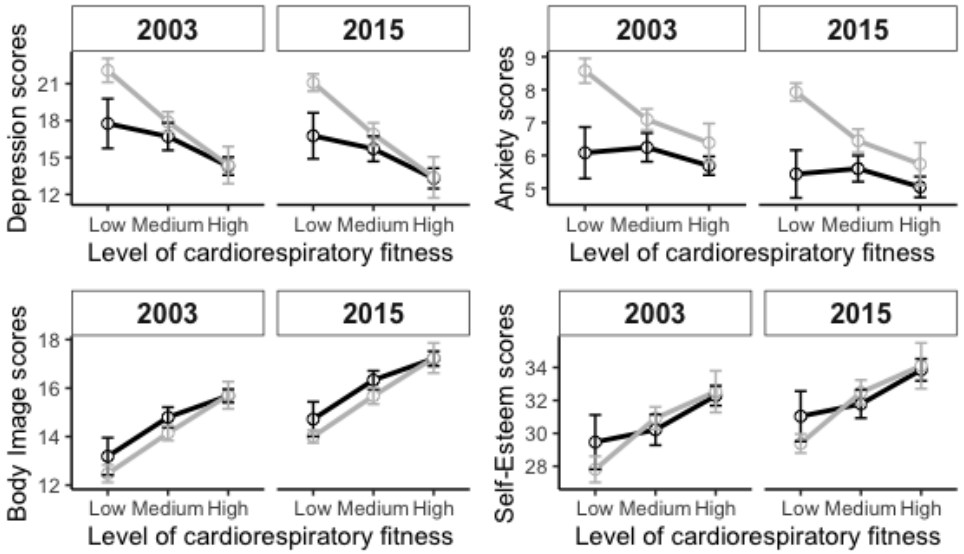

Figure 13. Mental health outcomes by cardiorespiratory fitness level and year.

5.3 The relationship between online communication and mental health and physical health among 15- to 17-year-olds (Paper III)

For the mixed longitudinal and cross-sectional data from 2015 to 2017 (cohort born in 1999), females consistently reported higher symptoms of depression and anxiety compared to males, with slight increases observed over time across sexes. In contrast, males reported greater self-esteem and a more positive body image than females in both years, with these trends showing relative stability from 2015 to 2017 (see Table 8 for details).

Table 8. Descriptive statistics for mental health variables in 2015 and 2017 by sex

Variable	Year	Sex	*n*	Mean	SD	Min.	Max.
Depression	2015	Males	124	14.43	6.16	10.0	41.0
		Females	172	20.22	10.21	10.0	50.0
	2017	Males	90	16.06	7.59	10.0	50.0
		Females	139	20.37	8.86	10.0	48.0
Anxiety	2015	Males	126	5.27	2.33	4.0	17.0
		Females	173	7.71	4.02	4.0	20.0
	2017	Males	91	5.47	2.37	4.0	17.0
		Females	144	7.63	3.69	4.0	17.0
Body Image	2015	Males	125	16.5	2.83	7.0	20.0
		Females	173	14.49	3.3	7.0	20.0
	2017	Males	85	16.45	2.35	9.0	20.0
		Females	144	14.46	3.02	5.0	20.0
Self-Esteem	2015	Males	125	32.42	6.91	10.0	40.0
		Females	172	30.51	6.66	11.0	40.0
	2017	Males	90	33.24	6.6	10.0	40.0
		Females	143	30.3	6.86	10.0	40.0

For the longitudinal data from 2015 to 2017, the total time spent on online communication increased over this period. Females consistently reported higher scores for online communication compared to males in both years, with a slight upward trend observed for both sexes over time (see Table 9 for details).

Table 9. Descriptive statistics for online communication scores by year and sex.

Year	Sex	*n*	Mean	*SD*	Min.	Max.
2015	Males	75	3.35	1.01	2.0	7.0
	Females	107	4.15	1.45	1.57	7.0
	Total	182	3.82	1.3	1.57	7.0
2017	Males	75	3.9	1.37	1.0	7.0
	Females	110	4.36	1.2	2.0	7.0
	Total	185	4.16	1.26	1.0	7.0

For time spent online communicating as a categorical variable, a chi-square test showed that there was a difference between 2015 and 2017, χ^2 (6, n = 367) = 15.94, p = .014, where most participants spent 1-2 hours in 2015 but 2-3 hours in 2017 (see Figure 14).

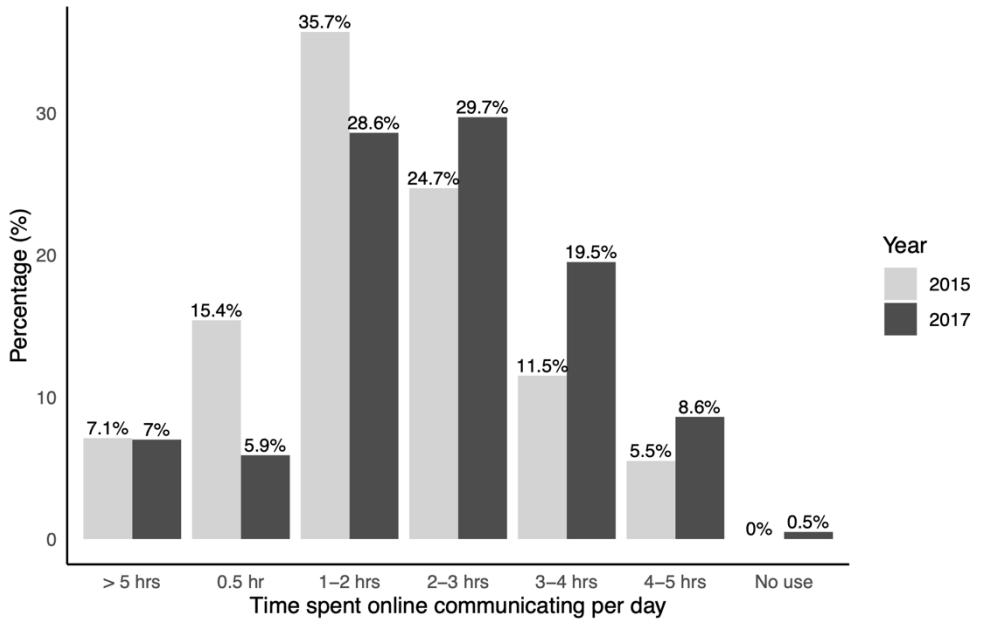

Figure 14. Changes in time spent online communicating per day from 2015 to 2017.

5.3.1 The relationship between online communication and mental health 2015-2017

Mixed-effects models examined the relationship between online communication and mental health outcomes, including depression, anxiety, self-esteem, and body image, as summarized in Table 11. All models included SES and sex. SES remained consistent, with 67% of participants having at least one parent with a university degree in 2015, slightly increasing to 67.9% in 2017, showing no statistically significant change.

Increased online communication correlated with higher depression scores ($p < .001$), with females reporting higher levels of depression than males ($p < .001$), and higher SES was associated with lower depression scores ($p = .003$). Anxiety scores also increased with more online communication ($p = .032$), with females reporting significantly higher levels of anxiety than males ($p < .001$), while SES had no notable effect.

Self-esteem decreased as online communication increased ($p = .006$), with females scoring lower than males ($p = .034$). Higher SES correlated with improved self-esteem ($p = .040$). Similarly, body image scores declined with increased online communication ($p = .010$), with females reporting poorer body image than males ($p < .001$). SES showed no significant relationship with body image.

Overall, interaction effects between online communication, year, sex, and SES were not significant across all mental health variables. The models highlighted the independent effects of online communication on mental health, with random effects contributing substantially to the variance explained. Full statistical details are provided in Table 10.

Table 10. Overview of main effects and interactions for the mixed effect models for mental health.

Predictor	Outcome	*B*	*SE*	95% CI	*df*	*p*
Online communication	Depression	1.07	0.31	(0.47, 1.67)	498	<.001
	Anxiety	0.26	0.12	(0.02, 0.50)	512	0.032
	Self-esteem	-0.71	0.26	(-1.21, -0.21)	509	0.006
	Body Image	-0.28	0.11	(-0.50, -0.07)	499	0.010
Year (2015 – 2017)	Depression	0.66	0.65	(-0.61, 1.94)	251	0.309
	Anxiety	0.03	0.27	(-0.49, 0.55)	264	0.916
	Self-esteem	0.68	0.58	(-0.44, 1.81)	274	0.235
	Body Image	0.24	0.24	(-0.24, 0.72)	264	0.322
OC ✻ Year	Depression	-0.53	0.50	(-1.52, 0.46)	306	0.296
	Anxiety	-0.17	0.21	(-0.58, 0.23)	323	0.399
	Self-esteem	0.66	0.44	(-0.20, 1.53)	346	0.134
	Body Image	0.17	0.19	(-0.20, 0.54)	328	0.373
OC ✻ Sex	Depression	0.36	0.61	(-0.83, 1.56)	498	0.551
	Anxiety	0.03	0.25	(-0.45, 0.51)	512	0.910
	Self-esteem	-0.73	0.51	(-1.72, 0.27)	510	0.155
	Body Image	-0.38	0.22	(-0.81, 0.04)	499	0.079
OC ✻ SES	Depression	-0.13	0.60	(-1.30, 1.05)	482	0.835
	Anxiety	0.07	0.24	(-0.40, 0.54)	505	0.774
	Self-esteem	0.19	0.50	(-0.80, 1.17)	510	0.708
	Body Image	0.16	0.22	(-0.27, 0.58)	488	0.472

Note. OC = Online communication. SES = Socioeconomic status.

Random intercepts from the models revealed substantial individual differences in mental health Variance in baseline scores across individuals was observed for depression (variance = 37.56, *SD* = 6.13), anxiety (variance = 5.55, *SD* = 2.36), self-esteem (variance = 18.76, *SD* = 4.33), and body image (variance = 0.232, *SD* = 0.481). These variances highlight the importance of individual characteristics in shaping the studied outcomes, as reflected in the disparities between marginal and conditional R^2 across models.

5.3.2 The relationship between online communication and physical health 2015-2017

A modest negative relationship was observed between online communication and CRF as more online communication corresponded to slightly lower CRF scores (p = .003). The model explaining these outcomes demonstrated a marginal R^2 of 0.351 and a conditional R^2 of 0.866. CRF levels were significantly lower among females compared to males (p < .001), but SES did not appear to affect CRF outcomes (p = .460). Interaction effects between online communication, year, sex, and SES were not statistically significant in relation to CRF outcomes. Detailed results are provided in Table 11.

Random intercepts revealed individual differences in CRF. The variance in baseline scores across individuals was 0.232 (*SD* = 0.481).

Table 11. Overview of the main effects and interactions for the cardiorespiratory fitness model.

Predictor	*B*	*SE*	95% CI	*df*	*p*
Online communication	-0.05	0.02	(-0.09, -0.02)	340	0.003
Year (2015 – 2017)	-0.11	0.03	(-0.18,- 0.05)	199	0.001
Online communication ✻ Year	0.01	0.03	(-0.04, 0.07)	232	0.624
Online communication ✻ Sex	-0.04	0.04	(-0.11, 0.03)	340	0.274
Online communication ✻ SES	0.01	0.03	(-0.07, 0.07)	333	0.967

Note. SES = Socioeconomic status.

6 Discussion

The overall aim of this thesis was to explore how online communication was related to adolescent mental and physical health, examining changes over time, sex differences, and associations between mental and physical health. There was no observed relationship between online communication and mental health in 2003. However, in 2015, online communication was associated with increased depressive and anxiety symptoms in adolescent girls, whereas no such association was found for boys. At the same time, cardiorespiratory fitness (CRF) declined between 2003 and 2015. Poorer CRF was also associated with worse mental health. When examining the same cohort over time, online communication at ages 15 and 17 (2015–2017) remained consistently linked to poorer mental health and lower CRF, with no differences based on socioeconomic status (SES). These findings highlight age 15 as a particularly important period for understanding the relationship between digital habits such as online communication and long-term health outcomes.

6.1 Online communication and mental health: A cross-sectional comparison from 2003 to 2015

The result showed a worsening trend in depressive symptoms for 15-year-old females between 2003 and 2015, whereas 15-year-old males showed no such trend. Anxiety levels remained stable for both sexes from 2003 to 2015. Interestingly, body image improved slightly for males but stayed constant for females, while self-esteem was unchanged across groups. This aligns with previous studies reporting increasing mental health difficulties among adolescent girls in the 2010s (Bor et al., 2014; Twenge et al., 2017). In line with these findings, Kelly et al. (2018) showed that social media use was strongly associated with poorer mental health among adolescent girls, but less so for boys. These findings suggest a complex and sex-specific interaction between mental health and online communication.

The emergence of a sex-specific relationship between online communication and mental health by 2015 is a pivotal finding. Unlike in 2003, when no significant associations were observed, females in 2015 reported higher depressive and anxiety symptoms associated with increased online communication. This is in line with findings from the UK Millennium Cohort Study, where social media use was more strongly associated with depressive symptoms in girls than boys (Kelly et al., 2018). This time-specific effect may reflect the rise of smartphones and algorithm-driven social platforms around 2012–2013, which coincides with the increased prevalence of internalizing problems among adolescent girls (Haidt & Twenge, ongoing). There may be several

explanations for this shift over time. Changes in social media mechanisms, such as algorithmic content prioritization and feedback-based engagement (e.g., likes, shares), may reinforce exposure to appearance-focused content and feedback-driven behavior (Chen & Lee, 2013). Moreover, the content itself, such as curated highlight reels and influencer posts, may promote unrealistic ideals, triggering upward social comparisons. Time spent online could also be a factor, especially when it replaces offline socializing or sleep (Alonzo et al., 2021; Dredge & and Schreurs, 2020). Another possible explanation is that increased social media use is associated with stress (Wolfers et al., 2020) and stress is bad for overall health (O'Connor et al., 2021). The reasons why these factors might impact females more are possibly related to how the sexes use the internet differently. Females predominantly use online communication for social networking, whereas males engage more in gaming or task-oriented activities, which involve different emotional and social dynamics (Lenhart, 2015). Additionally, platforms that promote social comparison may disproportionately affect adolescent girls, who are often more sensitive to appearance-focused content (Fardouly et al., 2015).

These findings align with the theoretical framework proposed in this thesis based on social comparison theory (Festinger, 1954), which suggests that online communication fosters upward social comparison, leading to negative mental health outcomes. Additionally, increased online communication may replace offline interactions, contributing to misjudgments in social interpretation and emotional disconnection (Lieberman & Schroeder, 2020). These dynamics appear to disproportionately affect females, whose online interactions often involve emotionally charged content, intensifying social comparison and exacerbating negative mental health outcomes (Svensson et al., 2022).

Interventions should consider these differences between the sexes and aim to promote healthier digital habits, such as limiting exposure to appearance-focused content and fostering critical media literacy. Encouraging balanced face-to-face interactions and improving sleep hygiene may also help mitigate some of the negative effects. Educational programs could emphasize managing social comparison and understanding the curated nature of online content and empower adolescents to critically evaluate the media they consume. Recent intervention studies, such as social media literacy programs in schools, have shown promising results in reducing the negative effects of digital comparison and improving adolescents' self-esteem and well-being (Gordon et al., 2021; Jeong et al., 2012). Additionally, peer-led or teacher-facilitated workshops that discuss online behaviors and emotional responses have been found effective in promoting reflective digital use (Chassiakos et al., 2016).

