Physical activity and sport participation in adolescence

Health implications related to musculoskeletal pain, mental health and obesity

The HUNT Study

by

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Acronyms and abbreviations

BMI – body mass index

CI – confidence interval

CNS – central nervous system

HUNT – The Trøndelag Health Study (Helseundersøkelsen i Trøndelag)

IOTF – International Obesity Task Force

LBP – low back pain

LEP – lower extremity pain

NSP – neck and shoulder pain

OR – odds ratio

PA – physical activity

RSES – Rosenberg Self-Esteem Scale

SCL-5 – Hopkins Symptom Check List Five items

WHO – World Health Organization

List of papers included in the thesis

I. Guddal MH, Stensland SØ, Småstuen MC, Johnsen MB, Zwart JA, Storheim K. **Physical Activity Level and Sport Participation in Relation to Musculoskeletal Pain in a Population-Based Study of Adolescents. The Young-HUNT Study.** The Orthopaedic Journal of Sports Medicine 2017, 5(1).

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Summary

Musculoskeletal pain and mental health problems are common and burdensome health challenges among adolescents. Adverse health impacts include poorer quality of life, absence from school and high use of medication and medical care. Further, pain and mental health problems in adolescence often persist into adulthood.

Physical activity (PA) and sport participation are modifiable lifestyle factors suggested to positively impact these health challenges. However, there is uncertainty regarding factors that may be of importance in the relationship between PA and both musculoskeletal and mental health. Studies examining the potential impact of adolescents' PA on musculoskeletal pain have provided inconsistent results, and we have little knowledge about whether type of sport participation and localization of pain are important factors in this context. The mental health benefits of PA are more extensively documented, however, evidence about the impact of different types of sports participation across gender and adolescent age groups remains limited. Further, the transition from adolescence to young adulthood is a period of high risk for development of obesity, which may set the stage for adverse long-term health consequences. Physical inactivity is suggested to be a key target in obesity prevention. Although physical inactivity, musculoskeletal pain, and mental health problems are major public health concerns, we have limited knowledge about the potential long-term weight-related consequences of their co-occurrence during adolescence.

The overall objective of this thesis was to study the relationships between adolescent PA, including sport participation, and musculoskeletal pain and mental health problems. Further, the aim was to study how PA behaviors and co-existing health challenges in adolescence can affect the probability of obesity in the long term. Data were obtained from the Trøndelag Health Study (The HUNT study), a longitudinal population-based health study in Norway (https://www.ntnu.edu/hunt). Cross-sectional data from adolescents (13 -19 years old) participating in the adolescent part of the study (Young-HUNT3, 2006-08) were used for Papers I and II. For Paper III, longitudinal data from participants in Young-HUNT1 (1995-97) who also participated in the third Trøndelag health study (HUNT3) for adults, 11 years later (2006-08), were used.

The first aim was to explore associations between PA level, participation in sports, and musculoskeletal pain in different locations (Paper I). Results showed that PA at a moderate

level was associated with reduced odds of neck and shoulder pain and low back pain, while a high level of PA was associated with increased odds of lower extremity pain, among both girls and boys. Associations between participation in sports and musculoskeletal pain differed according to *type* of sport and *localization* of pain. Findings indicated that participation in endurance sports, (i.e. cross-country skiing, swimming, running) may be beneficial. Other types of sport participation may, however, represent risk factors for musculoskeletal pain. Specifically, participation in technical sports (i.e. track and field, alpine skiing) was associated with increased odds of low back pain, and team sport participation (i.e. handball, football, volleyball) was associated with increased odds of lower extremity pain.

Next, the aim was to describe PA levels and sport participation rates among girls and boys, and to explore how PA and sport participation are associated with mental health in different age groups (Paper II). Results revealed that PA levels and sport participation rates were lowest among girls in senior high school (≥ 16 years old). A high PA level was favorably associated with mental health outcomes, including reduced odds of psychological distress, low self-esteem, and low life satisfaction, especially for adolescents in senior high school. Further, the results showed that participation in team sports may be particularly beneficial. These study findings indicate that efforts helping adolescents to initiate, maintain, or increase attendance in regular and social physical activities may contribute to improving their overall mental health.

The final aim was to evaluate the impact of adolescent's PA and co-existing musculoskeletal pain and mental health problems, on the probability of obesity in young adulthood (Paper III). Higher probabilities of obesity in young adulthood were found across combinations of lower levels of PA and co-occurrence of musculoskeletal pain in adolescence, while the added impact of early psychological distress was low. These results suggest that efforts to prevent obesity may be directed towards inactive adolescents who struggle with musculoskeletal pain.

In conclusion, findings show that adolescents who are physically active have less neck and shoulder pain and low back pain, and have better mental health compared to inactive adolescents. Participation in team sports was most strongly associated with good mental health. Further, findings suggest that physical inactivity and musculoskeletal pain cumulatively increase adolescents' probability of developing obesity in the transition to young adulthood. Along with PA promotion, prevention and treatment of musculoskeletal pain in adolescence may therefore make a valuable contribution to obesity prevention strategies.

Sammendrag på norsk (Summary in Norwegian)

Muskel- og skjelettsmerter og psykiske helseplager er vanlig blant ungdommer og kan være en stor belastning. Negative helsekonsekvenser omfatter dårligere livskvalitet, fravær fra skole og høyt forbruk av medisiner og behandling. Slike helseplager i ungdomsårene vedvarer ofte inn i voksen alder.

Fysisk aktivitet (FA) og idrettsdeltagelse er modifiserbare livsstilsfaktorer som synes å ha en positiv innvirkning på disse helseutfordringene. Mye usikkerhet eksisterer imidlertid fortsatt om faktorer som kan være viktige i sammenhengen mellom FA og både muskel- og skjelett- og mental helse. Studier som har undersøkt betydningen av FA for muskel- og skjelettsmerter blant ungdommer har vist sprikende resultater, og det finnes spesielt lite kunnskap om hvorvidt type idrettsdeltagelse og lokalisering av smerte er av betydning. Fordelene av FA for mental helse er i større grad dokumenterte, men kunnskap om betydningen av ulike typer idrettsdeltagelse på tvers av kjønn og aldersgrupper er fortsatt begrenset. Videre vet man at overgangen fra ungdomsår til voksen alder er en periode med høy risiko for utvikling av fedme, en tilstand som ofte vil medføre langsiktige negative helsekonsekvenser. Tiltak rettet mot fysisk inaktivitet er en sentral del av arbeidet for å forebygge fedme. Selv om fysisk inaktivitet, muskel- og skjelettsmerter og mentale helseproblemer er svært store folkehelseutfordringer, så har vi per i dag begrenset kunnskap om hvorhvidt samvariasjonen av disse uhelsefaktorene i ungdomsårene gir vektrelaterte konsekvenser inn i voksenlivet.

Det overordnede målet for dette arbeidet var å undersøke forholdet mellom FA, inkludert idrettsdeltagelse, og muskel- og skjelettsmerter og mentale helseproblemer blant ungdom. Videre var målet å undersøke hvordan FA-atferd i kombinasjon med andre helseutfordringer i ungdomsårene kan påvirke sannsynligheten for fedme på lang sikt.

Data ble hentet fra Helseundersøkelsen i Trøndelag (HUNT studien), en norsk befolkningsbasert kohortestudie (https://www.ntnu.edu/hunt). Tverrsnittsdata fra personer (13 -19 år) som deltok i ungdomsdelen av studien (Ung-HUNT3, 2006-08) ble benyttet for artikkel I og II. For artikkel III ble det benyttet longitudinelle data fra deltagere i Ung-HUNT1 (1995-97) som også deltok i den tredje Helseundersøkelsen i Trøndelag for voksne (HUNT3), 11 år senere (2006-08).

Det første formålet var å utforske sammenhenger mellom FA-nivå, deltagelse i idrett, og ulike lokalisasjoner av muskel- og skjelettsmerter (artikkel I). Resultatene viste at et moderat nivå

av FA var assosiert med redusert odds for nakke- og skuldersmerter og korsryggsmerter, mens et høyt nivå av FA var assosiert med økt odds for smerter i underekstremiteter, både blant jenter og gutter. Sammenhengene mellom deltagelse i idrett og muskel- og skjelettsmerter varierte ut fra *type* idrett og *lokalisering* av smerte. Resultatene indikerte at deltakelse i utholdenhetsidretter (f.eks. langrenn, svømming, løping) kan være gunstig. Andre typer idrettsdeltagelse kan imidlertid representere risikofaktorer for muskel- og skjelettsmerter. Spesielt var deltakelse i tekniske idretter (f.eks. friidrett, alpint) assosiert med økt odds for korsryggsmerter, og deltagelse i lagidretter (f.eks. håndball, fotball og volleyball) var assosiert med økt odds for underekstremitetssmerter.

Deretter var målet å beskrive FA-nivåer og idrettsdeltagelse blant jenter og gutter, og å undersøke hvordan FA-nivå og idrettsdeltagelse er assosiert med mental helse i ulike aldersgrupper (artikkel II). Resultatene viste at FA-nivå og idrettsdeltagelse var lavest blant jenter på videregående skole (≥ 16 år). Et høyt FA-nivå var gunstig assosiert med ulike mentale helseutfallsmål, inkludert redusert odds for symptomer på angst og depresjon, lav selvtillit og lav livstilfredshet, spesielt for ungdommer på videregående skole. Videre viser resultatene at deltakelse i lagidrett kan være spesielt gunstig. Disse studiefunnene indikerer at innsats for å hjelpe ungdommer til å starte med, opprettholde eller øke deltagelse i regelmessige sosiale, fysiske aktiviteter kan bidra til å forbedre deres generelle mentale helse.