6.2 Mental health and CRF

CRF declined among 15-year-olds between 2003 and 2015, with males consistently outperforming females. These persistent sex differences in CRF reflect well-established

biological and behavioral factors, such as differences in activity, intensity and cardiovascular capacity (Ekelund et al., 2007). This decline in CRF from 2003 to 2015 occurred despite self-reported physical activity levels remaining stable, suggesting that adolescents may overestimate their activity levels or underestimate the impact of increased sedentary behavior. The discrepancy between objectively measured CRF and self-reported physical activity suggests that this misalignment could indicate a broader misconception among adolescents about the state of their health. Such misconceptions may lead to complacency, reducing motivation to engage in more effective physical activity regimens. The decline in CRF mirrors global trends and may be linked to increased screen time and reduced unstructured outdoor activity (Dyrstad et al., 2012; Leone et al., 2023; Lissak, 2018).

Furthermore, higher CRF was in general associated with better mental health outcomes for both sexes, aligning with prior research that highlights the possible protective role of physical fitness for mental health (Kandola et al., 2019; Melo et al., 2025; Riddervold et al., 2024).

These findings align with the theoretical framework proposed in the background that mental health and physical health influence each other and make the influence of online communication more complex. It also highlights that it could be beneficial to target both mental and physical health when helping adolescents work on healthier online communication and digital habits.

Educational programs should aim to improve adolescents' understanding of fitness and health, emphasizing the importance of reducing sedentary behavior (mostly through less online communication and more offline interactions) and engaging in sustained high-intensity physical activities. Schools and communities could play a pivotal role by promoting accessible, engaging physical fitness initiatives tailored to different age groups and sexes.

6.3 Online communication, mental health, CRF, and SES: A longitudinal comparison from 2015 to 2017

In agreement with the results from 2003 - 2015 (the cross-sectional comparison of 15-year-olds born in 1988 and 1999), increased time spent on online communication in 2015 -2017 was longitudinally associated with poorer mental health for 15–17-year-olds (the 1999 cohort). Adolescents who reported more online communication exhibited more depressive and anxiety symptoms, lower self-esteem, and poorer body image. Additionally, increased online communication correlated with lower CRF, suggesting that extensive engagement in online communication might limit opportunities for physical activities. Notably, while females reported worse mental health and lower CRF compared to males, and adolescents from higher SES reported fewer depressive symptoms and higher self-esteem, neither sex nor SES moderated the relationship between online communication and health outcomes. The stability of these associations

across the study period highlights the persistence of these effects during a transformative developmental stage.

These findings that online communication is linked to poorer mental health align with previous empirical studies showing associations between social media use and increased depressive and anxiety symptoms (Kelly et al., 2018; Twenge & Campbell, 2019; Vogel et al., 2014). The associations observed in this study were modest but consistent, similar to those reported in prior large-scale surveys, suggesting that while the impact is not dramatic on an individual level, it may be meaningful at the population level. Social comparison pressures, prevalent in online environments, likely contribute to the observed associations between online communication and lower self-esteem and body image. Other mechanisms may also be at play, including disrupted sleep patterns, reduced physical activity due to screen time displacement, and emotional contagion from negative content (Alonzo et al., 2021; Dredge & and Schreurs, 2020; Keles et al., 2020). Adolescents frequently encounter idealized representations of peers, which may intensify feelings of inadequacy and dissatisfaction (Fardouly et al., 2015). Importantly, no significant interaction effects emerged between online communication and sex or SES in these models, indicating that these mental health associations are broadly applicable across demographic groups. This finding is in partial contrast with some earlier studies suggesting stronger effects for females or lower SES groups (Nesi & Prinstein, 2015), but aligns with others showing relatively uniform effects across subgroups (Alonzo et al., 2021). The findings suggest that widespread use of online communication affects adolescents similarly, regardless of SES background, with stable associations observed across the ages of 15 to 17. This indicates that the increased autonomy and difference in social environment at age 17 does not appear to be making the impact of online communication worse for mental health. Instead, it gives clues that the association has already been established at age 15 reinforcing the need for earlier intervention to teach adolescents about healthy communication online.

These findings show a novel link between increased online communication and lower CRF. High levels of online communication may displace time otherwise spent on physical activities, contributing to reduced physical fitness. This aligns with established associations between sedentary screen time and decreased physical activity (Chen et al., 2022) as well as the relationship with social media use and PA (Morningstar et al., 2023). Furthermore, the relationship between online communication and CRF appears consistent across sex and SES, suggesting that its impact on physical health is independent of whether an individual is male or female or has a parent with a university education.

Consistent with existing literature, adolescent females demonstrated greater vulnerability to internalizing mental health challenges, reporting higher levels of depression and anxiety, along with lower self-esteem, compared to males (Keyes &

Platt, 2024; Svensson et al., 2022). However, the results suggest that the observed impact of online communication is consistent between males and females between the ages of 15 and 17. Similarly, higher SES was associated with fewer depressive symptoms and better self-esteem, but SES did not moderate the relationship between online communication and mental health and CRF. These findings suggest that while individuals with higher SES may in general experience certain advantages, this does not appear to shield them from the negative impact of online communication on mental health or CRF.

The dual impact of online communication on mental and physical health highlights the importance of targeted interventions. Public health strategies should aim to educate adolescents about the risks associated with excessive online communication, emphasizing the need to balance digital engagement with physical activity. Schools and communities can play a pivotal role in promoting structured physical fitness programs and fostering awareness about the potential impacts of sedentary screen behaviors.

6.4 The role of sex and SES and connecting the findings

One of the key takeaways from these findings is that sex differences partly shape the relationship between online communication, mental health, and physical health. Adolescent females appear to be more vulnerable to the mental health risks associated with online communication while also having lower CRF than males. Given that CRF is linked to mental health, this combination, of higher online communication and lower CRF, may amplify the risk of mental health challenges for 15-year-old females. This is particularly concerning since the average onset age of mental health disorders is around 14.5 years (Solmi et al., 2021), reinforcing the importance of fostering healthy habits during this critical developmental stage.

Several explanations have been proposed for why adolescent females might be at more risk. Biologically, hormonal fluctuations during puberty, particularly in estrogen and cortisol levels, may contribute to increased emotional sensitivity and a heightened stress response in females (Blakemore & Mills, 2014). Socially, adolescent girls tend to rely more on online communication for social validation and peer support, making them more susceptible to the negative aspects of social comparison, cyberbullying, and appearance-focused content (Nesi & Prinstein, 2015). Passive consumption of social media, which is more common among females, has been linked to anxiety and depressive symptoms (Verduyn et al., 2017). Perfectionism is another factor that could contribute to the sex difference. Perfectionism is more common for girls (Madigan, 2019) and perfectionism has been linked to increased stress (O'Connor & O'Connor, 2003). Additionally, the societal pressures on body image disproportionately affect adolescent girls, making exposure to idealized portrayals on social media particularly harmful (Fardouly et al., 2015). Together, these factors point to the need for gender-sensitive interventions promoting healthy digital habits and physical activity.

While sex differences play a major role in these findings, the absence of an SES effect on how online communication influences health outcomes is equally noteworthy. This suggests that online risks are widespread, not limited to low-SES groups. More general interventions may therefore be more appropriate than those targeting SES alone. However, this does not mean that SES is irrelevant, adolescents from lower-SES backgrounds still face other challenges (Devenish et al., 2017; Jørgensen et al., 2024) that could moderate the relationship between online communication and mental health, which future studies should look into.

While this thesis highlights the risks of excessive online communication, it is also important to recognize that online interactions can offer support (Kysnes et al., 2022), especially for adolescents with social anxiety or geographic isolation (Best et al., 2014; Office of the Surgeon General, 2023). In some cases, social media platforms offer spaces for self-expression, activism, and identity exploration that can be empowering (Uhls et al., 2017). There are even examples of churchgoing becoming more popular in Iceland because of social media (Björnsdóttir, 2025). Therefore, the challenge is ensuring that this engagement is enriching rather than detrimental, and in moderation.

Looking ahead, the landscape of online communication is rapidly shifting, with artificial intelligence (AI) playing an increasingly prominent role. AI-driven algorithms already shape much of what adolescents see and engage with online, reinforcing echo chambers and fueling the addictive nature of social media (Skare, 2024; Zakon, 2020). The rise of AI chatbots and virtual companions (e.g., Replika, Character.AI) introduces new questions: Will AI provide adolescents with valuable social support, reducing loneliness and improving mental well-being (Pani et al., 2024)? Or will it further isolate them from real-world interactions, increase polarization and exacerbate social disconnection (Jacobs, 2024; Rodilosso, 2024)? As AI becomes more integrated into social media, its role in shaping adolescent mental health will need close scrutiny. These questions highlight the importance of continuing research that looks at the relationship between online communication and health since it is a rapidly developing field (Bidargaddi & Looi, 2023).

Digital engagement may also displace physical activity, contributing to sedentary lifestyles. Yet digital tools can also promote movement. Interactive gaming, VR-based fitness programs, and AI-driven coaching show promise for increasing physical activity, especially among youth who struggle with traditional exercise (Khan et al., 2017; Rose et al., 2017). The question is whether technological advancements will be harnessed to support adolescent health or inadvertently contribute to further declines in physical and mental well-being.

Ultimately, these findings highlight the need for proactive strategies to guide adolescents toward healthier digital habits.

6.5 Strengths and limitations

One of the primary strengths of this thesis is its mixed longitudinal and cross-sectional design, which allows for a nuanced examination of how online communication, mental health, and physical health (CRF) have evolved across time. By analyzing two adolescent cohorts (born in 1988 and 1999) at age 15 in 2003 and 2015, respectively, and then following the 1999 cohort to age 17, this study provides valuable insights into developmental trends and how digital behavior such as online communication has changed alongside broader societal shifts.

Another key strength is the integration of both mental and physical health indicators. Unlike previous research that often examines these domains separately and mostly just mental health, this study recognizes their interdependence and systematically explores how CRF and mental health are jointly influenced by online communication. This holistic approach enables a more comprehensive understanding of adolescent well-being, acknowledging that mental and physical health should not be studied in isolation.

This thesis also benefits from the use of objective CRF measurements. Unlike self-reported physical activity, which can be prone to bias and overestimation, objective CRF measures provide a more accurate reflection of fitness levels, reducing measurement error and strengthening the validity of the findings.

A further strength is the relatively high participation rate at age 15 in both cohorts, particularly in 2003, when data were collected from schools across Iceland, ensuring a broad geographical representation. This makes the dataset reasonably representative of the adolescent population at the time, enhancing the study's external validity. While the 2015 and 2017 data were collected exclusively in the capital area, additional analyses confirmed that key variables did not differ significantly between urban and non-urban participants in 2003, reducing concerns about selection bias.

This thesis has a few limitations that need to be considered. One limitation is the reliance on self-reported data, which introduces the possibility of bias. One specific type of bias is known as social desirability bias, defined as the "tendency for an individual to present him/her, in a way that makes the person look positive with regard to culturally derived norms and standards in test-taking situations" (Ganster et al., 1983). However, it is worth noting that a study has indicated that this bias is not a significant concern when it comes to self-reported physical activity among adolescents (Motl et al., 2005). On the other hand, self-report bias does pose a challenge when assessing digital media usage in general (Parry et al., 2021), and evidence suggests that participants tend to underreport their usage (Ohme et al., 2021). In future research, it may be advisable to incorporate objective measures of social media and online communication. One approach could involve asking participants to share their mobile data from apps such as iOS Screen Time (Ohme et al., 2021).

Another significant limitation is the inability to establish causality. While the study identifies associations between online communication, mental health, and CRF, the observational design does not allow for definitive conclusions about directionality. For example, while increased online communication is associated with poorer mental health, it is also possible that adolescents experiencing mental health difficulties are more likely to engage in excessive online communication as a coping mechanism (Chen & Lemmer, 2024). Similarly, while lower CRF correlates with worse mental health, mental health symptoms (e.g., low energy and social withdrawal) could contribute to lower physical activity levels rather than the other way around. Future research using experimental designs or intervention studies could help clarify these relationships.

The homogeneity of the samples is another factor that limits the generalizability of the findings. Iceland is a small, ethnically homogeneous, and high-income country with strong social support systems, high education levels, and relatively equal access to healthcare and recreational activities (Country Deep Dive on the Well-Being Economy: Iceland, 2023). These characteristics may mean that findings may not fully translate to adolescents in more diverse or socioeconomically divided populations, where digital inequalities, cultural attitudes toward screen time, and access to mental health resources differ significantly. Comparative studies across multiple countries and socioeconomic backgrounds would be necessary to determine whether these trends are globally applicable.

Finally, this study captures a specific time frame (2003–2017), and given the rapid evolution of digital technology, findings may not fully reflect the current environment of adolescent online behavior. Since 2017, the rise of TikTok, AI-driven social media algorithms, and real-time engagement metrics has fundamentally changed how adolescents interact with digital content. Future research should continue monitoring these trends, particularly considering increasing concerns about screen addiction, misinformation exposure, and AI-driven digital interactions.

7 Conclusions

This thesis explored how online communication relates to adolescent mental and physical health, examining changes over time, sex differences, and the interaction between mental and physical health. By analyzing data from 2003 to 2017, the findings offer insights into how online communication has evolved and its role in adolescent health. The key finding is that while online communication was not linked to mental health in 2003, by 2015, it had become significantly associated with increased depressive and anxiety symptoms, particularly among adolescent females. At the same time, cardiorespiratory fitness (CRF) declined significantly from 2003 to 2015, and lower CRF was consistently linked to poorer mental health. The relationship between online communication and physical health was also evident, with more time spent online correlating with lower CRF at both ages 15 and 17.

Taken together, these findings highlight that adolescent overall health is shaped by a combination of digital and physical factors. While online communication has benefits, such as social connectivity, it also presents mental health risks, particularly for adolescent females around the age of 15. The decline in physical fitness suggests that rising screen time may contribute to more sedentary lifestyles, reinforcing the link between physical and mental health.

The takeaway message is clear, adolescence is a critical period for forming lifelong habits, and both mental and physical health must be addressed together with digital habits. Public health efforts should focus on promoting balanced online engagement, encouraging physical activity, and fostering resilience against negative social comparisons. By integrating digital literacy, mental health support, and physical activity initiatives, policymakers, educators, and caregivers have the opportunity to shape a healthier future for adolescents. Equipping young people with the tools to critically engage with digital content, build emotional resilience, and maintain active lifestyles will not only mitigate the risks associated with excessive online communication but also empower them to thrive in an increasingly digital world. Ensuring that technology serves as a force for connection and well-being, rather than isolation and decline, is essential for safeguarding the health and development of the next generation.

8 Future perspectives

These findings highlight the need for further studies on possible interventions that address both digital and physical well-being. Subsequently, schools and policymakers should move beyond simply restricting screen time and instead implement strategies that promote balanced online engagement, digital literacy, and physical activity. Schools can integrate digital literacy education into the curriculum to equip adolescents with the skills to navigate online spaces critically, recognize social comparison, and develop emotional resilience. Physical activity should be embedded into daily school life, not only through physical education classes but also through active learning environments and accessible extracurricular activities. Additionally, mental health initiatives should emphasize coping strategies for digital stress and promote offline social interactions that strengthen real-world connections.

Public health efforts should focus on guiding adolescents toward healthier digital habits rather than demonizing online communication. This means encouraging meaningful online interactions while simultaneously fostering a lifestyle that prioritizes movement and mental well-being. By shifting the focus from restriction to empowerment, educators, policymakers, and caregivers can help adolescents harness the benefits of online communication while mitigating its risks, ensuring that digital engagement supports rather than undermines adolescent health.

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Original Publications

Paper I

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ORIGINAL ARTICLE

The relationship between online communication and adolescents' mental health: Long-term evaluation between genders

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Abstract

Aims: In a relatively short time, online communication has become an important part of adolescents' lives, and concerns have been raised about its potential effects on mental health. The first aim was to compare mental health status and online communication in 15-year-old Icelanders born in 1988 and in 1994. The second aim was to assess whether the relationship between online communication and mental health has changed among 15-year-old Icelanders from 2003 to 2015 across genders. *Methods:* Analysis used data from self-reports from 2003 (N=385, 51% males) and 2015 (N=302, 42% males). Mental health was assessed with subscales of Symptom Checklist 90 and online communications with self-reports. To evaluate the difference in anxiety and depression, a factorial analysis of variance was conducted between gender and years. Multigroup structural equation modelling was used to assess the change in the relationship between years. *Results:* Symptoms of anxiety and depression remained unchanged for males. Symptoms of depression increased for females, while anxiety was stable between 2003 and 2015. In 2003, there was no relationship between online communication and mental health. However, in 2015, an association was found for females. *Conclusions:* Depression is getting worse for adolescent females, and an association between time spent online communicating and mental health emerged for them in 2015, which did not exist in 2003. These findings add to the possibility that online communication is harmful for mental health, but more detailed studies are still needed.

Keywords: *Online communication, social media, mental health, depression, anxiety, adolescence, gender differences*

Background

The relationship between online communication, such as social networking and social media, and mental health is unclear and debated [1–3]. The advancements in broadband technology and smartphones over the last two decades have made the internet and communication online almost instantly available anywhere and at any time. In 2003, online communication was still emerging, with only 36% of adolescents using the internet for online communication, such as emails and instant messaging [4]. In 2015, most people had access to social media networks such as Facebook, which had 1.22 billion users worldwide [5]. At the same time, around 84% of teens had smartphones [6]. This digital access indicates that adolescents in both 2003 and 2015 had the option to communicate online, but its scope has changed immensely.

There are indications of an increase in mental health problems in the 21st century, especially among females [7,8], which is a public health concern. The growth has been most evident in internalizing problems, including symptoms of depression and anxiety. For instance, depressive symptoms increased from 9% in 2005 to 14.8% in 2015 in a longitudinal cohort

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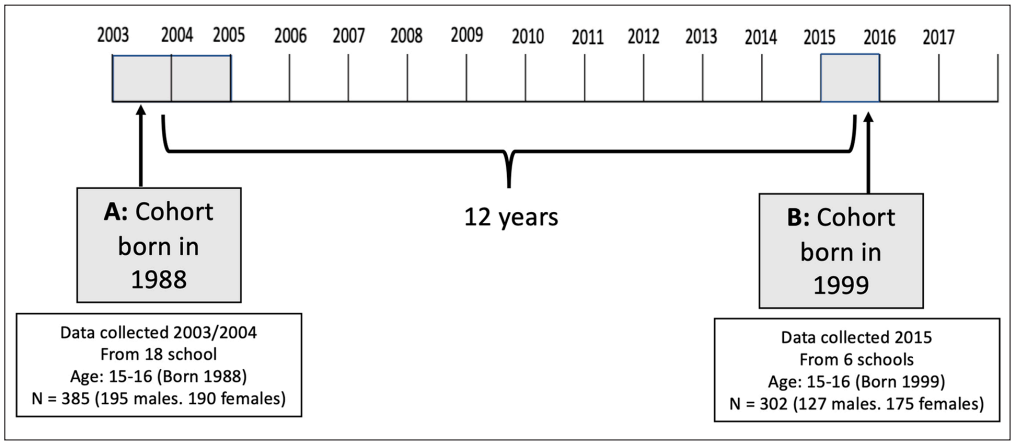

Figure 1. Timeline showing the main description of the cohorts used in the study.

study of British 14-year-olds [9]. Furthermore, females have more depressive and anxiety symptoms than males during adolescence [7,8]. Adolescent females are also more likely to have symptoms of depression than males [9].

In general, online communication has been shown to be related to mental health problems in adolescents [10–12], while other studies show little to no relationship with online communication [1,13]. Studies on the relationship between online communication and anxiety symptoms, in particular, are scarce. A recent systematic review concluded that previous studies indicate an association between anxiety symptoms and general internet use. However, most of those studies have methodological limitations, including many cross-sectional studies [14]. A meta-analysis and a systematic review of online communication and depression have shown mixed results but mainly weak to moderate associations [2,15]. One possible reason for mixed results, according to Valkenburg et al. [3], is that many studies lack the inclusion of gender in their analysis.

Although there is an indication that mental health problems are increasing simultaneously as online communication among adolescents is on the rise, there is limited information in the current literature on the relationship between mental health and online communication and whether the association has changed over the years. In addition, studies on gender differences in the matter are also lacking. The motivation and novelty behind this study is to compare an early-born cohort at the rise of online communication with a younger cohort during the current online usage on the association between online communication and mental health.

Aims

The aim of the study is twofold. The first aim was to compare mental health status and online communication in 15-year-old Icelanders born in 1988 and in 1994. The second aim was to assess whether the relationship between online communication and mental health has changed among 15-year-old Icelanders from 2003 to 2015 across genders.

Methods

Sample and data collection

All data was collected with self-report questionnaires in Icelandic. An overview of the two cohorts can be seen in Figure 1. The older cohort, born in 1988, came from 18 randomly selected elementary schools located all over Iceland (60% of those schools were in the capital area of Iceland). Participants were assessed in 10th grade during the school year 2003–2004. A total of 661 were invited to participate, and 385 participants (195 males and 190 females) accepted and had complete data for the variables of interest (58% participation rate). This data has been used in a few other studies (e.g. Gestsdottir et al. [16]). The younger cohort, born in 1999, came from six elementary schools in the capital area of Iceland and that data was collected from April to September 2015 [17]. A total of 471 were invited to participate, and 302 participants (127 males and 175 females) accepted and had complete data for the variables of interest (73% participation rate). Therefore, the total sample data for both cohorts was 687 (53% females).

Ethics

All participants and their parents or guardians signed informed consent. The study was approved by the Icelandic Data Protection Authority and the National Bioethics Committee (VSNb200605002/03 for 2003 and VSNb2015020013/13.07 for 2015).

Measures

Socio-economic status was approximated by maternal education, where the mothers are grouped by university education and no university education based on self-reports from the participants.

Participants were asked how many hours per day they spent online during weekdays and weekends, with examples of online communication such as *chatrooms* in 2003 and *Facebook* in 2015. Since the question was in two parts, with one for average use on weekdays (five days of a seven-day week) and the other for the weekend (two days of a seven-day week), the weighted average (weekend*0.29 + weekdays*0.71) was taken to generate a single variable measuring the amount of total weekly online communication. In 2003 the possible responses were: 1 = almost none, 2 = 0.5–1 h, 3 = about 1 h, 4 = about 2 h, 5 = about 3 h, 6 = about 4 h, 7 = about 5 h, 8 = 6 h or more. In 2015 the possible answers were almost the same, but the maximum score was 7 for 'More than 5 hours'. Because of this discrepancy in the Likert scales between years, the following transformation was done in accordance with Schwarz et al. [18]. They concluded that subjects answering the scale might be using the response alternatives as a comparison for their answer instead of the actual meaning of *hours* in the options [18]. Therefore, response option = 8 (meaning six or more hours) from 2003 was transformed to response option 7, representing five or more hours. The transformation had minimal effect on the mean, which lowered only by 0.05 for males and females.

Symptoms of depression and anxiety were measured with the depression and anxiety subscales of the Icelandic translation of Symptom Checklist 90 (SCL-90). The scale asks how various symptoms had bothered the participant over the last week. Scoring options were: 1 = not at all, 2 = a little bit, 3 = moderately, 4 = quite a bit, and 5 = extremely. The depression subscale has 10 items; examples are 'Feeling no interest in things' and 'Feeling blue'. The anxiety subscale has four items; examples are: 'Suddenly scared for no reason' and 'Feeling tense or keyed up'. Each subscale was summed up for the factorial analysis of variance (FANOVA). Depression scores ranged from 5 minimum to 50 maximum, and anxiety scores ranged from 5 to 20. The original version has shown a good construct validity [19] and a good factor structure and reliability [20]. A newer study shows that the scale is acceptable for screening and as an outcome measure for adolescents [21]. The Cronbach's alpha from 2003 was 0.89 for the depression subscale and 0.74 for the anxiety subscale. The Cronbach's alpha from 2015 was 0.94 for the depression subscale and 0.88 for the anxiety subscale, indicating acceptable to excellent internal consistency.

Statistical analysis

Data analysis was conducted in Jamovi and R [22]. The structural equation modelling used Lavaan for R [23]. The descriptive statistics for all variables included the mean and dispersion for all four groups (both males and females in 2003 and 2015). An independent *t*-test was used to assess the difference in average time spent online communicating between genders and between years. To evaluate the differences between the four groups across the factors of time and gender, two separate FANOVAs (one for anxiety and one for depression) were used. Alpha level was set at 0.05 for all analyses. The Tukey post hoc test was used to assess differences between groups if the interaction was statistically significant.

A multigroup structural equation modelling was conducted to determine whether the association between online communication and mental health (depression and anxiety) had changed. Online communication was treated as an exogenous variable in the model. Depression and anxiety were treated as endogenous latent variables with raw scores of the depression and anxiety items from SCL-90 as indicators. The model also included covariance between the two latent variables and variance for each item. Dependent variables for all groups were slightly positively skewed, heteroscedastic and based on ordinal Likert scores. Therefore, the Maximum Likelihood to estimate model fit (the standard) did not suffice. Instead, Diagonally Weighted Least Squares was used with the Satorra–Bentler method to scale the chi-square for better approximation because of non-normality. The comparative fit was assessed with the Comparative Fit Index (CFI) and Tucker–Lewis Index (TLI). For both indices, a value over 0.90 indicates an acceptable fit, and over 0.95 a good fit [24]. The root mean square error of approximation (RMSEA) was also used to assess the goodness-of-fit where the index should ideally be under 0.05 or at least under 0.08 [24]. Two versions of the model were computed to assess a difference between groups. One version had the intercepts and regressions coefficients free to vary between groups, and in the other version they were constrained across the four groups.

Table I. Demographic characteristics of both samples.

	2003	2015
Total *n*	385	302
Males	195 (51%)	127 (42%)
Females	190 (49%)	175 (58%)
Mean age	15.3 (SD 0.3)	15.9 (SD 0.3)
Minimum age	14.7	14.5
Maximum age	16.1	16.4
Maternal education:		
University education	81 (21%)	182 (60%)
No university education	304 (79%)	120 (40%)

All percentages are calculated within columns (years).

Then the significance between the two models was assessed using the chi-square (χ^2) difference test.

Results

Demographic characteristics of samples both from 2003 (cohort 1988) and 2015 (cohort 1999) are presented in Table I. In 2003 the proportion of males and females was almost identical in size (51% males), and in 2015 females were in greater numbers (58%). The proportion of participants' mothers having a university education was 21% in 2003 and 60% in 2015.

There were no gender differences regarding time spent online communicating in 2003 ($t(383) = 0.23$, p=0.818), where males scored 3.20 (approximately 70 min a day) and females 3.16 (approximately 70 min; Table II). Compared with males, females spent, on average, almost an hour longer online communicating in 2015, scoring 4.21 and males 3.31 (approximately 130 min and 80 min, respectively, $t(300) = 5.89$, $p<0.001$). Time online communicating for males did not change between 2003 and 2015. The time for females increased significantly by approximately an hour from 2003 to 2015 ($t(363) = 5.61$, $p<0.001$).

Gender differences in mental health between the years 2003 and 2015

The FANOVA for anxiety revealed a statistically significant interaction between year and gender on anxiety ($F(1,1) = 4.519$, $p = 0.033$). A simple main effect for gender was also significant ($p < 0.001$), showing that females scored higher on anxiety compared with males (Figure 2(a)). Year alone did not have a main effect (p=0.541). The post hoc Tukey test for anxiety showed that females had more anxiety symptoms than males in both 2003 and 2015.

For the analysis of depression, the FANOVA also revealed statistically significant interaction between year and gender on depression ($F(1,1) = 6.960$, $p = 0.009$) with significant main effect for both year ($p = 0.008$) and gender ($p < 0.001$; Figure 2(b)). The post hoc Tukey test for depression showed that females had a significantly higher score on depression both years. The Tukey test also showed a statistical difference between depression for females in 2003 and females in 2015, indicating depression is getting worse for females (Figure 2(b)).

The relationship between online communication and mental health across gender

The fit for the constrained model was $\chi^2(394, N = 687) = 1007$, $p < 0.001$ (scaling correction factor = 0.312), TLI = 0.90, CFI = 0.91, RMSEA = 0.10. The model fit with all parameters freely estimated for all groups, was $\chi^2(352, N = 687) = 526$, $p < 0.001$ (scaling correction factor = 0.240), TLI = 0.99, CFI = 0.99, RMSEA = 0.05. All indicators for latent variables for all groups in both models were acceptable, suggesting construct validity of depression and anxiety. The χ^2 difference test between model fits indicated a significant difference ($p<0.001$), rationalizing the use of the model with the better fit, which

Table II. Descriptive statistics for time online communicating, and anxiety and depressive symptoms by year and gender.

	Year	Gender	*n*	*M*	SD	Min.	Max.
Time online communicating	2003	Males	195	3.20	1.75	1.00	7.00
		Females	190	3.16	1.79	1.00	7.00
	2015	Males	127	3.31	1.05	1.71	7.00
		Females	175	4.21	1.47	1.58	7.00
Anxiety	2003	Males	195	5.70	2.33	4.00	20.0
		Females	190	7.05	2.99	4.00	16.0
	2015	Males	127	5.35	2.48	4.00	17.0
		Females	175	7.69	4.01	4.00	20.0
Depression	2003	Males	195	14.51	5.80	10.00	50.0
		Females	190	17.31	6.94	10.00	43.0
	2015	Males	127	14.51	6.19	10.00	41.0
		Females	175	20.38	10.23	10.00	50.0

Time online communicating is shown with the Likert score, not hours.