Til slutt var formålet å evaluere betydningen av ungdommers FA-nivå og ko-eksisterende muskel- og skjelettsmerter og mentale helseproblemer, på sannsynligheten for fedme i ung voksen alder (artikkel III). Høyere sannsynlighet for fedme i ung voksen alder ble funnet på tvers av kombinasjoner av lavere FA-nivåer og forekomst av muskel- og skjelettsmerter, mens det å i tillegg ha mentale helseproblemer var av liten betydning. Disse resultatene antyder at større innsats rettet mot forebygging av fedme kan rettes mot inaktive ungdommer som sliter med muskel- og skjelettsmerter.

For å konkludere så viser funnene at ungdommer som er fysisk aktive har mindre smerter i nakke- og skuldre og korsrygg, og har bedre mental helse sammenlignet med inaktive ungdommer. Deltagelse i lagidrett hadde sterkest sammenheng med god mental helse. Videre antyder funnene at fysisk inaktivitet og muskel- og skjelettsmerter kumulativt øker ungdommers sannsynlighet for å utvikle fedme i overgangen til ung voksen alder. Tiltak som fremmer fysisk aktivitet og bidrar til å forebygge, avdekke og behandle smerteproblematikk hos unge kan derfor gi verdifulle bidrag til strategier for å forebygge fedme.

1. Introduction

Adolescence is a formative period of rapid physical, psychological, and behavioral changes, cognitive growth, and identity formation. Personal lifestyle choices and health-related behaviors, such as physical activity habits, are often established during this life phase (1, 2). Life-course epidemiology has established that engagement in physical activities and sports in adolescence is an important component of a healthy lifestyle that has implications for lifelong health, highlighting adolescent years as a critical time for laying the foundations for future health (3, 4). Conversely, inactivity and health problems in adolescent years may set the stage for adverse health outcomes which carry on into adult life (3).

Musculoskeletal pain and mental health problems are prevalent among adolescents (5, 6), they commonly co-occur (7), and are leading causes of health-related disability in this age group (6, 8, 9). Obesity is another major public health burden worldwide (10, 11), with the transition from adolescence to young adulthood highlighted as a period of particularly high risk for development of obesity (12, 13). Physical activity (PA) and engagement in sports are modifiable lifestyle behaviors suggested to be of importance for both prevention and management of musculoskeletal pain (14-18), mental health problems (19-21), and weight regulation (22, 23). However, knowledge gaps still exist in our understanding of the potential impact of PA on these health challenges among adolescents (24-26), including the role of sports participation. Moreover, there remains a paucity of evidence on how PA behaviors, along with musculoskeletal and mental health in adolescent years, may impact health challenges, such as obesity, over time.

This thesis is based on data from the Trøndelag Health Study (HUNT Study), a large population-based cohort study. The main focus of this thesis is to examine the relationships between PA, including sport participation, and 1) musculoskeletal pain and 2) mental health problems among adolescents. Using a cross-sectional study design, this thesis should contribute to the field by improving knowledge about how these relationships may differ between; genders, age groups, type of sport participation, and localization of pain or mental health dimension. Further, a longitudinal study was conducted to address potential long-term consequences by examining the impact of PA and co-existing musculoskeletal pain and mental health problems in adolescence on obesity in young adulthood. Research that provides deeper insight into the potential role of these factors, particularly during adolescence, can inform and influence the direction of preventive efforts.

2. Background

2.1 Adolescent health – challenges and opportunities

Adolescence encompass the physical, psychological, and social transition from childhood to adulthood. Although age is a rough marker of adolescence, the World Health Organization (WHO) defines an adolescent as an individual between 10-19 years of age (27). Adolescence can be categorized into three primary developmental stages; early adolescence, middle adolescence, and late adolescence (28).

Interest in adolescent health is growing along with an improved understanding of the developmental processes that take place during this period. Adolescence clearly represents a highly dynamic and influential period of human development. This period of heightened malleability has been referred to as the "age of opportunity" (29). The physical, cognitive, emotional, and social resources acquired during these years are central for health and well-being, and also shape the capabilities which are taken forward into adulthood (3, 30).

Thus, common and burdensome health challenges that typically emerge during adolescence, including diminished PA (31), musculoskeletal pain (5), and mental health problems (6, 32), may have consequences for both present and future health. Notably, gender differences with higher prevalence rates of such health problems among girls than boys, seem to increase over the course of adolescence (5, 31, 33, 34). In addition to the worrying trend of increasing rates of obesity across adolescence and young adulthood (10, 35), these health problems represent significant public health challenges of our modern society, now and in the decades to come (3, 36).

There is increasing support for the view that preventive interventions are crucial during adolescent years (2, 37), and the abovementioned challenges are among the major public health promotion areas suggested for adolescents in particular (2, 3, 30, 38, 39). Development of population-level approaches and health promotion messages, however, depends on knowledge about behavioral factors that influence these health outcomes. Specifically, increasing levels of PA seems to be a promising approach to mitigating this adverse trend in the physical and mental health of adolescents and young adults (14, 15, 19, 21, 39).

2.2 Physical activity – definition and methods of assessment

PA is a multidimensional behavior that occurs in various forms and in different contexts, commonly defined as; *any bodily movement produced by skeletal muscle that results in energy expenditure* (40). Dimensions of PA include intensity, frequency, and duration, which together constitute the total volume of activity. Other dimensions of PA are type of activity (e.g. type of sport or recreational activity) and the setting in which the activity is performed (e.g. at school, playground, transport) (41). The social aspect of sports may in part relate to the type of sports practiced, such team vs. individual sports (42).

Both subjective and objective measurement methods have been used to assess PA levels. Subjective methods include, for example, self-reported questionnaires, interviews, and activity diaries. Examples of objective measurement methods are heart-rate monitoring, pedometers, and accelerometers (41, 43, 44). Due to the multidimensional nature of PA, there is no available measure that can assess all facets of PA. In large-scale epidemiological studies, considerations of budget, time, and resources have often led to the use of self-reported assessment of PA (45). Weaknesses of self-reports of PA compared to objective measures include inaccuracies in responses and recall, the tendency to over-report levels of PA, and inability to compare results across studies due to the different wording of questions in various questionnaires (45, 46). Questionnaires frequently used to assess PA in population-based studies of adolescents are the World Health Organization Health Behaviour in Schoolchildren (WHO HBSC) Survey Questionnaire and The International Physical Activity Questionnaire (IPAQ) (47).

2.3 Physical activity and sport participation among adolescents

PA provides fundamental health benefits for adolescents and reduces the risk and burden of non-communicable diseases such as cardiovascular diseases, some cancers, and diabetes type 2 (48-50). The health benefits of a physically active lifestyle during adolescence include improved muscular strength and flexibility, improved bone health, and a healthier cardiovascular profile (50-53). Further, it is essential to achieving and maintaining a healthy weight. These health benefits of PA are seen in both the short and long term (4, 39, 50, 54). There is also growing evidence that PA has a positive impact on cognitive development, mental health, and sleep (53, 55, 56). For adolescents in particular, participation in regular physical activities and sports may also encompass an important social dimension as peer relationships and peer influence become more significant during adolescence (57).

To increase levels of PA in the population has become a global priority (58). PA habits seem to continue from adolescence into adulthood, and data from several studies suggest that engaging in activities and sports during adolescence has a positive influence on the development of lifelong PA (59-62). Moreover, high levels of physical fitness during adolescence are found to exert both direct and indirect positive effects on cardiovascular risk profiles into adulthood (63). This knowledge has led to growing attention to opportunities for policy actions to promote PA among adolescents in particular.

Technological advances leading to changes in our living environments have created a less active society, and screens, tablets, and phones have become part of adolescents' everyday lives. Recent decades have seen a substantial increase in the amount of time adolescents spend in sedentary behaviors (64-66). To combat this adverse trend, the WHO World Health Assembly stated that their goal is to reduce inactivity among adolescents by 15% globally by 2030 (67).

Further, as screen time has increasingly replaced outdoor play and activities (65, 66), many adolescents in our modern society get much of their PA through participation in sports (68-71). Therefore, the growing focus on the wide range of health benefits of PA has highlighted the importance of participation in sports to increase adolescents' overall PA levels (68, 72-74). Improving access to sport activities and promoting different types of sport participation were emphasized as important elements in increasing PA globally in the abovementioned WHO Global Action Plan 2018-2030 (67).

2.3.1 Physical activity recommendations and adherence

WHO developed the "Global Recommendations on Physical Activity for Health" to promote PA and to provide policy makers with guidance on the amount of PA needed for prevention of non-communicable diseases (75). The recommendations states that children and adolescents should accumulate at least 60 minutes of PA, of moderate to vigorous intensity, daily (75). National PA recommendations similar to those promoted by the WHO are available in Norway (76) and many other countries around the world (77).

However, a global country-by-country report on adolescents' self-reported PA levels, including reports from 1.6 million adolescents (11 to 17 years) from 146 countries, suggests that the vast majority of the world's adolescents are insufficiently active. In 2016, only about 20% of adolescents worldwide met the recommendations of 60 minutes of daily PA. While rates of inactivity dropped slightly from 2001 to 2016 for boys, the rates for girls remained unchanged (78). Despite the WHO's ambitious global targets for reduction in inactivity, these results reveal that the effort to increase PA has not resulted in a measurable impact on population-level PA behaviors among adolescents.