M: mean; SD: standard deviation, Min.: minimum score; Max.: maximum score

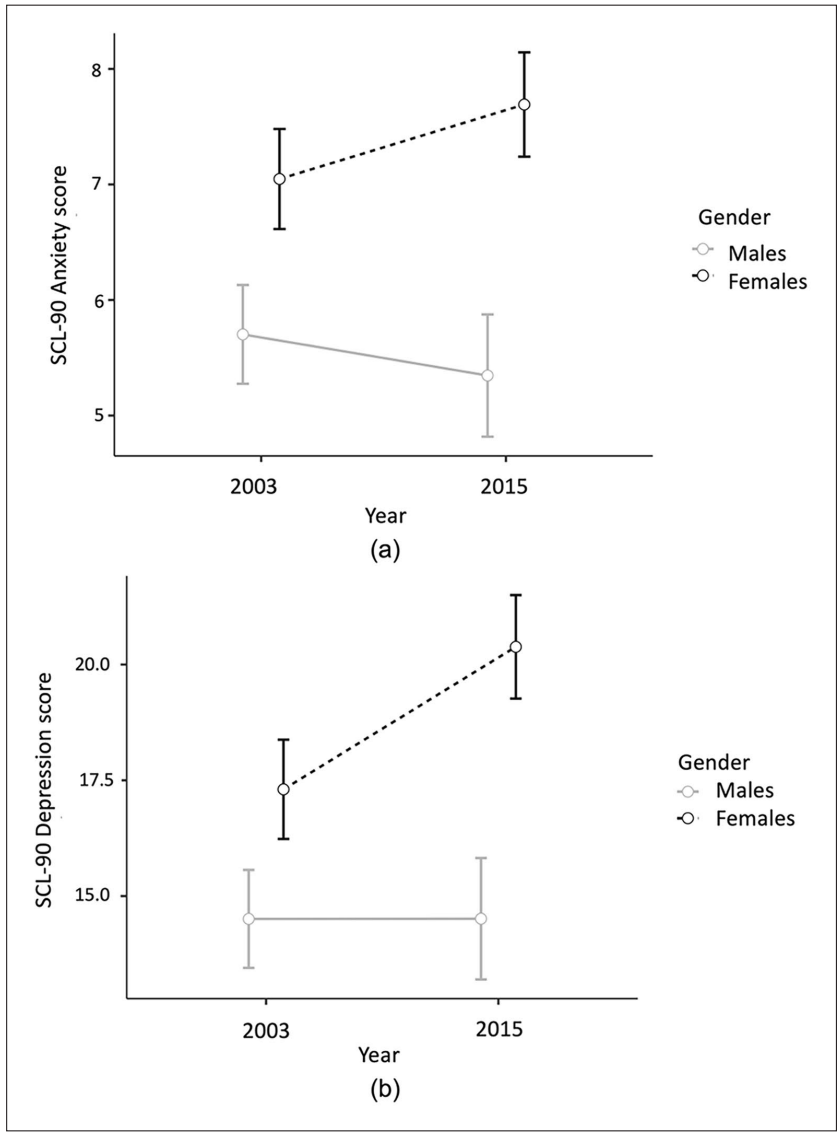

Figure 2. (a) Anxiety scores for males and females from 2003 to 2015 showing estimated marginal means. (b) Depression scores for males and females from 2003 to 2015 showing estimated marginal means.
SCL-90: Symptom Checklist 90

was the one where the parameters were not constrained between groups, thus indicating valid differences between groups. The results from that model (Figure 3) show that there is no significant relationship between time spent online communicating and anxiety or depression, except for females in 2015, where anxiety increased significantly by 0.14 standard deviations and depression by 0.21 standard deviations for each increase in the score for time online communicating.

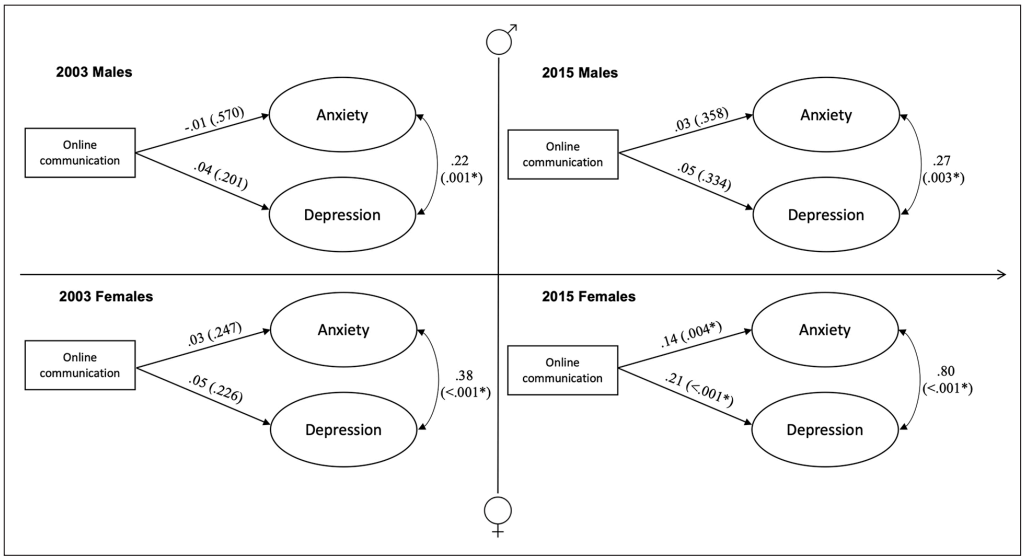

Figure 3. Comparison of the relationship between time spent online communicating and mental health.
The figure shows the standardized parameter estimates with the *p*-value in parentheses, where the asterisk (*) indicates significance at $p < 0.05$. The single-headed arrows show regression, and the double-headed arrows show covariance. The 14 indicators for the latent variables are excluded for clarity of the diagram.

Discussion

The main findings were that adolescent females in 2015 spent more time online communicating and had more symptoms of depression compared with adolescent females in 2003. Whereas males spent similar time online communicating at both time points, and no difference was found in their depressive symptoms. Anxiety symptoms did not change for males or females from 2003 to 2015. In 2003, time spent online communicating was not associated with mental health (symptoms of depression and anxiety) for either males or females. However, in 2015, there was a relationship between time spent online communicating and both anxiety and depressive symptoms for females.

As a relationship between online communication and mental health was apparent only for females and only in 2015, this begs the question: what has changed between 2003 and 2015 that seems to be affecting females only? One possible answer is the ever-present reminder of how females are represented online on social media, which was instantly available through smartphones in 2015 but not in 2003. Supporting that idea is that females use social media more than males [25], thus adding to the possibility the content on social media that affects mental health. Social media and other means of online communication could affect females' body image more than males through skewed standards for females presented online [26]. In return, body image dissatisfaction increases the risk of depression [27]. Another proposed mechanism has been online bullying [28], where girls are more likely to be bullied online than boys [29]. Related to that is that females have higher levels of fear of cybercrimes, which could contribute to the relationship [30]. Another possible mechanism could be that sedentary behaviour and physical inactivity are more common in adolescent girls [31], and both are related to mental health [32,33]. There is also a possibility that the relationship could be attributable to mediating variables such as sleep problems [34]. The current study is cross-sectional, so reverse causality cannot be ruled out. However, longitudinal studies have not found reverse causality [35]. Further cross-sectional and longitudinal research on mediation variables is needed, where gender is included, to understand the relationship better. The lack of analysis of gender differences in online communication could be part of the weak association found in previous studies between social media and mental health [3].

An expected increase for 15-year-old adolescents was found in online communications from 2003 to 2015 but only for females. That is in accordance with previous studies where female adolescents are found to use the internet more in general compared with males, whereas adolescent males tend to be gaming more [25]. In 2003, males and females spent almost similar time online communicating, but females surpassed males by approximately an hour more per day in 2015.

There was no increase in anxiety symptoms over time in the present study, which is in contrast to previous studies [8], which have found a rise in anxiety among adolescent females. One possible reason why anxiety has not increased could be traced to the fact that mental health discussion has increased in Iceland and, thus, more people seek treatment for mental health problems [36]. It could also be speculated that a more sensitive measurement tool, with more than only four items assessing symptoms of anxiety, might have detected an increase in symptoms of anxiety.

This study has a few limitations. The independent variable of time online communicating had minor discrepancies between Likert levels from 2003 to 2015 but was dealt with by transforming the data, which had minimal effect on the mean. The time spent using online communication platforms was based on self-report. In the future, objective data from screen time reports from adolescent devices will increase the accuracy of time spent on social media and other digital tools. Another limitation is that the data from 2003 was from schools all over Iceland. In contrast, the data from 2015 was from schools only in the capital area, which could partly explain the discrepancies in the mothers' educational level and possibly the difference in depression between the cohorts. However, no study to date has explored the difference in the symptoms of depression between the capital area and other parts of the country, so there is a possibility that the data represents two different populations. But overall, education in Iceland has changed similarly all over Iceland during this time. In 2003, around 30% of women in Iceland had completed a university degree, but in 2015, the number was almost 50% [37]. Furthermore, a study from 2018 found that parental education did not seem to have an effect on trends in depression from 1991 to 2018 [38]. Finally, it should be noted that adolescent males play games more often than females [25,39] and that games today are mostly played online and often include communication. Therefore, there is a possibility that online communication could be related to mental health for males if games were included in the analysis of the current study. However, since games can also be non-communicative, it was not included in this study as we did not have a question about communications in games specifically.

Conclusions

The main findings are that depression scores are getting worse for adolescent females, and time spent online communicating has increased for them from 2003 to 2015. The results also suggest that the time spent online communicating could affect female and male adolescents differently since an association was found between mental health and online communication in 2015 for females only. These findings hint that there is a possible relationship between online communication and mental health. However, a more detailed gender comparison is needed to shed light on potential mechanisms affecting the association between online communication and mental health.

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Declaration of conflicting interests

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Paper II

PLOS ONE

RESEARCH ARTICLE

Adolescent mental health and cardiorespiratory fitness: A comparison of two cohorts 12 years apart

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Abstract

The aim of the study was to compare the mental health and cardiorespiratory fitness (CRF) of adolescents in two cross-sectional cohorts, one measured in 2003 and the other in 2015, both at age 15 and across sexes. The study also sought to estimate the association between mental health and CRF in the two cohorts and examine the relationship between the level of CRF and mental health in each cohort overall and by sex. Data from 443 participants born in 1988 (228 males, 215 females) and 303 participants born in 1999 (126 males, 177 females) were analyzed. Mental health was assessed using self-reports of body image, self-esteem, and symptoms of depression and anxiety. CRF was estimated using a maximal cycle ergometer test. From 2003 to 2015, body image scores improved ($p = .043$), self-esteem remained stable, and CRF declined significantly ($p < .001$). No self-esteem differences were observed between sexes in any cohort. Males had higher CRF and body image scores than females in both cohorts ($p < .001$ for all comparisons). Higher CRF correlated with fewer depressive symptoms across sexes and cohorts. Specifically, higher CRF was associated with anxiety in females and improved body image in males (2003) and both sexes (2015). Increased CRF was linked to higher self-esteem in females but not in males. Overall, higher CRF levels were associated with better mental health outcomes for both sexes. These results highlight the potential of improving adolescent mental health through increased physical fitness.

Introduction

Adolescence is marked by profound physical, social, and psychological transformations. Recent trends suggest that both mental health and cardiorespiratory fitness (CRF), which is a marker for physical health, are declining over time [1–4], with a potential link between the two [5]. Notably, rates of depression have increased among adolescents [6,7], particularly among females [8,9]. Moreover, low self-esteem, depression, and anxiety tend to be more prevalent

Competing interests: The authors have declared that no competing interests exist.

among females than males, during adolescence and adulthood [10–13]. Body image dissatisfaction is getting worse for adolescents and is more prevalent with girls and women [14]. When it comes to sex differences in CRF, males tend to have higher levels than females [15,16]. However, longitudinal studies are lacking when it comes to assessing if males and females show different trends in CRF.

The relationship between CRF and mental health is complex. Studies indicate that lower CRF increases the risk of mental health problems [5] and conversely, higher CRF is linked to more positive mental health outcomes [17,18]. Furthermore, intervention programs targeting CRF have shown promise in enhancing self-esteem [19,20]. Additionally, high CRF has also been shown to predict more positive body image longitudinally [21].

Overall, these trends point to a concerning scenario in which both physical and mental health among adolescents appear to be deteriorating. Thus, it is of interest to examine the changes in mental health and CRF and the relationship between the two at the beginning of the 21st century in Iceland.

In our study, results from two 15 years old Icelandic cohorts, one born in 1988 and the second born in 1999 were compared. Note, that in a recently published article using the same data, we investigated the comparasion between depressive sypmtoms and anxiety where we discovered that depressive symptoms are worse for females in the 1999 cohort then the 1988 cohort. [8]. Therefore, the objective of this study was twofold.

Firstly, to conduct a comparative analysis of body image, and self-esteem, and CRF in these two cohorts aged 15. Secondly, to assess the association between mental health (symptoms of depression, symptoms of anxiety, body image, and self-esteem) and CRF, in both cohorts across sexes. In relation to the second aim, the relationship will also be assessed between three levels of CRF (low, medium, and high) across the mental health variables.

Materials and method

Design and subjects

Data came from two longitudinal cohort studies, one cohort born in 1988 (n = 443) and the other cohort in 1999 (n = 303) both measured at age 15. A total of 746 (392 females and 354 males) participated. See attrition chart in Fig 1. Data from the 1988 cohort [22] was collected between August 2003 and January 2004, and the participants came from 18 randomly selected schools from different parts of Iceland, in proportion to where the population lived (60% from the capital area, 35% other urban area, and 5% rural area). Every student in 10^{th} grade from the selected schools were offered to participate through the school and on school time. The 1999 cohort came from six randomly selected schools in the capital city and was measured between January and March 2015. All 10^{th} graders in those schools were offered to participate through the school and on school time. In both cohorts, the primary reasons for not participating were being absent from school on the days of measurement and possibly having no interest in the study.

Because of the discrepancy of location of participants between the years, the data from 2003 was split into two distinct groups: Group 1 from the capital area and Group 2 from regions outside the capital. Analysis of the key variables in our study revealed no significant differences between participants from these two groups giving evidence that there is little or no difference between participants from the capital area and other locations. Further description of the invitation to participate in the studies, participation rate, and dropout, has been published already. See Johannsson et al. (2006) [22], and Gestsdottir et al. (2015) [23] for the 1988- cohort, and Brychta et al. (2019) [24] for the 1999-cohort, and Birgisson et al. (2023) for both cohorts.

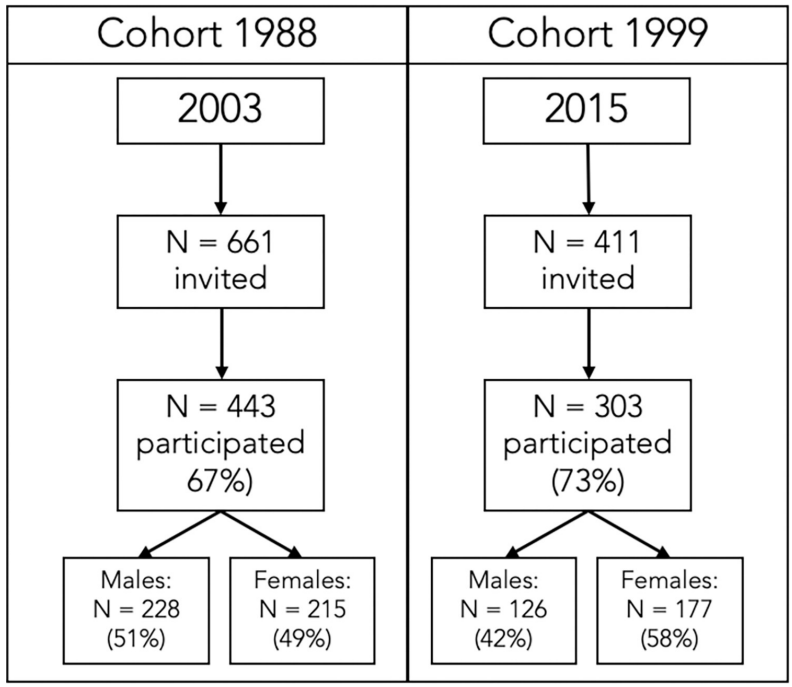

Fig 1. The attrition of the participants used in the study. Figure shows total participation while participation between measures varied.

https://doi.org/10.1371/journal.pone.0300810.g001

Access to data for this retrospective study was granted and accessed on October 1st 2021 with no identifiable information.

Ethics

Both research projects were approved by the Icelandic Data Protection Authority according to the Icelandic Act on Processing of Personal Data, and the Icelandic Bioethics Committee (VSNb200605002/03 for 2003 and VSNb2015020013/13.07 for 2015). Written informed consent was obtained from all the participants and their parents before data collection, for details see Johannsson et al. (2006) [22] and Brychta et al. (2019) [24]. Strict procedures were followed to ensure confidentiality.

Measures

In both cohorts, the same self-reported questionnaires in Icelandic were used to measure mental health, and the same objective measures were collected on physical health (CRF and BMI).

Socioeconomic status (SES). Parents' education was measured with questions about their education level, e.g., if they finished primary school, secondary school, apprenticeship, or university. Participants also answered questions about whom they lived with, e.g., with both parents, with either mother or father, with grandparents, or other living arrangements. To simplify analysis for the multiple regression one variable was created to indicate SES where the value of 3 was assigned to participants who had both parents with a university education and

live with both parents, a value of 2 to participants who have either one parent with a university education or live with both parents and a value of 1 to participants who have neither parent with a university education nor live with both parents [25–27].

Depression. Symptoms of depression was measured with a ten-item Subscale of Symptom Checklist 90 (SCL-90)[28]. It was scored on a five-point Likert scale rated from 1 (almost never) to 5 (almost always), asking about feelings of depression like "*Did you feel that the future is hopeless*", in the preceding week. Higher scores indicate more symptoms of depression. Cronbach's alpha for the full scale was used to evaluate internal consistency, which was α = 0.88 (good reliability) for the 1988 cohort and α = 0.94 (excellent reliability) for the 1999 cohort.

Anxiety. Symptoms of anxiety was measured with a four-item Subscale of Symptom Checklist 90 (SCL-90)[28]. It was scored on a five-point Likert scale rated from 1 (almost never) to 5 (almost always), asking about feelings like 'Suddenly scared for no reason' in the preceding week. Higher scores indicate a higher level of anxiety. Cronbach's alpha for the full scale was used to evaluate internal consistency, which was α = 0.74 (acceptable reliabililty) for the 1988 cohort and α = 0.88 (good reliability) for the 1999 cohort.

Body Image. Body image was assessed with five items from the *Body and Self-Image subscale of the Offer Self-Image Questionnaire* [29]. Participants were asked how well they agreed with five statements e.g. "*I'm satisfied when I think about how my body will look in the future*". All items were rated on a four-point response scale, where *1 = Not at all true of me*, and *4 = True of me*. Higher scores indicate higher levels of body image (i.e. more positive body image). Cronbach's alpha for the scale was used to evaluate internal consistency, which was α = 0.70 (acceptable reliability) for the 1988 cohort and α = 0.85 (good reliability) for the 1999 cohort.

Self-esteem. Global self-esteem was assessed, using the Rosenberg Self-Esteem Scale [30,31]. The scale consists of ten statements, each rated as negative or positive, with four response options ranging from "strongly agree"(3) to "strongly disagree"(0). Higher scores (15 points or higher) reflect a higher level of self-esteem. The Rosenberg scale has been widely used in measuring self-esteem in young people, and its reliability and validity are well documented [13,32]. Higher scores indicate a higher level of self-esteem. Cronbach's alpha was used to evaluate the internal consistency of the scale, which was α = 0.87 (good reliability) for the 1988 cohort and α = 0.91 (excellent reliability) for the 1999 cohort.

Cardiorespiratory fitness. CRF was assessed objectively using the maximal cycle ergometer test on a Monark stationary bike [33]. CRF are in similar studies expressed as absolute maximal power output (W_{max}) as well as maximal power output relative to body mass (W/kg) to account for differences in body size [34,35]. The mechanical power (W_{max}) was used in this study, after being dived by the participants' weight, to assume the VO_2 max. The test has been validated in adolescents and predicted oxygen uptake from this test correlates very well with measured oxygen uptake [36,37]. Furthermore, Saevarsson et al. found no significant differences when CRF was expressed in relative or absolute terms, supporting the use of relative measure in this study [38]. However, to ensure that possible effects of CRF are not attributable to differences in participants weight we also included the absolute value (W_{max}).

Body mass index. Body mass index (BMI) was calculated from participants´ measured weight and height (kg/m^2).

Self-reported vigorous physical activity. The physical activity was assessed with the question "How often, per week, do you perform physical activity that makes you breathe more rapidly or sweat?". Response options were six ranging from 1 = never to 6 = almost every day.

Statistical analysis

Descriptive summaries are presented as means and standard deviations for continuous variables and as frequencies or percentages for categorical variables. Study variables were analyzed for distributional properties. The alpha level for significant differences is set at 0.05. To assess differences between cohorts an independent sample t-test was used when the variance was equal and Welch's T-test when the variance was assumed unequal. Cohen's *d* effect size represents the differences between cohorts for continuous variables and Cramer´s *V* for categorical. For the multiple linear regression analyses, our goal was to examine the relationship between mental health outcomes (as dependent variables) and CRF, adjusting for SES as a covariate. Specifically, the models were structured as follows: the dependent variable (Y) represented the mental health measures (body image, depressive symptoms, anxiety symptoms, and self-esteem), and the independent variables included CRF (W_{max} /kg) as X1 and SES (encompassing both parental education and living arrangement) as X2. The adjusted R-squared values were reported to quantify the proportion of variance in the mental health outcomes explained by the models, after accounting for the effects of SES. Finally, the CRF variable (W_{max} /kg) was divided into three levels by using cut points for three equal groups (Low levels: <2.65, Medium levels: 2.65–3.39, and High levels: >3.39). An analysis of variance (ANOVA) was used to assess if there was a difference between the level of CRF and body image, symptoms of depression and symptoms of anxiety, and self-esteem for both cohorts across the sexes.

Results

Demographic characteristics

Participants SES based on parents' education and living arrangements changed from 2003 to 2015 (Table 1). In 2003 a higher proportion of participants lived with both parents (χ^2 (4) = 21.04, $p < .001$, V = 0.18) and a higher proportion had a mother with university education (χ^2 (3) = 97.40, $p < .001$, V = 0.44) than in 2015.

Differences between the 1988 and 1999 cohorts

The body image score was higher in 2015 (t(670) = -2.03, p = .043) than in 2003. Self-esteem remained stable over the years. These findings are further detailed in Table 2. In 2003 CRF (relative values) scores (t(504) = 10.73, $p < .001$) as well as absolute values (t(523) = 8.59, $p < .001$) were significantly higher and BMI (t(751) = -4.26, $p < .001$) was lower compared to scores in 2015 (Table 2). No change was found in self-reported vigorous physical activity (Table 1).

Differences between the sexes

In 2003, males had higher CRF, self-esteem, and body image (t(222) = 11.34, $p < .001$; t(369) = 2.30, p = .022; t(372) = 4.82, $p < .001$, respectively) compared to females. No sex-based difference was observed in 2003 regarding BMI.

In 2015, males demonstrated higher CRF (t(291) = 8.38, $p < .001$), higher self-esteem (t (295) = 2.40, p = .017), and higher body image scores (t(287) = 5.65, $p < .001$). However, there was no significant difference in BMI between sexes in 2015 (Table 3).

Association between mental health and cardiorespiratory fitness

Between symptoms of depression and CRF, an association was observed for both males and females after adjusting for SES (see Table 4). Among males, CRF was significantly associated with symptoms of depression in 2003 (B = -3.83, SE = 1.42, p = 0.009) and 2015 (B = -1.23,

Table 1. Descriptive statistics for participants SES and weekly physical activity.

		2003		2015	
		Male	Female	Male	Female
Lives with	both parents	145 (74.4%)	129 (67.9%)	76 (61.3%)	90 (51.1%)
	mother only	21 (10.8%)	28 (14.7%)	15 (12.1%)	30 (17.0%)
	father only	8 (4.1%)	6 (42.9%)	15 (12.1%)	17 (9.7%)
	mother and stepparent	16 (18.2%)	22 (11.6)	9 (7.3%)	20 (11.4%)
	father and stepparent	1 (0.5%)	3 (1.6%)	3 (2.4%)	4 (2.3%)
	other arrangements	3 (1.5%)	2 (1.1%)	6 (28.6%)	15 (71.4%)
	Total	195 (100%)	190 (100%)	124 (100%)	176 (100%)
Mother‘s education	University	42 (37.5%)	50 (40.3%)	84 (72.4%)	98 (60.1%)
	Apprenticeship	8 (7.1%)	4 (3.2%)	17 (14.7%)	35 (21.7%)
	Secondary school	25 (22.3%)	27 (21.8%)	4 (3.4%)	15 (9.3%)
	Primary school	37 (33.0%)	43 (34.7%)	11 (9.5%)	13 (8.1%)
	Total	112 (100%)	124 (100%)	116 (100%)	161 (100%)
Father‘s education	University	27 (27.0%)	40 (36.4%)	58 (49.2%)	86 (57.7%)
	Apprenticeship	40 (40.0%)	31 (28.2%)	15 (12.7%)	15 (10.1%)
	Secondary school	15 (15.0%)	11 (10.0%)	33 (28.5%)	33 (22.1%)
	Primary school	18 (18.0%)	28 (25.5%)	12 (10.2%)	15 (10.1%)
	Total	100 (100%)	110 (100%)	118 (100%)	149 (100%
Physical activity[a]	Never	8 (4.1%)	4 (2.1%)	0 (0.0%)	6 (3.5%)
	Less than 1x a week	8 (4.1%)	15 (7.9%)	5 (4%)	11 (5.4%)
	1x a week	13 (6.7%)	22 (11.6%)	9 (7.3%)	17 (9.8%)
	2-3x a week	34 (17.5%)	51 (27%)	24 (19.4%)	42 (24.3%)
	4-5x a week	60 (30.9%)	60 (31.7%)	37 (29.8%)	47 (27.2%)
	Almost every day	71 (36.6%)	37 (19.6%)	49 (39.5%)	50 (28.9%)
	Total	194 (100%)	189 (100%)	124 (100%)	173 (100%)

[a] Self-reported vigorous physical activity.

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SE = 0.59, p = 0.039). Similarly, among females, significant associations were found in 2003 (B = -4.87, SE = 1.92, p = 0.014) and 2015 (B = -2.27, SE = 1.99, p = 0.049).

Regarding the relationship between CRF and symptoms of anxiety, an association was found only among females, both in 2003 (B = -1.77, SE = 0.85, p = 0.042) and in 2015 (B = -1.14, SE = 0.46, p = 0.014).

Table 2. Differences between 2003 and 2015 with 95% Confidence Intervals and effect sizes.

	M						95% CI	
	2003	2015	t-value	df	p-value	Effect Size	Lower	Upper
BMI	21.03	22.00	-4.26	751	< .001	0.32	-0.46	-.017
CRF (W/kg)	3.42	2.80	10.73	504	< .001	0.96	0.76	1.15
W_{max}	210	166	8.59	523	< .001	0.73	0.55	0.91
Self-Esteem	31.47	31.31	0.32	666	.752	0.03	-0.13	0.18
Body-Image	14.85	15.33	-2.03	670	.043	0.16	-0.31	-0.01

Note. BMI refers to Body Mass Index. CRF = Cardiorespiratory fitness(W/kg), relative values, W_{max} = Absolute values of CRF, M = Mean score. Df = Degrees of freedom. Effect sizes are reported as Cohen's d. CI = Confidence Interval.

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Table 3. Differences between the sexes for 2003 and 2015.

								95% CI	
	Year	Male	Female	t-value	df	p-value	Effect Size	Lower	Upper
BMI	2003	20.98	21.07	-0.32	441	.751	0.24	-0.65	0.47
	2015	21.74	22.18	-1.18	308	.239	0.14	-1.18	0.29
Cardiorespiratory fitness (W/kg)	2003	3.78	3.03	11.34	222	< .001	1.47	0.62	0.88
	2015	3.09	2.21	8.38	291	< .001	0.99	0.67	1.09
Cardiorespiratory fitness W_{max}	2003	245.20	172.54	-16.27	216	< .001	2.09	-81.46	-63.85
	2015	209.80	134.60	-10.65	215	< .001	1.32	-89.11	-61.27
Self-Esteem	2003	32.15	30.75	2.30	369	.022	0.24	0.20	2.60
	2015	32.42	30.51	2.40	295	.017	0.28	0.34	3.47
Body-Image	2003	15.53	14.16	4.82	372	< .001	0.50	0.81	1.93
	2015	16.50	14.49	5.65	287	< .001	0.66	1.31	2.71

Note. BMI = Body Mass Index, df = Degrees of freedom. Effect size is Cohen's d.

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When examining the relationship between CRF and body image, association was observed among males (B = 2.03, SE = 0.68, p = 0.004) and females in 2003 (B = 2.39, SE = 0.75, p = 0.002), but only females in 2015 (B = 0.92, SE = 0.36, p = 0.012).

Lastly, in the analysis of CRF and self-esteem, an association was found only among females both in 2003 (B = 3.87, SE = 1.65, p = 0.022) and 2015 (B = 1.41, SE = 0.97, p = 0.019).

Differences in mental health depending on the level of cardiorespiratory fitness

The analysis consistently demonstrated a significant main effect of CRF levels on mental health outcomes across all variables. Specifically, there was a significant reduction in depression (F(2,

Table 4. Association between mental health (symptoms of depression, anxiety, body image and self-esteem) on CRF after adjusting for SES.

	Year	Sex	R^2	B	SE	p-value
CRF-> Depression	2003	Male	0.24	-3.83	1.42	0.009**
	2015	Male	0.10	-1.23	0.59	0.039*
	2003	Female	0.09	-4.87	1.92	0.014*
	2015	Female	0.06	-2.27	-1.99	0.049*
CRF -> Anxiety	2003	Male	0.04	-0.62	0.51	0.224
	2015	Male	0.09	-0.41	0.22	0.071
	2003	Female	0.06	-1.77	0.85	0.042*
	2015	Female	0.06	-1.14	0.46	0.014*
CRF-> Body Image	2003	Male	0.16	2.03	0.68	0.004**
	2015	Male	0.03	0.33	0.27	0.227
	2003	Female	0.14	2.39	0.75	0.002**
	2015	Female	0.06	0.92	0.36	0.012*
CRF -> Self-Esteem	2003	Male	0.12	2.24	1.28	0.087
	2015	Male	0.02	0.84	0.68	0.217
	2003	Female	0.10	3.87	1.65	0.022*
	2015	Female	0.06	1.41	0.97	0.019*

CRF = cardiorespiratory fitness (W/kg) and SES = socioeconomic status.

* $p < 0.05$

** $p < 0.01$.

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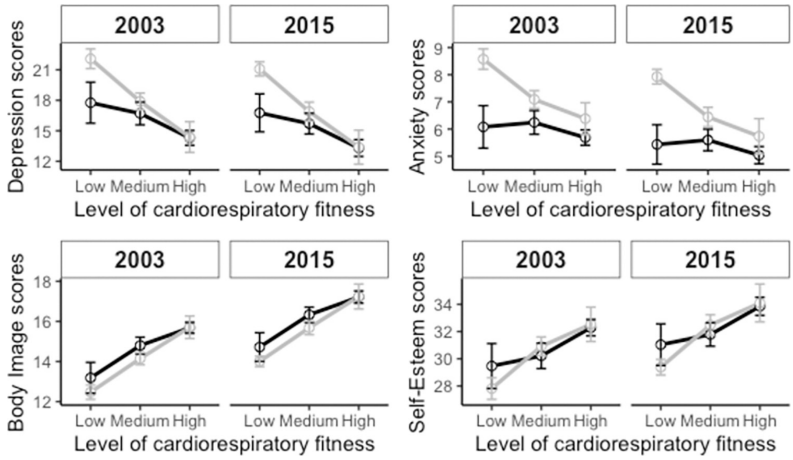

Fig 2. The relationship between three levels of cardiorespiratory fitness and symptoms of depression, anxiety, body image, and self-esteem score. Each part of the figure shows both the results for 2003 and 2015 with the black line indicating males and gray indicating females. Error bars show the standard error.