Similar to global rates, the country specific numbers from the WHO study showed that 83.5% of adolescents in Norway were insufficiently active in 2016 (78). The numbers were, however, lower in the Norwegian national monitoring of PA level among children and adolescents in 2011-2012, the Physical Activity among Norwegian Children study (PANCS 2) study (79). In PANCS 2, PA was assessed by accelerometer, and the results showed that half of the participating 15-year-olds met the PA recommendations (80). Although comparability with the self-reported data included in the latter WHO study is limited, these data still show that the proportion of insufficiently active adolescents is alarmingly high.

Importantly, efforts to increase adolescents' knowledge and to provide information about the health benefits of PA does not seem to be sufficient for enhancing PA behavior (29, 81). A physically active lifestyle and adherence to the PA recommendations relates to motivation for PA behavior. Elements suggested to be of particular importance in motivating adolescents to initiate and continue with physical activities and sports include: feelings of competence, perception of choice or autonomy, supportive relationships with peers and adults, and enjoyment of the activity or sport (81).

2.3.2 Gender and age differences

Results from several population-based studies have revealed that girls are less physically active than boys (33, 78, 82-86), and they are also less engaged in sports (33, 59, 85, 87, 88).

Age differences in PA throughout adolescence are evident; PA levels are shown to decline with increasing age, especially among girls (31, 33, 80, 89). Further, studies of secular changes in PA among adolescents suggests a decline in PA levels during the past 15 years, especially among girls (80, 90). Thus, gender differences are distinct both in longitudinal trends of PA throughout adolescent years, and in secular trends of adolescents' PA in recent decades.

Although extensive research has been carried out on PA surveillance (78, 91, 92) and data exists on memberships in organized sports clubs (not sport specific) and gyms/fitness centers (69, 70, 93), there is a lack of data on participation rates in different types of sports between genders and adolescent age groups from large population-based studies. Such data may provide valuable information useful in efforts to prevent decline in PA and dropout from sports during adolescence.

2.4 Musculoskeletal pain among adolescents

Definitions

The International Association for the Study of Pain (IASP) has a widely accepted description of pain as a *"an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage"* (94). This definition implies that pain is subjective, with both physical and emotional components.

Acute pain serves as a warning signal of imminent or actual damage, is normally sudden in onset and time limited, and has important functions in the body's protective system. In contrast, chronic pain typically continues beyond normal tissue healing time, and is most commonly defined as persistent or recurrent pain that lasts longer than three months (95, 96). Musculoskeletal pain, acute or chronic, arises from conditions affecting bones, joints, muscles, or related soft tissues (96). The causes of chronic musculoskeletal pain are still not fully understood and are likely to be complex and multifactorial involving biological, psychological, and social mechanisms, referred to as biopsychosocial processes (97, 98). Chronic pain in multiple locations is found to be more strongly associated with psychosocial and mental health factors, including symptoms of anxiety and depression, compared to localized pain (99-101).

Musculoskeletal pain can further be divided into traumatic and non-traumatic pain. Traumatic pain arises from acute injuries or trauma associated with a specific, clearly identifiable event, while a non-traumatic complaint is not caused by a single event (102). Sports-related overuse injuries are typically non-traumatic, they may still lead to long-term pain conditions. They commonly occur as a result of repetitive micro-trauma and submaximal loading of the musculoskeletal system where structural adaption has not taken place due to insufficient rest (103, 104).

Prevalence

Musculoskeletal pain is a common health complaint among adolescents (5, 105-108). Prevalence rates among children and adolescents have been found to range from 4% to 40% (105), but estimates from reviews and large cohort studies indicate that between one-third and half of adolescents report musculoskeletal pain monthly or more (5). In a meta-analysis, the one-year prevalence for adolescent LBP was 34% (109), while the one-year prevalence estimates for neck and shoulder pain are found to range from 21% to 42% (110). Pain in the lower extremities is also common among adolescents (111-113), but a systematic review on extremity pain showed that an estimate of prevalence was not feasible due to heterogeneity of pain outcomes (111).

Among adolescents who are active in sports, LBP, neck and shoulder pain, and pain in the lower extremities are the most commonly reported pain locations (113-115), and are often related to overuse symptoms or injuries (115, 116). It is estimated that as many as 50% of all sports-related injuries among children and adolescents are caused by overuse or repetitive trauma (117, 118).

Studies regarding the epidemiology of musculoskeletal pain among adolescents are, however, difficult to compare (119). The fact that musculoskeletal pain in multiple locations is frequently reported among adolescents (105, 106, 108, 120-122) is also receiving increasing attention. Overall, the studies mentioned above report large variations in prevalence rates, likely due to differences in definitions of pain, recall periods, the age groups studied, and the size of the study samples (105, 107, 109, 110, 123). Of particular note, however, is that the prevalence of musculoskeletal pain appears to be increasing (107, 109, 124), especially concomitant neck and back pain (121).

Gender and age-differences

Despite the heterogeneity in descriptions of the prevalence of musculoskeletal pain among adolescents, gender and age differences are clearly apparent. Most studies have found that girls generally experience more musculoskeletal pain than boys, and that prevalence rates increase with age during adolescent years (5, 105, 125, 126). Moreover, by the end of adolescence, the prevalence rates approach adult levels (5, 125).

Burden of adolescent musculoskeletal pain

The disability burden of musculoskeletal pain in adolescence is large (5, 8). Musculoskeletal pain may have a major impact on adolescents' lives, and is associated with reduced quality of life and high consumption of pharmaceuticals and healthcare (127-131).

Musculoskeletal pain is strongly related to symptoms of anxiety and depression (132-134), and pain and depression frequently co-occur in adolescence (7, 135). Musculoskeletal pain in adolescent years also increases the risk of chronic pain conditions in adulthood (5, 136-138). Chronic pain into adulthood has severe consequences as it confers a substantial burden onto both individuals and society. In recent years, particular attention has been paid to the long-term consequences of LBP. As shown in the WHO Global Burden of Disease studies from 2010 and 2017, LBP in adulthood causes more disability globally than any other disease or health complaint, measured by the aggregate number of years lived with disability (YLDs) (139, 140). Further, a series of articles published in the Lancet in 2018 (15, 141, 142) outlining the increasing burden of LBP worldwide identified it as a major global health challenge, and highlighted the lack of research on preventive strategies. The third paper in this series was a call for national and international action to make LBP a priority and to try to mitigate the increasing burden and costly effects of LBP (142).

2.4.1 Associations between physical activity, sport participation, and musculoskeletal pain

A potential *protective effect* of PA on musculoskeletal pain has been supported by results from studies including adolescent samples. Being physically active was associated with reduced odds of NSP in a cross-sectional population-based study (132), and a three year longitudinal study found that PA seemed to protect against LBP in early adolescence (143). Another longitudinal study reported that inactive adolescents, who remained inactive at three-year follow-up, had a higher risk of musculoskeletal pain (144).

In contrast, other cross-sectional studies have reported *no or weak associations* between adolescent PA and musculoskeletal pain (134, 145) or LBP (146-148). Further, longitudinal studies have shown that level of PA at age 11-13 years was not associated with neck pain or LBP at two-year follow-up (149), and PA level among 9- to 13-year-olds did not predict the recurrence of musculoskeletal pain at four-year follow-up (129). Moreover, in a review by Jones & Macfarlane (2005) the authors did not find evidence of an increased risk of LBP associated with prior level of PA (150).

Of note, high levels of PA and sport activities have been associated with musculoskeletal pain in cross-sectional studies with population-based adolescent samples (122, 151, 152). Further, a longitudinal study of 16 year-olds with a two-year follow-up found an increased risk of multiple musculoskeletal pains among girls with a high PA level (99).

In summary, research on the association between PA and musculoskeletal pain in adolescents has generated a mix of conflicting small positive, negative, and null associations. Differences in measures of PA and assessment of musculoskeletal pain makes it difficult to compare the aforementioned study results. A systematic review also reported inconsistent results on the association between PA and musculoskeletal pain in studies including adult samples (153).

Most previous studies with adolescent samples include PA exposures assessed as frequency or duration of PA (most often days or hours per week), but do not examine specific types of activities or sports. There is, however, reason to believe that potential impact of sport participation may vary between different types of sports due to variations in physical load on the musculoskeletal system. As an example, adolescent athletes, especially in sports such as soccer and track and field, seem to be more prone to overuse injuries causing long-term pain conditions (154, 155).

Within the context of the establishment of health-related behaviors during adolescence, we know that choice of sport activities is a modifiable factor. Thus, there is a need to identify potentially protective sport activities, as well as sports associated with high prevalence of musculoskeletal pain among adolescents. Further, whether these relationships are dependent on location of pain has not been thoroughly investigated in population-based studies. Another limitation in previous research in this field is the lack of control of potential confounders such as psychological distress/depressive symptoms. As these factors may impact both PA level and MS pain, they should be considered as confounding factors in order to reduce bias in the estimation of these relationships.

Possible mechanisms

Although it is not within the research scope of this thesis, this section provides a brief overview of potential underlying mechanisms explaining the relationship between PA and musculoskeletal pain. Research suggests that regular PA and exercise can ease long-term pain by increasing circulation and blood flow and improving muscle strength and flexibility (156). Further, regular PA have an impact on psychological co-morbidities. As musculoskeletal pain and mental health problems often co-occur (7, 135, 141), and are associated with increased pain and disability (7), reduction of pain during or after PA/exercise may be a result of improvements in mental health and psychological well-being (157). Participating in PA or sports with peers also provides opportunities to establish friendships, and thus reduce experiences of loneliness. Social pain, created by social rejection or social loss, is found to be closely related to physical pain and the neuropsychological social and physical pain processes overlap (158, 159). Lack of social support and social stress, such as prolonged isolation, seem to play an exacerbating role in the development of pain (158). Access to and attainment of increased social support and peer acceptance through engagement in activities and sports may therefore also help alleviate the pain experience.