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459) = 29.254, $p < 0.001$) and anxiety scores ($F(2, 461) = 20.000$, $p < 0.001$), along with increases in body image ($F(2, 458) = 26.113$, $p < 0.001$) and self-esteem ($F(2, 454) = 12.061$, $p < 0.001$) associated with higher CRF levels. These effects were consistent across both the 2003 and 2015 measures, as depicted in Fig 2. Notably, no significant interaction effects between CRF levels and sex or year were found, indicating the relationship between CRF and mental health outcomes was stable irrespective of these variables.

Discussion

Main findings

In comparing 2015 to 2003, a decline in CRF was evident, while there was an improvement in body image. However, self-esteem showed no significant changes between these two cohorts. Males had higher self-esteem both in 2003 and 2015 though effect size was low. Furthermore, CRF and body image displayed consistent variations between sexes in both years, with males consistently exhibiting higher levels of CRF and more positive body image perceptions compared to females. Regarding the relationship between CRF and mental health, an association with symptoms of depression was observed for both males and females in both 2003 and 2015. However, the association between CRF and symptoms of anxiety was exclusively significant for females across both years, with no notable association found for males. Moreover, CRF was linked to body image for males in 2003 and for females in both 2003 and 2015, but this association was absent for males in 2015. Similarly, CRF was associated with self-esteem for females in both 2003 and 2015 but did not show a significant relation for males. In summary, these findings underscore a consistent relationship between higher CRF levels and improved mental health, with variations in how this connection manifests between sexes and across the years.

Differences between the cohorts

Even though BMI got higher between the years the CRF got worse both in absolute and relative values, suggesting that the decline in CRF is independent of participants' weight. The decline

in CRF scores observed in this study can be understood in light of the low adherence of adolescents to the recommended levels of PA in the 2020 WHO guidelines on physical activity and sedentary behavior for children and adolescents aged 5–17 years [39]. Notably, the 2020 WHO guidelines acknowledge that PA and sedentary behavior are distinct entities according to new evidence, and therefore guidelines for sedentary behavior have now been included in the WHO guidelines [39]. This distinction may partly explain why the cohorts in this study report similar physical activity. Specifically, an increase in sedentary behavior may be a contributing factor in the increase in worse CRF, even though self-reported physical activity remains unchanged. However, as we did not have measures of sedentary behavior in this study these are merely speculations.

Females had worse CRF and worse body image than males both in 2003 and 2015. The sex differences regarding CRF are consistent with previous studies [40,41] as are the results on body image [21].

Self-Esteem appeared to be stable between 2003 and 2015 and self-esteem did not differ between sexes either year. The fact that there is no difference between sexes may be seen as surprising, however, a longitudinal study has shown that though males usually have higher self-esteem than females, it is least different at the age of 14 before it increases for males and decreases for females [42]. So far, there is no consensus on whether self-esteem is getting better or worse over time, and that could possibly be due to limitations of self-esteem measurements such as ceiling effects and skewed distribution of data [43].

The finding that CRF is getting worse suggests that there may be factors at play that are contributing to the decline for this age group. One such possible factor is, as mentioned above, the increased sedentary behavior with the emergence of screentime (specifically social media) with the former being known to affect physical and mental health [44] and the latter is negatively associated with mental health [8,45–48]. Sedentary behavior is related to less PA and studies have shown that PA is related to mental health [4,44,49] and it has been shown that an active lifestyle during childhood can have positive effects on mental health later in adolescence and life in general [50,51]. However, self-reported physical activity increased between years according to the current study. Furthermore, mediation analysis is needed to test these types of relationships. Another interesting finding of this current study is that despite the decline in CRF observed in the younger cohort, both cohorts reported relatively healthy body image and self-esteem.

Association between CRF and mental health in each cohort

The present study revealed a significant association between CRF and symptoms of depression for both sexes in both years indicating that higher CRF could be important to consider when preventing or treating depression. In fact, a study has shown that interventions where the main focus is to improve CRF level can be effective as an alternative treatment for depression [52]. That study showed that CRF had more positive effect on depression then the control groups for strength training and relaxation [52]. However, the findings show a reduction in beta-coefficients from 2003 to 2015 for both males and females between CRF and depression. This means less explanatory power of CRF for variations in symptoms of depression between the years as seen by lower R^2 from 2003 to 2015. One plausible interpretation of this trend could be the emergence and influence of new social and environmental factors that were less prevalent in 2003. For instance, the rise of social media and its impact on mental health [45] could be a contributing factor and potentially diluting the relative influence of traditional predictors like CRF.

According to the current results, there was only a relationship between symptoms of anxiety and CRF for females and not males. Studies suggest that females have higher anxiety sensitivity

[53] and a higher CRF level can have a positive effect on anxiety [54] and thus possibly explain the sex difference in this current study. CRF was also associated with body image for all groups except males in 2015. It could be attributable to the fact that the media emphasizes aesthetics rather than performance for males [55], so it is possible that males work out to build muscles rather than to increase CRF. Finally, CRF was only related to self-esteem for females but not for males. At least one other study has shown similar results [56].

It is important to consider the potential impact of SES on the relationship being studied. Prior research has indicated that individuals from lower SES backgrounds are more susceptible to poor mental and physical health outcomes [57,58]. This suggests that the discrepancies in SES between the two groups being compared may have affected the current study's findings. That is, the 1988 cohort had worse SES than the 1999 cohort. However, if higher SES alone would lead to better mental health, then the 1999 cohort should show better mental health than the 1988 cohort and that was not the case in this current study.

These results highlight the potential benefits of interventions aimed at improving CRF in adolescents, as it may lead to an improvement in mental health. However randomized controlled trials are needed to shed better light on this possible benefit and future research is necessary to identify other potential factors contributing to this relationship and to better understand the underlying mechanisms.

Differences in mental health depending on the level of cardiorespiratory fitness

The relationship between mental health and the level of CRF is also of importance, as it contributes to the growing body of evidence that suggests that improving CRF levels can possibly have a positive impact on mental health [17,18,59]. In addition, this adds to the converse finding that lower levels of CRF are linked to poorer mental health outcomes [60]. Thus, maximizing CRF levels in adolescents could lead to greater potential mental health benefits. These results highlight the importance of promoting physical activity in this age group and the need for school systems to support physical activity to improve the CRF levels of adolescents [61]. Despite numerous attempts to promote physical activity and fitness among adolescents [62–64], the findings of this current study add to the evidence that those prior efforts have not been effective in reversing the trend of declining mental and physical health in this population. As a result, public health policies could try to incorporate CRF levels when making physical activity recommendations for this age group. That is, put more emphasis on vigorous PA and high levels of CRF to possibly help prevent mental health problems.

Strength and limitations

The main strength of the study is the proportion of 15-year-olds participating. Since Iceland has a low population, participation reached around 10% of the cohort populations and such percentages in similar studies are rare. The limitation of this study includes the cross-sectional analysis which limits the interpretations of causality. The reliability of the anxiety and body image measures were barley acceptable [65] in 2003 and could be attributable to the fact that few questions were behind the construct [66]. Finally, even though 60% of the population lives in the capital area of Iceland it would've made analysis stronger to include other parts of the country in the 2015 data. However, as declared in the method section, no difference was found between variables across location of the participants in the data from 2003. Furthermore, class division is not as apparent in Iceland as it is in many countries. All schools in the study were public and follow the same national curriculum. It can be assumed that these factors increase the likelihood that both cohorts represent the same population. Finally, further research is

required to identify the underlying factors contributing to the decline in mental and physical health among adolescents and to understand the mechanisms linking CRF and mental health.

Conclusions

The findings of this 12-year cross-sectional cohort study suggest that there has been a decline in CRF for adolescents over time. The study also revealed a clear association between CRF and mental health in adolescents, with those who had lower levels of CRF experiencing poorer body image, higher depression and anxiety scores, and lower self-esteem compared to those with higher levels of CRF. Furthermore, the relation between CRF and mental health is more evident for females than males, as highlighted in the regression analysis. However, the ANOVAs also revealed that low levels of CRF increase the likelihood of worse mental health irrespective of the sex of the participant or when it was measured. The findings of this study highlight the possible role of CRF in working on better mental health among adolescents. Therefore, developing effective interventions that focus on improving CRF can be an essential addition to the strategy to promote better mental health in this age group.

Supporting information

S1 File.
(CSV)

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Paper III

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The relationship between online communication and mental health and cardiorespiratory fitness from ages 15 to 17: a longitudinal cohort study

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Abstract

Background Adolescence is a critical developmental period marked by significant mental and physical health changes. This longitudinal study examines the relationship between online communication and health from age 15 to 17, focusing on mental health indicators (depression, anxiety, self-esteem, and body image) and cardiorespiratory fitness (CRF). We aimed to assess whether increased time spent in online communication is associated with poorer mental health and lower CRF among adolescents, with consideration of potential moderating effects of sex and socioeconomic status (SES).

Methods Data were collected from 315 Icelandic adolescents at age 15 (2015) and age 17 (2017; $N = 236$). Linear mixed-effects models were used to examine the association between online communication and health outcomes, including depression, anxiety, body image, self-esteem, and CRF. Models accounted for year, sex, and SES, with random intercepts for individual variability.

Results More online communication was significantly associated with poorer mental health outcomes, including more symptoms of depression ($p < 0.001$, marginal $R^2 = 0.14$), anxiety ($p = 0.032$, marginal $R^2 = 0.13$), lower self-esteem ($p = 0.006$, marginal $R^2 = 0.07$), more negative body image ($p = 0.010$, marginal $R^2 = 0.13$), and lower CRF; $p = 0.003$, marginal $R^2 = 0.35$). These associations did not change between years and were consistent across sex and SES groups. CRF declined from age 15 to 17. Females reported generally worse mental health and lower CRF than males, while higher SES was linked to lower depression scores and higher self-esteem. However, no significant interactions were found between online communication, sex, or SES, suggesting that the impacts of online communication on health were broadly applicable across demographic groups.

Conclusions This study underscores the potential negative effects of online communication on mental and physical health among adolescents, regardless of sex or SES. The findings highlight the importance of balancing time spent online communicating with physical activity to support overall adolescent well-being. These insights could inform

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public health initiatives and preventive strategies to foster healthier digital habits in an increasingly online world, especially during this sensitive developmental period.

Keywords Online communication, Social media, Adolescence, Mental health, Physical health

Background

Adolescence is a critical developmental period marked by rapid biological, cognitive, and social changes, making it a sensitive time for both mental and physical health [1, 2]. Over recent decades, mental health challenges among adolescents have increased significantly, with internalizing problems such as depression and anxiety showing notable rises, particularly among girls [3, 4]. At the same time, there is evidence of a decline in cardiorespiratory fitness (CRF) among young people [5, 6], which is a key predictor of long-term physical health and is associated with a lower risk for cardiovascular disease and diabetes [7, 8]. These health trends are unfolding alongside a surge in online communication and social media use [9], which may be contributing to the challenges adolescents face.

A growing body of research highlights the complex relationship between online communication and mental health in adolescents. Studies show that heavy social media use correlates with increased symptoms of depression and anxiety, possibly driven by factors such as sleep disruption, social comparison, and online harassment [10, 11]. In particular, studies have found that girls may be more vulnerable to these effects, showing greater increases in depressive symptoms associated with more online communication [12, 13]. Moreover, online communication has been negatively correlated with self-esteem [14] and negative body image [15] which are both important parts of adolescent mental health [16, 17, 18, 19]. However, some studies also suggest potential benefits of online communication, such as increased social support and self-expression, which could possibly buffer against some mental health challenges [13].

While there is substantial research on mental health, there remains a lack of studies examining the impact of online communication on physical health outcomes like CRF. Sedentary behaviours linked to extended screen time, including time spent in online communication, may contribute to poorer physical health by displacing physical activity [20]. Given that CRF is a crucial marker of adolescent health and has long-term implications, it is vital to understand whether online communication impacts CRF.

In addition, socioeconomic status (SES) and sex are known to influence adolescent health. Adolescents from lower SES backgrounds may face heightened mental health challenges due to stress, reduced healthcare access, and limited social support [21, 22]. The social gradient in health may mean that online communication impacts adolescents differently depending on their SES and sex. Exploring these moderators in any analysis of online communication and health, in general, is crucial. Furthermore, adolescence involves substantial individual variability in development, personality, and responses to social influences, which can affect outcomes like mental health and CRF [23, 24]. This variability makes it essential to use mixed-effects models, which allow us to include random intercepts to account for individual differences in baseline levels. Fixed factors in the model, such as sex, SES, and year, enable us to examine overarching trends across the population while still capturing unique individual trajectories [25].

The aim of this study was to examine the relationship between online communication and mental and physical health (CRF) in adolescents, while observing changes from age 15 to 17. Specifically, we hypothesized that increased online communication would, over both years, be associated with poorer mental health outcomes (depression, anxiety, self-esteem, and body image) and lower CRF. We also aimed to investigate whether these relationships differed by sex and SES.

Methods

Longitudinal data from the Health behaviours of the Icelandic youth study (*Heilsuhegðun ungra Íslendinga*) was used. This is a comprehensive, longitudinal study examining the health of young people in Iceland, focusing on their various health behaviours and physical and mental health [26]. Before gathering data, written consent was secured from the participants and their legal guardians.

Participants

This study involved a total of 315 participants in 2015 and 236 participants in 2017. All participants were born in 1999 and were recruited from the six largest primary schools in Reykjavík, Iceland, using a cluster sampling approach, as entire schools were selected rather than individual students from the general population. In 2015, 411 tenth graders, the last grade in compulsory school attended between the ages of 15–16, were invited to participate in the study. Of these 411, 315 agreed (77%) to participate, comprising 183 females (58%). These participants represented 23% of the total 1368 tenth graders in Reykjavík that year. In 2017, we followed up by inviting them to participate while attending upper-secondary school. Of these, 236 agreed (56%), including 144 females (61%). Of the original 315 participants from 2015, 168 agreed to participate again, providing usable data for the follow-up (53%), with 60% of them being female. See

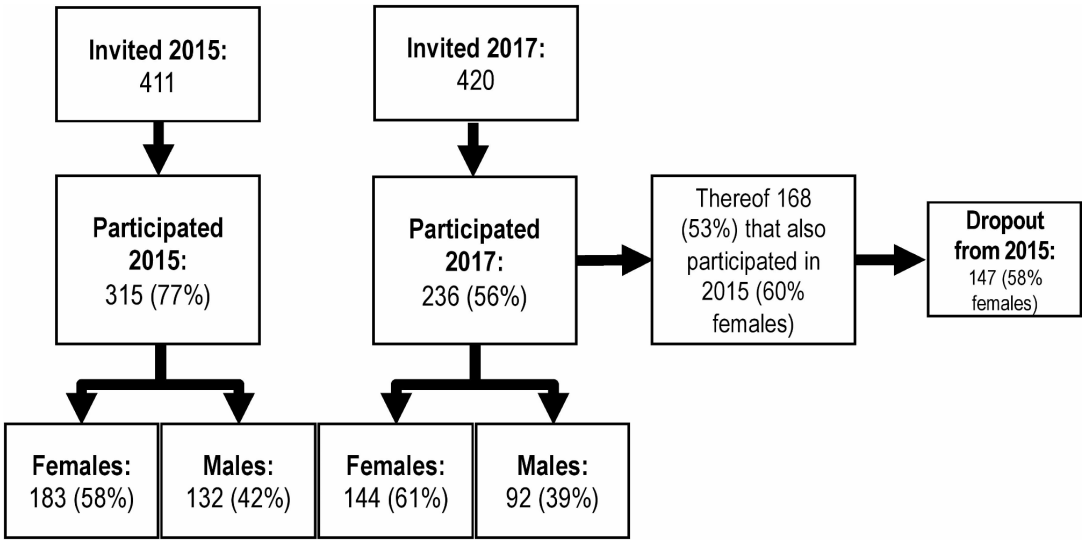

Fig. 1 The flow of participants from 2015 to 2017

Table 1 Analysis showing t-tests between dropouts and non-dropouts

	Dropouts		Non-dropouts		*df*	*t*	*p*
	M	*SD*	*M*	*SD*			
Depression	17.54	8.54	17.96	9.61	268	-0.39	0.696
Anxiety	6.58	3.62	6.74	3.62	242	0.71	0.480
Self Esteem	31.66	6.89	31.09	6.78	245	-1.86	0.064
Body Image	15.60	3.21	15.15	3.23	268	-0.39	0.696
CRF	2.70	0.66	2.85	0.69	242	0.71	0.480
OC	3.88	1.46	3.82	1.34	237	0.36	0.718

Note: "Dropouts" consists of participants who only participated in 2015, and "Non-dropouts" consists of participants who were measured both in 2015 and 2017, and the means (M), standard deviations (SD), and degrees of freedom (df) are from 2015. CRF = Cardiorespiratory fitness; OC = Online communication

Fig. 1 for an overview of participant recruitment. This participant composition makes the data both longitudinal and cross-sectional, allowing for a more comprehensive analysis by capturing changes over time as well as differences across groups at a single point in time.

Dropout analysis

To analyze whether participants who dropped out in 2017 differed systematically from those who continued, t-tests were conducted on depression, anxiety, self-esteem, body image, CRF, and online communication measured in 2015. The analyses showed no difference (all p´s > 0.05) between those who dropped out and those who continued participation in 2017 (see Table 1), thus validating the longitudinal comparison between years.

Measures

All measures except CRF were self-reported questionnaires administered online. All questions were in Icelandic, and the same questions were used in 2015 and 2017. Symptoms of depression, anxiety, self-esteem, and body image were used to measure mental health. For physical health, an objective measure of CRF was used.

Online communication

Online communication was measured by two questions asking how many hours on average per day the participant spent communicating online on weekdays and weekends. The questions provided examples of online communication, such as using Facebook and writing or reading e-mails. The possible answer ranged from 1 to 7 where 1 = no use, 2 = around ½ hour, 3 = 1–2 h, 4 = 2–3 h, 5 = 3–4 h, 6 = 4–5 h, and 7 = more than 5 h.

Symptoms of depression

Symptoms of depression were measured with a 10-item Subscale of the Symptom Checklist 90 (SCL-90; [27]. It was scored on a five-point Likert scale rated from 1 (*Almost never*) to 5 (*Almost always)*, asking about feelings of depression like "*Did you feel that the future is*

hopeless", in the preceding week. Higher scores indicate a higher level of depression. Cronbach's alpha for both years (combined) was used to evaluate internal consistency, which was α = 0.93. Older studies have confirmed the construct validity of SCL-90, indicating its ability to distinguish between depression and anxiety [28].

Symptoms of anxiety

Symptoms of anxiety were assessed using a four-item anxiety subscale from the SCL-90 [27]. Participants responded to items such as *"Suddenly scared for no reason"* based on their experiences over the past week, using a five-point Likert scale that ranged from 1 (*Almost never)* to 5 (*Almost always*). Higher scores on this scale suggest increased anxiety. The combined reliability of the scale was α = 0.84. As stated earlier, research by Morgan et al. (1998) supports the SCL-90's ability to distinguish between anxiety and depression.

Self-esteem

The Rosenberg Self-Esteem Scale was used to measure global self-esteem [29, 30]. This scale is comprised of ten items that are evaluated as either negative or positive, with respondents selecting from four choices ranging from 1 (*Strongly disagree*) to 4 (*Strongly agree*) to statements like *"I feel that I have a number of good qualities"*. A score of 15 or above indicates better self-esteem. The scale has good psychometric properties [31, 32]. Additionally, the combined scale´s internal consistency was α = 0.92 in this current study.

Body image

The assessment of body image used five items from the Body and Self-Image subscale of the Offer Self-Image Questionnaire [33]. Participants rated their agreement with statements such as "*I'm satisfied when I think about how my body will look in the future*" on a four-point scale, ranging from 1 (*Not at all true of me*) to 4 (*True of me*). Scores on this scale reflect the positivity of one's body image, with higher scores indicating more positive perceptions. The combined internal consistency, using was α = 0.83. Previous studies have found the scale's validity to range from weak to moderate [34, 35, 36, 37].

Cardiorespiratory fitness

CRF was objectively measured for each individual, indirectly using a maximal cycle ergometer test conducted on a Monark stationary bike, where maximal mechanical power (W_{max}) was adjusted for participant weight to estimate VO_2 max [38]. This method has been validated for use in adolescent populations, with previous studies demonstrating a strong correlation between estimated and measured VO_2 max [39, 40].

Socioeconomic status

To estimate participants' SES, they were asked about their parent's education level. Response options were a degree from a compulsory school (includes primary and lower secondary school), a degree from a gymnasium (upper secondary school), a degree from a vocational school (upper secondary school), and any university degree. The participants also had an option of answering "another education", "I don't know", and "I don't want to answer". To simplify the analysis, the variable was changed to binary with either parent having a university degree (as a proxy for higher SES for the participant) or neither parent having a university degree (as a proxy for lower SES for the participant).

Statistics

All statistical analyses were conducted in R-Studio (version 2024.04.1 + 748 using R 3.6.0+) and Jamovi (version 2.3.28). Descriptive statistics were calculated for all variables. Since online communication was measured separately for weekdays and weekends, the weighted average between the raw scores was calculated as (weekdays * 5 + weekends * 2) / 7. However, in the descriptive results, the numbers were rounded and interpreted as the hourly categories they represented to get a better overview of changes in usage. A chi-squared test was used to see if time spent online communicating changed from 2015 to 2017 and to see if the parental education level changed between the years.

To assess the relationship between online communication and mental and physical health, five linear mixed-effect models (depression, anxiety, body image, self-esteem, and CRF) were conducted, controlling for year, sex of the participant, and SES. The main effects and the interactions between the variables above accounted for the fixed effects in the models. The intercepts for the participants accounted for the random effects to control for individual variability in the baseline of each dependent variable, acknowledging that each participant might have a unique starting point. The significance of fixed effects was assessed through Wald tests, and random effects variance components were estimated to quantify the variability attributed to subjects beyond the fixed effects. The marginal and conditional R-squared values were calculated to determine the proportion of variance explained by the fixed effects alone and by the entire model, respectively.

A mixed-effects model is ideal for this analysis because it handles unbalanced data. Using linear mixed models, we were able to include all participants and account for individual differences over time, providing more accurate and robust estimates. This approach inherently handles missing data by including all available cases, as it accounts for participants with incomplete data points

under the assumption of data missing at random (MAR), eliminating the need for imputation.

Results

Characteristics of the sample

The sample included participants with a mean age of 15.86 years in 2015 and 17.71 years in 2017. The sample was composed of 42% males and 58% females in 2015, and 39% males and 61% females in 2017 (See Fig. 1 for full details). SES was stable with 67.0% having a parent with a university degree in 2015 and 67.9% in 2017, (X^2 (1, $N = 537$) = 0.05, $p = 0.815$).

From 2015 to 2017, there was a significant increase in the time adolescents spent on online communication ($\chi^2(6, N = 367) = 15.94$, $p = 0.014$; see Fig. 2). Most participants reported spending between 1 and 2 h per day online in 2015, which rose to 2–3 h per day by 2017. Females ($M = 4.26$, $SD = 1.33$) reported significantly more online communication than males ($M = 3.62$, $SD = 1.23$); ($t(365) = -4.61$, $p < 0.001$). No difference in online communication was observed between participants with different SES backgrounds.

Mental health outcomes

The associations from the mixed effects models between online communication and the mental health variables, including depression, anxiety, self-esteem, and body image, are summarized in Table 2. The following is an overview of the main results displaying all p-values as they appear in the models.

Depression

Increased time spent communicating online was associated with higher depression scores ($p < 0.001$), with a marginal R^2 of 0.141 and a conditional R^2 of 0.618 for the depression model. Females had significantly higher depression levels than males ($p < 0.001$), while higher SES was negatively associated with depression ($p = 0.003$). No interactions were identified between online communication, year, sex, or SES in relation to depression.

Anxiety

Online communication was significantly associated with higher anxiety scores ($p = 0.032$; see Table 2). The model's marginal R^2 was 0.131, and the conditional R^2 was 0.576. Females reported significantly higher anxiety levels than males ($p < 0.001$), but SES did not significantly influence anxiety ($p = 0.287$). As with depression, no interaction effects were observed between online communication, sex, year, or SES for anxiety.

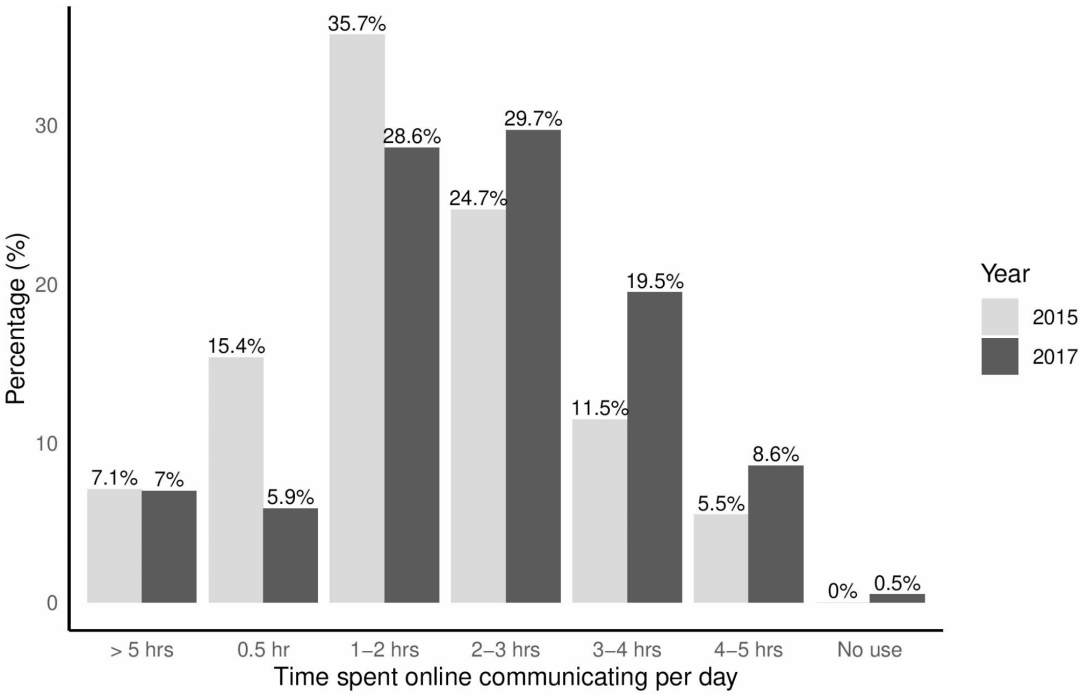

Fig. 2 Comparison of the time spent online communicating between 2015 and 2017

Table 2 Overview of main effects and interactions for the mental health models

Predictor	Outcome	B	SE	95% CI	df	*p*
Online communication	Depression	1.07	0.31	(0.47, 1.67)	498	< 0.001
	Anxiety	0.26	0.12	(0.02, 0.50)	512	0.032
	Self-esteem	-0.71	0.26	(-1.21, -0.21)	509	0.006
	Body Image	-0.28	0.11	(-0.50, -0.07)	499	0.010
Year (2015–2017)	Depression	0.66	0.65	(-0.61, 1.94)	251	0.309
	Anxiety	0.03	0.27	(-0.49, 0.55)	264	0.916
	Self-esteem	0.68	0.58	(-0.44, 1.81)	274	0.235
	Body Image	0.24	0.24	(-0.24, 0.72)	264	0.322
OC ✻ Year	Depression	-0.53	0.50	(-1.52, 0.46)	306	0.296
	Anxiety	-0.17	0.21	(-0.58, 0.23)	323	0.399
	Self-esteem	0.66	0.44	(-0.20, 1.53)	346	0.134
	Body Image	0.17	0.19	(-0.20, 0.54)	328	0.373
OC ✻ Sex	Depression	0.36	0.61	(-0.83, 1.56)	498	0.551
	Anxiety	0.03	0.25	(-0.45, 0.51)	512	0.910
	Self-esteem	-0.73	0.51	(-1.72, 0.27)	510	0.155
	Body Image	-0.38	0.22	(-0.81, 0.04)	499	0.079
OC ✻ SES	Depression	-0.13	0.60	(-1.30, 1.05)	482	0.835
	Anxiety	0.07	0.24	(-0.40, 0.54)	505	0.774
	Self-esteem	0.19	0.50	(-0.80, 1.17)	510	0.708
	Body Image	0.16	0.22	(-0.27, 0.58)	488	0.472

Note. OC = Online communication. SES = Socioeconomic status

Table 3 Overview of the main effects and interactions for the cardiorespiratory fitness model

Predictor	B	SE	95% CI	df	*p*
Online communication	-0.05	0.02	(-0.09, -0.02)	340	0.003
Year (2015–2017)	-0.11	0.03	(-0.18,- 0.05)	199	0.001
Online communication ✻ Year	0.01	0.03	(-0.04, 0.07)	232	0.624
Online communication ✻ Sex	-0.04	0.04	(-0.11, 0.03)	340	0.274
Online communication ✻ SES	0.01	0.03	(-0.07, 0.07)	333	0.967

Note. SES = Socioeconomic status

Self-esteem

Higher levels of online communication were associated with lower self-esteem ($p = 0.006$), with a marginal R^2 of 0.073 and a conditional R^2 of 0.469 for the self-esteem model. Females had significantly lower self-esteem than males ($p = 0.034$), while higher SES was positively associated with self-esteem ($p = 0.040$). No interactions were identified between online communication, year, sex, or SES in relation to self-esteem.

Body image

Increased online communication correlated with a lower body image score ($p = 0.010$), with females generally reporting worse body image than males ($p < 0.001$). SES did not significantly impact body image ($p = 0.31$). The marginal R^2 for body image was 0.131, and the conditional R^2 was 0.580, indicating that random effects substantially contributed to the model's variance explanation.

Cardiorespiratory fitness

Higher levels of online communication were modestly associated with lower CRF scores ($p = 0.003$; see Table 3), with a marginal R^2 of 0.351 and a conditional R^2 of 0.866 for the CRF model. Females had significantly lower CRF scores than males ($p < 0.001$), while SES did not significantly influence CRF outcomes ($p = 0.460$). No interactions were identified between online communication, year, sex, or SES in relation to CRF.

Individual variability

The random intercepts in each model indicated considerable individual variability in mental health outcomes and CRF. Variance estimates showed individual differences in baseline depression (variance = 37.56, SD = 6.13), anxiety (variance = 5.55, SD = 2.36), self-esteem (variance = 18.76, SD = 4.33), body image (variance = X, SD = X), and CRF (variance = 0.232, SD = 0.481), underscoring the role of individual characteristics in shaping these outcomes as shown in the differences between marginal and conditional R^2 in the models.