Further, the underlying mechanisms of how PA can help to prevent pain are now beginning to be revealed in basic science. PA is a factor influencing pain sensitivity, and, in general, higher levels of PA are associated with more pain inhibition and less pain facilitation (160).

In the *CNS* (brainstem inhibitory/facilitatory sites), regular PA increases inhibition from endogenous opioids and serotonin. In turn, their inhibition of facilitatory neurons results in reduced facilitation (157). Endogenous opioids, such as endorphins, are considered natural painkillers, similar to the drug morphine, and have therefore received the name "endogenous morphine" (161). Effects of PA on modulation of *the immune system* occurs locally (in the muscles), systemically, and in the CNS. Regular PA improves the balance between pro-and anti-inflammatory cytokines, resulting in more anti-inflammatory cytokines reducing the activity of nociceptors to prevent pain (157). Recently, there has been growing interest in the role of macrophages present in muscle tissue, as they are an important part of cytokine production. Regular PA seems to change the macrophage phenotype from pro-inflammatory M1 to the anti-inflammatory M2. M2 releases anti-inflammatory cytokines (like IL-10) which inhibit nociceptors, and thus may prevent development of chronic pain (157, 162). Exercise also seems to play a role in reducing systemic inflammation (157, 163), although it is not clear whether the anti-inflammatory health benefits of PA are due to the activity or exercise itself, or whether they are due to favorable changes in body composition (164). Further, in the CNS, regular PA and exercise seem to play a role in glia cell activation and normalization of neuroimmune signaling that may contribute to pain reduction (157).

2.5 Mental health problems among adolescents

Definition

According to WHO, good mental health is understood as more than just the absence of mental disorders, and has been defined as *"a state of well-being in which the individual realizes his or her own abilities, can cope with normal stressors in life, can work productively and fruitfully, and is able to make a contribution to his or her community"* (165). Mental health includes many dimensions, refers to how people evaluate their lives, and includes variables such as life satisfaction, coping, self-esteem, anxiety and depression, and moods and emotions (166).

Anxiety and depression are often studied together (167, 168) as they frequently co-occur and share the same risk factors and diagnostic overlap (167-170). Symptom scales are often used in epidemiological research, such as the Hopkins Symptom Checklist, encompassing symptoms of both anxiety and depression.

Prevalence

Population-based studies show that mental health problems are common among adolescents. It is indicated that up to one in five children and adolescents worldwide experience mental health problems (6, 32). A review of the epidemiology of mental disorders using data from the United States (U.S.) and Great Britain found that, at any time, 12% of children and adolescents have an impairing mental disorder (171). In a U.S. national survey of adolescents aged 13 to 17 the one-year prevalence of mental disorders was 40%, and the 30-day prevalence was 23% (172). The lifetime prevalence (onset by age 18) of at least one mental disorder is found to be 50% in a nationally representative sample of U.S. adolescents (173). There are no comparable population studies from Norway reporting prevalence rates of mental disorders in adolescents using clinical interviews. Childhood and adolescent circumstances and living conditions vary greatly between countries, with different social structures and access to resources.

Two of the most common mental disorders worldwide are anxiety and depression (173-176). A review on prevalence rates of mental disorders among adolescents (12-19 years) reported a point prevalence rate of 11% for anxiety disorders and 6% for depressive disorders, according to diagnostic interviews (177). If subclinical symptoms are included, the prevalence of anxiety and depression will be higher (178). This also applies to much of the relevant literature for this thesis, including large epidemiological studies based on self-report rather than diagnostic interviews, reporting prevalence rates from symptoms scale scores assessing anxiety, depression and/or psychological distress. As an example, in the Ungdata survey in Norway, psychological distress assessed with the Hopkins Symptom Checklist was reported among 6% of boys and among 20% of girls in 2016 (179).

Further, secular changes seem to be evident for mood disorders, with a steady rise in rates of depression between cohorts born from the early 1980s to the late 1990s (180). Clinical diagnosis and treatment of mental health disorders among adolescents has also increased in recent decades (181). Although these changes may, in part, be due to increased awareness as well as changes in diagnostic thresholds which lead to higher reporting, they do seem to reflect a true increase in high-income countries (181). In a systematic review examining changes in the mental health of children and adolescents over time, the majority of studies reported an increase in internalizing problems such as anxiety and depression in adolescent girls (182). Data retrieved from the Norwegian Youth Health Surveys have also revealed that the prevalence of psychological distress among adolescents increased from 19% in 2001 to 28% in 2009 (183).

Gender and age-differences

Gender differences are evident across various mental health outcome measures. Girls are more affected by mood disorders and emotional problems than boys, including depression, anxiety, and psychological distress (173, 184-189). This gender gap seems to increase during adolescence (34, 184). Conduct disorders and behavioral problems are more common among boys (173, 188, 190, 191).

The most notable increase in mental health problems occurs from the mid-teens (14-16 years) (192, 193), making this a particularly vulnerable time. In particular, mood disorders, including depression, seem to increases with age (34, 192). Merikangas et al. (2010) found that the prevalence of depression increases steadily during adolescence, with a prevalence almost twice as high in the 17- to 18-year age group as compared to the 13- to 14-year age group (173).

As mentioned above, the NOVA report on psychological distress among Norwegian adolescents revealed a significant gender difference in the prevalence rate (179). Both gender and age differences have also been found in other studies of Norwegian adolescents (183, 194). In a three-year follow-up study, 9% of boys reported psychological distress at 15 years increasing to 13% at 18 years, while the corresponding proportions for girls were 26% and 34% (195).

Burden of adolescent mental health problems

Mental health problems have a negative impact on adolescents' development, their quality of life, and their social integration (196), and is associated with reduced school attendance (197, 198), sleep disturbances (199), and multiple risk behaviors including drug and alcohol use (200). These conditions and challenges may affect adolescents' prospects, their coping strategies, hopes, and aspirations, and their opportunities to make healthy lifestyle choices. The severity is supported by the fact that mental health problems are ranked as the largest contributor to the burden of disease in adolescents (201). Data from the WHO Burden of Disease Study shows that anxiety and depression are responsible for approximately 13% of years lived with disability among 15- to 19-year-olds globally (9).

Mental health problems in adolescence often persists into adulthood (202, 203), with longer duration of mental health problems in adolescence found to be the strongest predictor for a mental disorder in adulthood (202). The serious consequences of mental health problems in adolescence on lifelong outcomes are also well documented across many other domains, including a wide range of economic and social outcomes (204, 205). Thus, as mental health problems in adolescence seem to have a strong impact on mental health and social and economic consequences across the life course, they have increasingly become a priority of the global health agenda (3, 206, 207).

2.5.1 Associations between physical activity, sport participation, and mental health

There is increasing evidence indicating that regular PA in adolescence has a positive impact on various dimensions of mental health. In a synthesis of reviews investigating mental health benefits of PA in children and adolescents, Biddle & Asare (2011) concluded that associations between PA and mental health outcomes are evident, including reduced depression and improved self-esteem with higher levels of PA, although associations were small to moderate (208).

A systematic review and meta-analysis including observational studies found that increased PA in childhood and adolescence was associated with decreased depressive symptoms (209). Previous systematic reviews have reported similar findings (210, 211). Overall, the cross-sectional studies that include large population-based samples of adolescents report an association between higher levels of PA and lower levels of depressive symptoms or psychological distress (33, 85, 212-214).

A potential long-term protective effect of PA can be drawn from the results of longitudinal studies showing that higher levels of PA in adolescent years reduces the risk for depression into young adulthood (215, 216). In contrast, other studies have concluded that there is no longitudinal relationship between PA level in early adolescence and depressive symptoms into late adolescence (217) and young adulthood (218). In the systematic review by Korzak et al. (2017), the strongest associations were found in cross-sectional studies, while associations with future onset of depressive symptoms were weaker (209).

Moreover, there is a growing body of research on the impact of adolescents' participation in sports. A systematic review of the mental health benefits of adolescent engagement in sports concluded that sport participation improved self-esteem, social interaction and depressive symptoms (42). Specifically, team sport participation was associated with improved health outcomes. Results from another systematic review of psychosocial outcomes across different types of sport activities also suggested that team sport involvement may be particularly beneficial (219).

Much of the previous research that has included population-based samples of adolescents has, however, focused on amount of PA without considering the nature or type of activities and sports. Further, researchers have not yet determined differences in the relationships between PA/sport participation and mental health across adolescent developmental stages or age groups. In Norway, adolescents transition from junior- to senior high school around the age of 16. The ages 15-16 years are characterized by physical and psychological changes that may relate to pubertal development and identity formation, as well as changes in the school context that affect social life (59). The major shift in psychosocial development tasks from the early adolescent stage to mid-late adolescence, accompanied by interactions with peers receiving a higher priority (220), gives reason to believe that the mental health benefits of PA and sport participation may be more prominent in older adolescents. In particular, activities which take place in a social setting (e.g. team sports) and that provide social interaction may provide a larger positive impact.

Another deficiency in previous research in this field is that adjustment of confounders has generally been limited to age, gender, and socioeconomic factors. Other factors known to impact both PA behaviors and mental health outcomes, such as exposures to violence, sexual abuse, and bullying (221-223), have, to the best of our knowledge, not been considered as potential confounders in the estimation of the relationship between PA and mental health in adolescence.

Possible mechanisms

Several biological, psychological, and social mechanisms have been suggested to explain why PA and sport participation have a positive influence on mental health. Some of the potential underlying mechanisms will be highlighted briefly below.