Discussion

Increased time spent with online communication was associated with poorer mental health and lower CRF among Icelandic adolescents aged 15 and 17. Adolescents who spent more time communicating online reported more symptoms of depression and anxiety, lower self-esteem, and poorer body image at age 15 and 17. Additionally, more time spent with online communication correlated with lower CRF, suggesting that extensive online communication might limit time spent on physical activities. While females reported worse overall mental health and had lower CRF compared to males, and adolescents from higher socioeconomic backgrounds (SES) had fewer depressive symptoms and higher self-esteem, neither sex nor SES moderated the relationship between online communication and health outcomes. Mental health indicators did not significantly change over time, underscoring the stability of these associations across the study period.

Online communication and mental health

The link between online communication and poorer mental health found in current study aligns with previous research suggesting that more online communication can heighten depressive and anxiety symptoms in adolescents [10, 41]. The association found between online communication and lower self-esteem and body image is likely influenced by social comparison pressures common in digital spaces, where adolescents are frequently exposed to idealized portrayals of others [14, 15, 42]. However, it is also important to recognize that body image dissatisfaction in adolescent females may not be solely driven by online communication but rather by broader sociocultural and developmental factors. Prior research has consistently shown that body image concerns are more prevalent among females due to heightened societal expectations, gendered beauty standards, and increased self-objectification pressures, which exist both online and offline [43, 44]. This suggests that while online engagement may exacerbate body dissatisfaction, it is likely part of a larger, multifaceted issue that extends beyond digital environments.

No significant interaction effects emerged between online communication and sex or SES, indicating that the mental health impacts of online communication may be broadly applicable across demographic groups. These findings indicate that widespread use of online communication like social media affects adolescents similarly, regardless of their background, and that these associations remain stable over time during the transformative years from 15 to 17.

However, while excessive online communication may be linked to mental health concerns, it can also offer psychosocial benefits, particularly for adolescents facing social isolation or anxiety. Digital platforms provide social support, self-expression, and connection with peers, which can help mitigate loneliness and depression [45, 46]. Additionally, online spaces can be especially valuable for marginalized groups, such as LGBTQ + youth, offering community and validation that may buffer against mental health challenges [47, 48].

Online communication and cardiorespiratory fitness

This study extends previous research by being among the first to link increased time spent on online communication to lower CRF, highlighting an important and previously underexplored dimension of adolescent health. While earlier studies have demonstrated the connection between online engagement and mental health challenges [10, 41], our findings add to the literature by showing that high levels of online communication may displace time that could be spent on physical activities, subsequently impacting CRF. Additionally, increased online communication could contribute to physical inactivity, with more time spent sitting or lying down. Those speculations align with existing findings that sedentary screen time, in general, is associated with decreased physical activity [20]. Notably, the association between online communication and CRF was consistent across both sex and SES groups, suggesting that online communication's impact on physical health might be widespread. Overall, female participants reported lower CRF than males, consistent with known biological sex differences [49], although both sexes appear similarly affected by the physical health impact of online communication. These findings underscore the need for adolescents to balance screen time, such as online communication with physical activity to promote both physical and mental health.

Sex and SES differences in mental health and CRF

Consistent with previous literature, adolescent females reported higher levels of depression and anxiety, along with lower self-esteem, compared to males, suggesting greater vulnerability to internalized mental health challenges [50]. However, no significant interactions were found between sex and online communication, implying that both sexes are similarly affected. This might be explained by the fact that the models included random effects, which means that individual differences explain the variance in the outcomes beyond the participants' sex. Higher SES was associated with fewer depressive symptoms and higher self-esteem, supporting the notion that socioeconomic advantages can buffer against mental health risks [51]. Nevertheless, SES did not moderate the association between online communication and mental health, indicating that while SES may offer general protective effects, it may not reduce the potential negative

impact of online communication on mental health and CRF.

Limitations and future directions

This study's reliance on self-reported data introduces the potential for recall bias and social desirability effects, particularly for variables like online communication, where adolescents may overestimate or underestimate their usage. While some variables, such as CRF, were measured objectively, self-reporting remains the most feasible approach in longitudinal research. Emerging methods, such as data donation, offer a promising alternative for obtaining more objective digital trace data from social media or smartphone logs [52, 53]. However, privacy concerns, ethical considerations, and technical challenges currently limit the large-scale implementation of these methods, particularly in adolescent research [54]. Future studies should explore integrating digital trace data with self-reports to enhance the accuracy of online communication measures.

Additionally, this study's Icelandic sample may limit the generalizability of findings to other cultural contexts. Future research should also distinguish between different types of online interactions, such as social media use, messaging, gaming, and educational activities, to better understand their unique impacts on adolescent mental and physical health. Extending this research into young adulthood could further clarify the long-term consequences of adolescent online engagement. Finally, future studies should investigate how personality traits, developmental stages, and socioeconomic factors moderate adolescents' responses to online communication.

Conclusions

Our findings emphasize that increased time spent on online communication is associated with poorer mental health outcomes, including heightened depression and anxiety, lower self-esteem, and more negative body image among adolescents. Additionally, we found a significant association between high levels of online communication and lower CRF. These effects appear consistent across demographic variables such as sex and socioeconomic status, indicating a broad and stable influence of online engagement on both mental and physical health across adolescent development.

This study is one of the first to explore online communication's dual impact on mental and physical health, highlighting the importance of limiting time spent online communicating, e.g., through social media networks, to support overall adolescent well-being. Our results suggest a need for public health strategies and policies that encourage healthier online habits among young people while promoting physical activity to mitigate the risks associated with sedentary screen behaviour, such as online communications.

Abbreviations

CRF Cardiorespiratory fitness
SES Socioeconomic status

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Author contributions

O.B. was responsible for the primary conception of the study, data, and statistical analysis, drafting the initial manuscript, and managing revisions. E.J. managed the project, contributed to data collection, provided supervision, and participated in manuscript revisions. S.G. contributed to data collection, provided supervision, and participated in manuscript revisions. H.R.E. and M.H. performed critical reviews of the manuscript and contributed to validation of the study findings. All authors read and approved the final manuscript.

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Data availability

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

Declarations

Ethics approval and consent to participate

The study received authorization from the Icelandic Data Protection Authority according to the Icelandic Act on Processing of Personal Data, and the Icelandic Bioethics Committee (VSNb2015020013/13.07). Complete confidentiality was guaranteed for all participants. Written informed consent was secured from the participants and their legal guardians. This study was conducted in accordance with the principles of the Declaration of Helsinki and Icelandic ethical regulations.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Publisher's note

Appendix A

Structural equation models for online communication, anxiety, and depression by sex and year.

	2003								2015							
	Girls				Boys				Girls				Boys			
	EST	SE	Z	p	EST	SE	Z	p	EST	SE	Z	p	EST	SE	Z	p
Latent model																
ANX =~ A1	1.000				1.000				1.000				1.000			
A2	1.339	0.229	5.843	<0.001	1.594	0.438	3.644	<0.001	1.051	0.113	9.322	<0.001	1.275	0.264	4.825	<0.001
A3	1.307	0.211	6.197	<0.001	0.974	0.211	4.610	<0.001	1.085	0.093	11.621	<0.001	1.177	0.284	4.144	<0.001
A4	0.934	0.196	4.759	<0.001	1.274	0.293	4.345	<0.001	0.960	0.130	7.397	<0.001	1.151	0.277	5.062	<0.001
DEP =~ D1	1.000				1.000				1.000				1.000			
D2	0.490	0.107	4.568	<0.001	0.819	0.094	8.755	<0.001	0.756	0.059	12.755	<0.001	0.719	0.152	4.716	<0.001
D3	0.775	0.088	8.769	<0.001	0.888	0.113	7.851	<0.001	0.876	0.078	11.175	<0.001	0.985	0.252	3.194	<0.001
D4	0.904	0.096	9.457	<0.001	0.515	0.168	3.065	0.002	0.968	0.075	12.957	0.002	0.725	0.162	4.479	<0.001
D5	0.711	0.116	6.128	<0.001	0.875	0.109	8.026	<0.001	0.742	0.086	8.608	<0.001	0.930	0.199	4.682	<0.001
D6	1.022	0.096	10.692	<0.001	0.844	0.114	7.379	<0.001	1.030	0.053	19.410	<0.001	1.047	0.133	7.859	<0.001
D7	0.801	0.090	8.912	<0.001	0.819	0.106	7.748	<0.001	1.038	0.050	20.690	<0.001	0.972	0.111	8.731	<0.001
D8	0.670	0.74	9.056	<0.001	0.680	0.138	4.933	<0.001	0.928	0.067	13.895	<0.001	0.883	0.115	7.651	<0.001
D9	0.651	0.095	6.872	<0.001	0.579	0.155	3.744	<0.001	0.998	0.058	17.102	<0.001	1.037	0.155	6.676	<0.001
D10	0.396	0.105	3.771	<0.001	0.556	0.162	3.427	0.001	0.660	0.093	7.098	0.001	0.677	0.141	4.811	<0.001
Regression																
TO->DEP	0.048	0.040	1.210	0.226	0.044	0.034	1.303	0.193	0.210	0.056	3.725	<0.001	0.050	0.050	1.001	0.317
TO->ANX	0.033	0.029	1.135	0.257	-0.009	0.015	-0.579	0.563	0.141	0.048	2.929	0.003	0.034	0.035	0.976	0.329
Covariances																
ANX<->DEP	0.378	0.074	5.145	<0.001	0.215	0.081	2.640	0.008	0.798	0.134	5.939	<0.001	0.265	0.035	0.976	0.329
Variances																
A1	0.456	0.088	5.200	<0.001	0.442	0.105	4.215	<0.001	0.479	0.095	5.018	<0.001	0.350	0.110	3.171	0.002
A2	0.610	0.083	7.353	<0.001	0.333	0.080	4.161	<0.001	0.715	0.097	7.366	<0.001	0.148	0.047	3.146	0.002
A3	0.450	0.081	5.557	<0.001	0.228	0.057	3.973	<0.001	0.241	0.066	3.649	<0.001	0.167	0.044	3.837	<0.001
A4	0.744	0.104	7.163	<0.001	0.603	0.099	6.102	<0.001	0.661	0.088	7.477	<0.001	0.231	0.066	3.516	<0.001
D1	0.423	0.062	6.885	<0.001	0.540	0.067	8.083	<0.001	0.490	0.057	8.619	<0.001	0.340	0.065	5.239	<0.001
D2	1.272	0.135	9.393	<0.001	0.425	0.066	6.102	<0.001	0.790	0.090	8.750	<0.001	0.387	0.087	4.464	<0.001
D3	0.586	0.106	5.540	<0.001	0.268	0.068	3.970	<0.001	0.604	0.101	5.985	<0.001	0.426	0.114	3.734	<0.001
D4	0.493	0.070	7.055	<0.001	0.171	0.043	3.972	<0.001	0.613	0.097	6.335	<0.001	0.271	0.086	3.162	0.002
D5	0.936	0.122	7.654	<0.001	0.820	0.132	6.208	<0.001	1.081	0.132	8.167	<0.001	0.942	0.143	6.573	<0.001
D6	0.294	0.058	5.069	<0.001	0.221	0.048	4.604	<0.001	0.376	0.063	5.982	<0.001	0.245	0.074	3.295	0.001
D7	0.369	0..067	5.474	<0.001	0.373	0.062	6.039	<0.001	0.350	0.052	6.703	<0.001	0.227	0.049	4.678	<0.001
D8	0.372	0.074	5.020	<0.001	0.376	0.076	4.951	<0.001	0.464	0.105	4.441	<0.001	0.200	0.049	4.080	<0.001
D9	0.313	0.054	5.768	<0.001	0.381	0.125	3.051	0.002	0.318	0.053	6.046	<0.001	0.230	0.056	4.090	<0.001
D10	0.336	0.070	4.824	<0.001	0.241	0.056	4.286	<0.001	0.535	0.083	6.454	<0.001	0.123	0.029	4.215	<0.001
ANX	0.310	0.091	3.412	0.001	0.161	0.085	1.896	0.058	0.791	0.173	4.587	<0.001	0.247	0.110	2.242	0.025
DEP	0.760	0.104	7.297	<0.001	0.503	0.089	5.676	<0.001	1.128	0.142	7.961	<0.001	0.424	0.124	3.414	0.001
TO	3.213	0.255	12.586	<0.001	3.054	0.255	11.990	<0.001	2.150	0.189	11.383	<0.001	1.104	0.184	5.996	<0.001
Intercepts																
A1	1.364	0.100	13.626	<0.001	1.356	0.073	18.467	<0.001	1.138	0.204	5.582	<0.001	1.201	0.127	9.453	<0.001
A2	1.950	0.143	13.592	<0.001	1.660	0.103	16.180	<0.001	1.583	0.218	7.272	<0.001	1.225	0.152	8.035	<0.001
A3	1.448	0.134	10.775	<0.001	1.217	0.070	17.387	<0.001	1.082	0.218	4.960	<0.001	1.126	0.136	8.272	<0.001
A4	1.808	0.115	15.757	<0.001	1.605	0.093	17.312	<0.001	1.459	0.205	7.103	<0.001	1.271	0.138	9.918	<0.001
D1	1.948	0.145	13.422	<0.001	1.746	0.121	14.452	<0.001	1.473	0.247	5.951	<0.001	1.433	0.170	8.431	<0.001
D2	2.194	0.113	19.460	<0.001	1.397	0.098	14.323	<0.001	1.488	0.191	7.811	<0.001	1.282	0.129	9.918	<0.001
D3	1.650	0.122	13.498	<0.001	1.305	0.102	12.770	<0.001	1.165	0.206	5.645	<0.001	1.341	0.164	8.169	<0.001
D4	1.631	0.131	12.412	<0.001	1.081	0.056	19.479	<0.001	1.410	0.237	5.958	<0.001	1.140	0.122	9.350	<0.001
D5	1.797	0.123	14.664	<0.001	1.605	0.113	14.151	<0.001	1.654	0.196	8.421	<0.001	1.767	0.177	9.995	<0.001
D6	1.555	0.146	10.654	<0.001	1.291	0.097	13.343	<0.001	1.395	0.242	5.755	<0.001	1.307	0.170	7.674	<0.001
D7	1.494	0.115	12.954	<0.001	1.412	0.097	14.583	<0.001	1.159	0.245	4.725	<0.001	1.288	0.164	7.855	<0.001
D8	1.398	0.097	14.389	<0.001	1.299	0.083	15.677	<0.001	1.033	0.219	4.709	<0.001	1.208	0.148	8.168	<0.001
D9	1.332	0.092	14.560	<0.001	1.195	0.076	15.646	<0.001	0.863	0.228	3.786	<0.001	1.174	0.165	7.100	<0.001
D10	1.176	0.062	18.998	<0.001	1.106	0.060	18.565	<0.001	0.812	0.147	5.513	<0.001	1.085	0.109	9.912	<0.001
ANX	3.158	0.130	24.277	<0.001	3.199	0.125	25.556	<0.001	4.208	0.111	37.963	<0.001	3.310	0.093	35.544	<0.001
DEP	0.000				0.000				0.000				0.000			
TO	0.000				0.000				0.000				0.000			

Note. EST = Standardized parameter estimate, SE = Standard Error, Z = Z Value, p = P(>|z|), ANX = Anxiety, DEP = Depression, A1:A4 = SCL-90 Items for the anxiety subscale, D1:D10 = SCL-90 Items for the depression subscale, TO = Time online communicating. The sign =~ means "as measured by", the sign -> means implied effect ,and <-> means covariance between.