Psychological and social factors mainly include concepts of 1) distraction, suggesting that distraction of unfavorable stimuli during and after PA may lead to improved mood, which can be seen as a 'time out' from depressing thoughts, 2) self-efficacy, concerning the beneficial effects on mood and self-confidence/self-esteem of engaging in challenging activities or sports, 3) social interaction, which deals with the social contact that accompanies engagement in PA or sports (224, 225). For adolescents in particular, social contact and supportive peer relationships play an important role for mental health (226).

Additionally, the proposed biological and physiological benefits of being physically active include lower levels of inflammation, better immune system function, and enhanced neural plasticity (224, 227). Benefits of PA also include increased synaptic transmission of monoamines involved in the regulation of stress, mood, alertness, and emotions, such as dopamine, serotonin, and noradrenalin. Dopamine is also central in reward mechanisms, and affects motivation and drive. As mentioned, PA also stimulates the production of endorphins, interacting with the opiate receptors in the brain to reduce the perception of painand emotional stress (161, 224, 225). Further, PA seems to increase the levels of a protein in the brain called brain-derived neurotrophic factor (BDNF), referred to as the brain's natural fertilizer (161). BDNF has important functions in supporting the growth and maturation of new nerve cells, and is associated with cognitive improvement and reduction of depression and anxiety (161, 228).

2.6 Obesity as a growing public health problem

Obesity is considered a top public health concern due to the increased risks of morbidity and chronic mortality among obese individuals, such as cardiovascular diseases, type 2 diabetes, some cancers, and depression (229-231). There has been a substantial increase in the prevalence of obesity among children, adolescents, and adults in recent years (10, 231-233). In 2016, 18% of children and adolescents aged 5-19 were overweight or obese, worldwide. For adults, 39% were overweight and 13% were obese (234), and it is projected that around 50% of adults in the U.S. will be obese by 2030 (235). In Norway, about 1 in 4 adolescents is overweight or obese, and this proportion appears to be increasing. Among Norwegian adults, only about 25% of men and 40% of women are within normal weight range, and the majority are overweight or obese (236).

Obesity is a complex health issue arising from a combination of causes and contributing factors creating an imbalance between energy intake and expenditure. At the population level, changes in the environment and living habits are likely to explain much of the increase in the prevalence of obesity in recent decades. We live in a society that requires little physical activity for day-to-day living, and, at the same time, encourages excessive food consumption (237). These social and environmental factors contributing to weight gain and obesity have been described as factors causing "obesogenic environments" (238, 239), which can be particularly challenging for adolescents. Of importance in public health research is the potential impact of the ‘‘built environment’’, representing all the working and living conditions collectively created by societies (239), encompassing buildings, transportation systems, parks, and sports facilities. Maintaining energy balance in an "unbalanced world" created by the increase in obesogenic environments is seen as a major public health challenge.

2.6.1 Inactivity, musculoskeletal pain, and psychological distress in adolescence – long term weight related consequences?

Obesity, and its related noncommunicable diseases, are largely preventable (240). Adolescence is an important phase for obesity prevention (12, 13, 241); few obese adolescents seem to achieve a normal weight status in young adulthood (241). As higher levels of PA are associated with lower BMI, PA is considered an important lifestyle factor in the prevention and management of obesity (22). The alarmingly low level of PA among adolescents is therefore concerning. In addition to the increasing levels of inactivity world-wide (78), musculoskeletal pain and mental health problems are common (5, 6, 242), and they frequently co-occur (7, 135). As mentioned, these health complaints are major public health concerns, constituting the leading causes of health-related disability among adolescents (6-9) and adults (141, 243).

The literature is, however, limited and inconclusive regarding the impact of these factors in adolescence on development of obesity into young adulthood:

Physical activity

Systematic reviews of longitudinal studies covering adolescent years have found low PA levels to be a predictive factor for development of obesity during adolescence (244, 245). However, others have had mixed results regarding the contribution of PA on obesity through adolescence (246). The possible long-term impact of low PA in adolescence on the risk of obesity in young adulthood has received less attention. Physically inactive adolescents, as well as those becoming inactive in the transition period from adolescence to young adulthood, are found to be at increased risk of obesity in adulthood (247, 248). However, another prospective study found that PA patterns from age 16-21 did not predict obesity incidence (249). In summary, results from systematic reviews do not provide clear evidence as to whether PA promotes a protective effect against development of obesity into young adulthood, and there is a lack of large, population-based studies using data from adolescent samples with follow-up into young adulthood (246, 250, 251).

Musculoskeletal pain

Musculoskeletal pain has also been suggested as an important factor in the development of obesity (252). The relationship between pain and BMI in adolescence seems to be bi-directional (252, 253), however, the majority of research on the relationship between musculoskeletal pain and obesity among children and adolescents has focused on the impact of obesity on musculoskeletal health (254-256). The evidence concerning the potential impact of musculoskeletal pain in adolescence on the risk of obesity in adulthood is limited, and, to our best knowledge, currently only includes evaluations of clinical samples of adolescents with chronic pain. These studies, including small sample sizes, suggest that young patients with musculoskeletal pain are at increased risk of being obese (252, 257).

Psychological distress

Longitudinal studies have shown that adolescents experiencing psychological distress and depression are more likely to become obese (258-261), and depressive symptoms in adolescence have been found to increase the likelihood of adult overweight (262) and obesity (263, 264), especially for females (265). In summary, results from five systematic reviews, including relevant longitudinal studies, suggests that psychological distress or depression/depressive symptoms in adolescence are predictive for development of obesity (261, 265-268), with two reviews suggesting that depression in adolescence is more strongly related to adult obesity among girls than boys (265, 266). These systematic reviews, however, included few studies of adolescent samples that were followed-up into young adulthood, and few studies used large, population-based cohorts.

Co-occurrence of these potential risk factors in adolescence

Given the high prevalence and co-occurrence of physical inactivity, musculoskeletal pain, and mental health problems among adolescents, there is a need to examine the long-term weight-related consequences of these health factors, and to identify groups of adolescents at higher risk of obesity. Despite their detrimental implications for public health, the potential adverse effects of the combined occurrence of these health problems, and how they may impact the risk profile for obesity, is a health care issue that has not been in focus.

3. Aims

The overall objective of this thesis was to study the relationships between adolescent participation in regular physical activities and sports and; 1. musculoskeletal pain, and 2. mental health. Further, an aim was to evaluate the potential impact of PA and co-existing musculoskeletal pain and mental health problems on later obesity.

Specific aims

Aim Paper I:

To examine the associations between PA level, sport participation, and persistent weekly musculoskeletal pain in the neck and shoulders, low back, and lower extremities in a population-based sample of adolescents.

Aim Paper II:

To describe PA levels and sport participation in a population-based sample of adolescents, and to explore how PA levels and sport participation are associated with mental health in different age groups.

Aim Paper III:

To investigate the individual and combined impact of common health problems in adolescence – physical inactivity, musculoskeletal pain, and psychological distress – on the probability of obesity in young adulthood.

4. Material and methods

4.1 Study design and population

4.1.1 The Trøndelag Health study

This project used data obtained from the Trøndelag Health Study (HUNT Study), an extensive, population-based study run by the HUNT Research Center. In the HUNT study, self-reported information as well as clinical measurements and biological material has been collected in order to perform public health research. The first data collection from adult inhabitants, HUNT1, occurred in 1984-86, followed by HUNT2 (1995-1997), HUNT3 (2006-2008), and HUNT4 (2017-2019). The first study including adolescents, Young-HUNT1, was conducted in 1995-1997, with a four-year follow-up in Young-HUNT2 (1999-2001), followed by Young-HUNT3 (2006-2008), and Young-HUNT4 (2017-2019).

The HUNT study is suitable for epidemiological research as all residents of the former Nord-Trøndelag County have been invited to participate. Nord-Trøndelag is situated in the middle region of Norway, and the former county of Nord-Trøndelag was mostly rural, with six small towns. This county had a relatively stable population size (131 555 inhabitants in 2010), and the majority of inhabitants were of Caucasian origin (269-271). In 2018, the two counties of Nord-Trøndelag and Sør-Trøndelag were merged into Trøndelag county. From the autumn of 2019, HUNT was expanded to include the entire county of Trøndelag.

In this thesis, a cross-sectional study design was used in Papers I and II with data from adolescents (13 -19 years old) participating in Young-HUNT3 (2006-2008). In Paper III we used a longitudinal study design including data from participants in Young-HUNT1 (1995-97) with an 11-year follow-up in adult HUNT3 (2006-08).

4.2 Data collection

4.2.1 Young-HUNT1 and Young-HUNT3

All students in junior high school (aged 13-16 years) and senior high school (aged 16-19 years) in the former Nord-Trøndelag County were invited to participate in the Young-HUNT1 (1995-1997) and Young-HUNT3 (2006-2008) studies.

While at school, participants spent one school hour filling out a self-reported questionnaire including the health and lifestyle topics of general wellbeing and self-rated health, health problems, PA behavior, interpersonal violence, diet, alcohol use, smoking, and digital screen use (272). Some of the questions asked in Young-HUNT1 and Young-HUNT3 differed, including those on frequency and location of musculoskeletal pain. Further, health examinations including measures of height, weight, waist circumference, and blood pressure were conducted by trained nurses who visited the schools within a month after completion of the questionnaires.

Junior high school is mandatory in Norway, and most adolescents continue on to senior high school. Those absent the day the survey was conducted at their school were invited to fill out the questionnaire at the time of the clinical measurements. Those not enrolled in school received an invitation and questionnaire in the post.

4.2.2 Adult-HUNT3

Inhabitants in the former Nord-Trøndelag County aged 20 years or more (93 860 residents) were invited to participate in the HUNT3 study, with data collection from 2006-2008. The study invitation, including the first self-reported questionnaire (Q1) and an information pamphlet letter, was sent by post. Q1 included questions regarding quality of life, lifestyle factors, prior or current diseases, and use of health services (272, 273). It was filled in at home and handed in together with the written consent when they attended the basic clinical health examination. The clinical examination included anthropometric measures (weight, height, waist and hip circumference), as well as measures of blood pressure and heart rate (270). At the examination, all participants were encouraged to fill in a second questionnaire (Q2) which included specific questions for men and women in different age groups (20–29, 30–69, 70+ years).

4.3. Study samples

4.3.1 Study samples in Papers I and II

In the Young-HUNT 3 study, 8200 (78.4%) of the invited adolescents completed the questionnaire, and, 7716 (73.7%) also attended the clinical examination (junior high school: n=4615, senior high school: n=3017, not in school: n=84). The response rate for both questionnaire and clinical data was 82% among junior high school students, 69 % among senior high school students, and only 17% among those not attending school. The main reason for non-participation was absence from school the day the Young-HUNT 3 study was conducted. Non-participants were older compared to participants and more often boys (269).

Participants were excluded from the analysis in the present papers (I and II) due to age ≥20 years, as the WHO defines adolescents as those between 10 and 19 years of age. In Paper I, participants with missing or incomplete responses to the musculoskeletal pain variables were also excluded. In Paper II, adolescents not enrolled in school were excluded. The study sample for Paper I consisted of 7596 adolescents, and the study sample for Paper II consisted of 7619 adolescents, as illustrated in Figure 1.

4.3.2 Study sample in Paper III

Paper III was based on data from adolescents participating in Young-HUNT1 who also participated in HUNT3 as young adults 11 years later, in total 1919 participants (36% of the invited young adults (n=5353) who had participated in the Young-HUNT1).

Participants were excluded if they were ≥20 years at baseline (n=10). Participants in HUNT3 who did not attend the clinical examination (n=11) or did not have available BMI measurements (n=10) were excluded, as well as those classified as underweight (BMI < 18.5) in HUNT3 (n=29). Thus, the study sample analyzed in Paper III comprised 1859 individuals who participated in both Young-HUNT1 (baseline, 13-19 years) and HUNT 3 (follow-up, 23-31 years) (Figure 1).

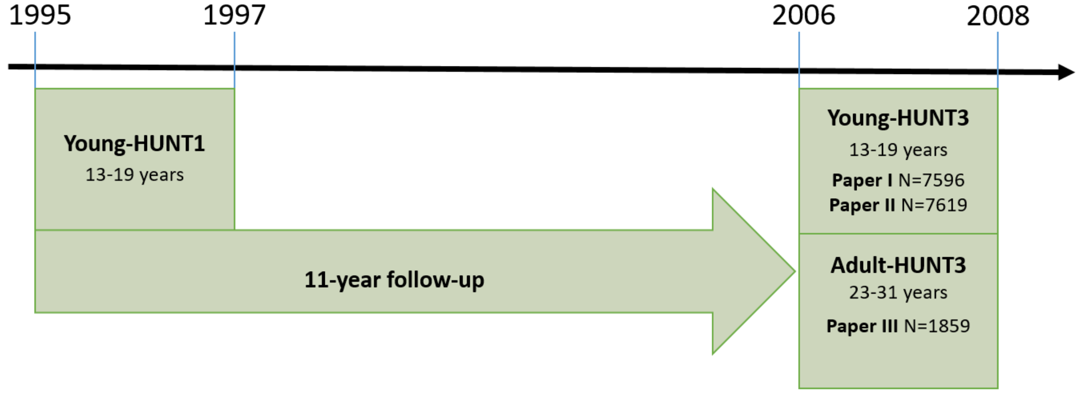

Figure 1. Study samples Papers I, II, and III.

4.4 Measurements

4.4.1 Physical activity and sport participation

Level of physical activity

PA level was an exposure variable in all three papers, and the PA measure was the same in both Young-HUNT1 and Young-HUNT3. PA was assessed with a question on frequency of leisure time PA from the World Health Organization Health Behavior in Schoolchildren (WHO HBSC) Survey Questionnaire (47, 274): Outside school hours: "How often do you usually exercise in your free time so much that you get out of breath or sweat?". The response options were: every day, 4-6 days/week, 2-3 days/week, 1 day/week, less than every week, less than every month, and never. As in previous studies (47, 275), responses were categorized into three levels: ''low PA'' (≤1 days/week), ''moderate PA'' (2-3 days/week), and ''high PA'' (≥4 days/week). The frequency question from the WHO HBSC survey is found to be reliable and to demonstrate acceptable validity in adolescent samples (47, 274). More specifically, the HBSC frequency question had substantial reliability (interclass correlation coefficient 0.73) and was found to be an acceptable instrument for measuring cardiorespiratory fitness (VO2peak), for girls in particular. The frequency question had a higher correlation with VO2peak than the duration question (47).

Sport participation

Participation in sports was an exposure variable in Paper I and II. Sport participation, including type and frequency, was assessed by the question: "How often have you participated in the following activities/sports in the last 12 months?", with response options; endurance sports (e.g. cross-country skiing, swimming, running), team sports (e.g. soccer, volleyball, handball), strength sports (e.g. weightlifting, bodybuilding), technical sports (e.g. track and field, alpine skiing, snowboard), aesthetic sports (e.g. dance, gymnastics), martial arts (e.g. judo, karate, boxing), extreme sports (e.g. rafting, rock climbing, paragliding), jogging/walking, and other sports. Jogging/walking was not defined as a sport participation exposure. Frequency of participation within each sport category was rated according to the alternatives: never, less than once a week, once a week, several times per week. For each sport category, active participation was defined as participating with a frequency of "at least once a week" in the respective sport. Reference groups consisted of participants who responded "never" or "less than once a week".

In Paper II, respondents were further divided into team sport participants (e.g. football, volleyball, handball) or individual sport participants (all other sports), while the reference group consisted of those participating less than once a week or never in all the sport categories, as well as those who reported a low level of PA.

4.4.2 Musculoskeletal pain

In Paper I, the musculoskeletal pain outcomes included neck and shoulder pain (NSP), low back pain (LBP), and lower extremities pain (LEP). In Young-HUNT3, musculoskeletal pain was assessed with a question about frequency of pain during the last three months in different body locations, as illustrated on an accompanying body chart. The pain reported should be unrelated to any known disease or injury. The adolescents were asked to specify the frequency of pain in each location on a 5-level scale ranging from “never or seldom” to “almost every day”. Pain with a frequency of at least once a week during the last three months was defined as *persistent weekly pain*. This cut-off was set to distinguish between participants who experience pain frequently and those with infrequent pain. The reference group consisted of those who reported experiencing musculoskeletal pain “never or seldom” or “less than once a month”. Overuse problems or injuries were included in our case definition of musculoskeletal pain, as the pain questionnaire comprised non-traumatic and not-disease related musculoskeletal pain.

The pain questions have been adapted from Mikkelson and colleagues (276, 277), which have shown good test-retest reliability for detecting occurrence of pain at least once a week, and have demonstrated good concurrent validity in comparisons with interviews (276, 278).

In Paper III, where we used baseline values from Young-HUNT1, musculoskeletal pain was one of the exposure variables. In Young-HUNT1, musculoskeletal pain was assessed by asking participants to report occurrence of neck- or shoulder pain and joint- or muscle pain in the past 12 months, with the response options: “never”, “seldom”, “sometimes”, and “often”. If participants responded “sometimes” or “often”, they were classified as having musculoskeletal pain.

4.4.3 Mental health

Psychological distress (symptoms of anxiety and depression)

Psychological distress was one of three psychological outcome variables in Paper II, and one of the exposure variables in Paper III. In Paper I, it was considered as a confounder. In Young-HUNT1- and Young-HUNT3, psychological distress was assessed with a validated five-item shortened version of the Hopkins Symptoms Checklist (SCL-5) (279). SCL-5 comprises statements about symptoms of anxiety and depression experienced in the last 14 days, including; "I have been constantly afraid and anxious", "I have felt tense or uneasy", "I have felt hopeless about the future", "I have felt dejected or sad", "I have worried too much about various things". These five statements were scored using a four-point scale ranging from "not at all bothered" (1) to "extremely bothered" (4). A mean score was calculated, and higher scores indicates higher level of psychological distress. A mean score above two was used as a cut-off for presence of psychological distress (279). The SCL-5 version has shown high reliability and is found to correlate well with the more comprehensive versions (SCL-25, SCL-10) (279, 280). This version has also demonstrated good internal consistency (Cronbach's alpha 0.87) (279). Specificity at 82% and sensitivity at 96% were found using the cut-off point of 2.0 to determine whether adolescents had symptoms of anxiety and depression (279). SCL-5 is shown to be a valid instrument for detecting symptoms of anxiety and depression in a Norwegian population above 16 years of age (280), and SCL-10 has been validated in a sample of Norwegian and Danish adolescents (14-16 years) (281).

Self-esteem

Self-esteem was one of the outcome variables in Paper II. Self-esteem was assessed with a short version of the Rosenberg Self-Esteem Scale (RSES), which is a widely used measure of self-esteem (282, 283). RSES originally comprised 10 items (284), and has shown adequate reliability and validity in adolescent and young adult samples (283, 285). In the Young-HUNT studies, a four item version has been used, including the statements: "I have a positive attitude toward myself", "I feel rather useless at times", "I feel that I don't have much to be proud of", and "I feel that I am a valuable person, at least equal to other people". Responses options were graded on a 4-point scale ranging from "I strongly agree" (1) to "I strongly disagree" (4). The scores were inversed in the first and the last items. A mean score was calculated, ranging from 4-16, in which higher scores indicate higher levels of self-esteem. To distinguish between low and high self-esteem, a cut-off was set at a mean score of 10, which is the midpoint of the scale. This cut-off corresponds to the cut-off at 25 recommended when using the original 10-item RSES scale (range 10-40) (286). The four-item version has shown good internal consistency (Cronbach's alpha 0.80), and is found to correlate at 0.95 with the full version (287, 288).

Life satisfaction

Life satisfaction was one of the outcome variables in Paper II. Life satisfaction was assessed with the question: "Thinking about your life at the moment, would you say that, by and large, you are satisfied, or are you mostly dissatisfied?" Response options ranged from "very satisfied" (1) to "very dissatisfied" (7). Participants who responded 1-3 (from "very satisfied" to "quite satisfied") were classified as having "high life satisfaction", while those who responded 4-7 (from "a bit of both" to "very dissatisfied") were classified as having "low life satisfaction". A single-item life satisfaction measure has demonstrated a substantial degree of criterion validity compared to the multiple-item Satisfaction with Life Scale (SWLS) (289), and is found to perform almost as well as the SWLS in adolescent samples (290).

4.4.4 Anthropometrics

Body mass index (BMI)

BMI was considered a confounder in Paper I. Body weight (kg) and height (cm) were measured by trained nurses in Young-HUNT3. BMI was calculated by dividing body weight in kilograms by the squared value of body height in meters (kg/m^2).

Obesity

Obesity in young adulthood, at 11 years follow-up in HUNT3, was the outcome variable in Paper III. Trained nurses measured weight, to the nearest half kilogram (kg), and height, which was given in whole centimeters (cm). Weight was measured with light clothes, but without shoes, jacket, and outdoor clothes. BMI was calculated as described above. According to the definition of adult obesity adopted from the WHO (291), participants with BMI ≥30 were defined as obese.

4.4.5 Socioeconomic status

Socioeconomic status, considered a confounder in Papers I and II, was measured with a question from the HBSC survey (292) that captures an adolescent's perception of their family's socioeconomical, financial, or social status (293). Participants' perceived family economies were divided into three categories; "above average", "average", or "below average".

4.4.6 Age, gender, and pubertal development

Data on sex and age were obtained from the Norwegian National Population Registry. Stratification on sex was conducted in all papers (I-III). In Paper II, we additionally stratified on school level (junior- vs. senior high school), where all participants in senior high school were ≥16 years old.

Pubertal development was considered a confounder in Paper II. Self-reported pubertal development was assessed with the validated Pubertal Development Scale (PDS) (294). Participants were asked to rate their own growth spurts and to rate axillary and pubic hair growth. Boys were also asked to rate changes in voice and facial hair growth, while girls were asked to report age at menarche and breast development. The rating scales for these pubertal changes ranged from "has not begun" (1) to "development completed" (4), while menarche for girls was dichotomised into yes (4) and no (1). An average PDS score was calculated based on these ratings.

4.4.7 Interpersonal violence

Exposures to interpersonal violence were considered confounders in Paper II.
Questions derived from The University of California at Los Angeles Post-traumatic Stress Disorder Reaction Index (295) were used to assess exposures to interpersonal violence. Participants were asked if they had ever (no/yes); been subjected to violence (beaten or injured) (1), been subjected to unpleasant/disagreeable sexual acts by someone approximately your own age (2), been subjected to unpleasant/ disagreeable sexual acts by an adult (3), been threatened or physically harassed by fellow students at school over a period of time (4). Responses were divided into three separate variables: "prior violence", "prior sexual abuse" (by peer or adult) and "prior bullying" (296).

Table 1 An overview of study design, outcomes, data source, and type of data

	Paper I	Paper II	Paper III
Design	Cross-sectional	Cross-sectional	Longitudinal, 11-year follow-up
Outcome measures (dependent variables)	Musculoskeletal pain (NSP, LBP, LEP)*	Psychological distress, Self-esteem, Life satisfaction	Obesity (BMI ≥ 30 kg/m^2)
Data source	Young-HUNT3	Young-HUNT3	Young-HUNT1 → HUNT3
Type of data	Self-reports	Self-reports	Self-reports Clinical measure: BMI

* NSP, neck and shoulder pain; LBP, low back pain; LEP, lower extremity pain

Table 2 A summary of the variables used in the papers

Variable	Paper I	Paper II	Paper III
Gender	**E**	**E**	**E**
Age	**C**	**C**	
Physical activity (PA)			
PA level	**E**	**E**	**E**
Sport participation			
7 types of sports	**E**		
Team, individual,- or no sports		**E**	
Musculoskeletal pain			
NSP, LBP, LEP*	**D**		
Musculoskeletal pain (baseline)			**E**
Mental health			
Psychological distress (SCL-5)†	**C**	**D**	**E**
Self-esteem (RSES-short)†		**D**	
Life satisfaction		**D**	
Anthropometrics			
Body mass index (BMI)	**C**		
Obesity (follow-up)			**D**
Sociodemographics			
Perceived family economy	**C**	**C**	
Pubertal development			
Puberty score (PDS)‡		**C**	
Interpersonal violence			
Physical violence		**C**	
Sexual abuse		**C**	
Bullying		**C**	

E: Exposure variable/group differences studied
C: Covariate/confounder
D: Dependent variable (outcome)
* NSP, neck and shoulder pain; LBP, low back pain; LEP, lower extremity pain
†SCL-5, Hopkins Symptom Check List Five items; RSES, Rosenberg Self-Esteem Scale
‡PDS, Pubertal Development Scale

4.5 Ethics

All participants in the HUNT studies receive information about the purpose of the health surveys through an information folder, followed by personal information at the screening sites as well as information via the HUNT homepage. Participation in the HUNT studies is voluntary. All participants have signed an informed consent form allowing the use of their data for research, including linkage to other public records. In the Young-HUNT studies, written consents was signed by participants 16 years of age or older. For those under 16 years of age, written consent was obtained from their parents in accordance with Norwegian law. Participants are free to withdraw from the study and can request that their data be deleted from the HUNT database at any stage without providing an explanation. In the school-based Young-HUNT studies, a trained teacher was present in the classroom to ensure that the self-reported questionnaires were completely privately, and neither fellow students nor teachers were able to see the answers provided.

The HUNT studies have been approved by the Regional Committee for Medical Research Ethics (REK) and the Data Inspectorate of Norway, and all information from HUNT has been treated according to the guidelines of the Data Inspectorate. The current PhD study has been approved by the REK - South East Norway (2014/1228/REK Sør-Øst A).

The data files we have received from HUNT were de-identified, i.e. they contain no names or social security numbers, only ID numbers. The Data Protection Officer at Oslo University Hospital has created storage space for the data material on the hospital network, and only those involved in the project are granted access.

4.6 Statistical analyses

Separate analyses were conducted for boys and girls in all papers. This stratification was based on the large gender differences in PA and sport participation, musculoskeletal pain, and mental health. For descriptions of the samples, chi-square tests (categorical variables) and the Student’s T-test (continuous variables) were used to compare distributions of selected variables between girls and boys (Papers I, II, and III) and between age groups (Paper II).

In Paper I, the associations between (1) PA level, (2) type of sport participation and musculoskeletal pain (NSP, LBP, and LEP) were analyzed using multiple logistic regression models, and separated models were fitted for the exposure variables and each of the dependent pain variables. We adjusted the analyses for potential confounders including age, BMI, socioeconomic status, and psychological distress. In the models where a specific type of sport participation served as exposure variable, we adjusted for participation in other types of sports. Additional sensitivity analyses were conducted for those reporting pain in only one of the locations studied (NSP, LBP, or LEP).

In Paper II, the associations between (1) PA level and (2) type of sport participation and mental health outcomes were analysed using multiple logistic regression models, with psychological distress, self-esteem, and life satisfaction as dependent variables in separate analyses. Analyses in Paper II were stratified by gender and school level (junior and senior high school). Adjustments were made for age, puberty development (PDS), socioeconomic status, prior violence, sexual abuse (by peer or adult), and bullying. A model-based imputation for pubertal development (PDS score) was conducted due to a relatively large proportion of missing data (14%). To impute, linear regression models stratified by gender were fitted with age and BMI. Missingness was considered missing at random (MAR assumption).

In Paper III, crude associations between each of the exposure variables (PA level, musculoskeletal pain, and psychological distress) at baseline and obesity in young adulthood were quantified using univariate binary logistic regression analyses. Variables with a *p*-value ≤ 0.2 in these univariate analyses were then entered into multiple models, including PA and musculoskeletal pain for both girls and boys, and psychological distress for girls only. Further, probabilities for obesity for different combinations of the exposure variables were calculated from the coefficients in these multiple models, and results were visualized in risk matrices. We conducted sensitivity analyses where participants who were overweight in the follow-up were excluded (BMI 25-29.9 kg/m^2), leaving those within a normal weight range in young adulthood (BMI 18.5-24.9 kg/m^2) as the reference group.

In all papers, results from logistic regression analyses are expressed as crude and adjusted odds ratios (ORs) with 95% confidence intervals (CIs), and *p*-values <0.05 are considered statistically significant. The data were analyzed with SPSS (SPSS Inc., Chicago, IL) version 21 (Paper I) and 25 (Paper II and III).

5. Summary of results

5.1 Paper 1

Physical Activity Level and Sport Participation in Relation to Musculoskeletal Pain in a Population-Based Study of Adolescents. The Young-HUNT Study

In Paper I, we examined relationships between PA level, sport participation, and persistent weekly musculoskeletal pain in three locations; neck and shoulders (NSP), low back (LBP), and lower extremities (LEP). The study sample included 7596 adolescents, with a mean age of 15.8 years (SD, 1.7). NSP was the most prevalent pain location, and all locations of musculoskeletal pain were more frequently reported among girls than boys (p<0,001).

PA level and musculoskeletal pain

A moderate PA level, compared to a low PA level, was associated with lower odds of NSP (OR = 0.79, 95% CI [0.63-0.99] among girls and OR = 0.74, 95% CI [0.55-1.00] among boys), and lower odds of LBP (OR = 0.77, 95% CI [0.60-0.98] among girls and OR = 0.70, 95% CI [0.51-0.95] among boys). A high PA level was significantly associated with increased odds of LEP (OR = 1.39, 95% CI [1.05-1.85] among girls and OR = 2.06 , 95% CI [1.44-2.95] among boys).

Sport participation and musculoskeletal pain

Regarding associations between type of sport participation and pain outcomes, we found that participation in endurance sports (e.g. cross-country skiing, swimming, running) was most strongly associated with lower odds of pain, particularly for LBP among girls (OR = 0.70, 95% CI [0.56-0.88]). Participation in technical sports (e.g. track and field, alpine skiing) was associated with increased odds of LBP among both girls (OR = 1.43, 95% CI [1.11-1.83]) and boys (OR = 1.33, 95% CI [1.00-1.76]), and team sport participation was associated with increased odds of LEP, especially among boys (OR = 1.69, 95% [CI 1.24-2.30]).

5.2 Paper 2

Physical activity and sport participation among adolescents: associations with mental health in different age groups. Results from the Young-HUNT Study: a cross-sectional survey

In Paper II, we described PA levels and sport participation among adolescents, and explored associations between PA level, type of sport participation and mental health in in different age groups. The study sample consisted of 7619 adolescents aged 13-19 years, of whom 4615 (61%) went to junior high school.

PA level and sport participation

Boys were more physically active and participated in sports more frequently than girls. Age differences in levels of PA were apparent among both girls and boys, with significantly lower levels reported among senior high school students (≥ 16 years). Regarding type of sport participation, team sports were most commonly reported. For both genders, participation in team and technical sports was significantly less common among adolescents in senior high school as compared to those in junior high school (p<0.001).

PA level and mental health

In both junior- and senior high school students we found that a high PA level, compared to a low level, was associated with reduced odds of low self-esteem and low life satisfaction, for both genders. A high level of PA was also associated with reduced odds of psychological distress among adolescents in senior high school (OR = 0.63, 95% CI [0.46-0.86] among girls and OR = 0.46, 95% CI [0.27-0.79] among boys).

Sport participation and mental health

For girls in both age groups, participation in team sports, compared with no/infrequent sport participation, was associated with reduced odds of low self-esteem and low life-satisfaction. A similar non-significant trend was observed in boys. Team sport participation was also associated with reduced odds of psychological distress among girls in senior high school (OR = 0.70, 95% CI [0.49 – 1.00]).

5.3 Paper 3

Obesity in Young Adulthood: The Role of Physical Activity Level, Musculoskeletal Pain, and Psychological Distress in Adolescence (The HUNT Study)

In Paper III, we examined the individual and combined impact of; physical activity level, musculoskeletal pain, and psychological distress, on the probability of obesity in young adulthood. The study sample constituted a total of 1859 participants (43.6% males), mean age 16 years (SD 1.8).

The results show a cumulative impact of the factors participation in regular PA and musculoskeletal pain in adolescence on obesity in young adulthood, for both genders. Psychological distress in adolescence did not contribute substantially to higher probability of obesity, and was included in the final model for girls only. More specifically, the lowest probability of obesity in young adulthood was found among girls with a high level of PA, who had no musculoskeletal pain or psychological distress (11%, 95% CI [6% to 16%]), and among boys with a high PA level and no musculoskeletal pain (14% (95% CI 9% to 19%). For girls, those with low PA in combination with both musculoskeletal pain and psychological distress had the highest probability of obesity (25%, 95% CI [11% to 39%]). Among boys, those with low PA who also reported musculoskeletal pain had the highest probability of obesity in young adulthood (27% (95%CI [16% to 38%]).

In support of the main results, sensitivity analyses including reference groups limited to participants within a normal weight range (excluding overweight participants) revealed an even stronger predictive value of PA level and musculoskeletal pain.

6. Discussion

6.1 Methodological considerations

Major strengths of this study were the large sample size including data from an unselected population of adolescents, the comprehensive information about sport participation (Papers I and II), reports of musculoskeletal pain including information about body location and frequency (Paper I), and the use of validated mental health measures (Paper II). The main strength of Paper III was the longitudinal design capturing an important transition period from adolescence into young adulthood. Further, we used stratified analysis accounting for potential gender (Papers I, II and III) and age differences (Paper II) during adolescence.

Several potential sources of error (biases) may, however, impact the study results, and need to be addressed in order to draw appropriate conclusions. In epidemiological studies research errors can be divided into random (lack of precision) or systematic errors (lack of internal validity) (297). In the following sections I will discuss strengths and limitations of the study designs, and then define and identify both random and systematic sources of error that may have affected the validity of this study.

6.1.1 Design

The disadvantages of the cross-sectional design used in Papers I and II must be recognized. The major limitation of this study design is that the exposure and outcome are measured at the same point in time (298, 299). It is therefore not possible to know whether the exposures PA and sport participation were actually responsible for the observed outcomes. Thus, conclusions about cause and effect cannot be drawn from these results as the "temporal sequence" of the relationship between exposure and outcome is not known. Findings from these studies have, however, contributed to our knowledge about the relationship between PA/sport participation and both musculoskeletal and mental health in adolescent years, highlighting differences between genders and age groups, as well as between types of sports participation, which will guide future research in the field.

In Paper III, we used a longitudinal observational design with an 11-year follow-up period from adolescence to young adulthood. The principal advantage of a longitudinal study is the inclusion of time dimension, which permits the researcher to investigate and infer causal relationships to a greater extent (299, 300). As the aim in Paper III was to study how several variables acted together over time leading to the outcome obesity, the benefit of longitudinal over cross-sectional studies is apparent. However, in this study we conducted analyses for prediction purposes to identify subgroups of adolescents at higher probability of obesity. This involves making predictions about the dependent variable obesity based on values of the independent variables. The intention is not to explain or understand the mechanisms behind the relationship between the variables, and it needs to be emphasized that causal inferences cannot be drawn from this type of analysis (301, 302). Thus, we cannot infer causality or imply underlying causes from the results of our analysis in Paper III.

6.1.2 Random errors/precision

Random errors, also called random variation, primarily affect precision, and represent the variability in the data that is random in nature and difficult to predict (303). Random errors that compromise precision are mainly caused by sampling variations or by factors that randomly affect the measurements (297).

Sampling variation is how much an estimate varies between samples. As no sample can be exactly identical to the target population, estimates will always vary from sample to sample. Confidence intervals (CIs) are used to indicate the precision of the study sample estimates as population values (304). The width of the CIs may depend on the sample size, with larger sample sizes resulting in higher precision with narrower CIs. Thus, although there is no way to eliminate or control such random errors, their impact can be reduced by enlarging the observed sample size (297).

The Young-HUNT studies are population based studies with large sample sizes. While the high sample size in the Young-HUNT3 study gave a fairly high precision in the overall results in Papers I and II, small sample sizes in subgroups of gender and age groups reduced the precision of the estimates and increased the probability of type II errors, known as false negative findings. In the prospective study in Paper III, the sample size was significantly lower and the estimates were less precise.

Random measurement variation affects the reliability of measurements, and can be minimized by securing precision in the measurements (297). Random error exists in all questionnaires, and is generally attributable to unreliable reporting and natural variation in behaviors over time (305). As both exposure and outcome variables in Papers I and II, as well as the exposure variables in Paper III, are self-reported measurements, the precision of these measures may have been reduced due to random measurement variation. Clearly, objective measurements, e.g. using accelerometers, would have been a more accurate method to assess the PA exposures in Papers I-III (306). Random errors cannot be eliminated from an experiment, but in terms of the severity of measurement error, they seem to be less problematic than systematic errors (307) (see information bias, 6.1.3.2).

Another issue that is relevant to discuss in this context is multiple testing and the chance of making a type I error, also called a false positive referring to the error of rejecting a null hypothesis when it is actually true. In this study, p-values <.05 were considered statistically significant. In Paper I we studied associations between PA levels, seven different types of sport participations, and three different pain locations. Thus, multiple tests were performed, increasing the possibility for some observations to have occurred by chance. In the discussion we therefore emphasize the pattern in our findings, and provide evidence from previous studies reporting similar associations or trends, supporting the validity of our findings. In our interpretation of the results in Paper II, examining the associations between PA/sports and various mental health outcomes, we tried to emphasize the actual point estimates and their 95% confidence intervals in addition to the p-values, and the clinical relevance of the revealed association. As pointed out above, the probability estimates for obesity in young adulthood in Paper III had low precision as seen in the wide 95% CIs. Our results should therefore be interpreted with caution due to low precision and the large number of hypotheses being tested.

6.1.3 Systematic errors

Systematic errors are often called “bias”, and relates to a systematic tendency to underestimate or overestimate the estimator of interest because of a deficiency in the design or execution of a study (308). Systematic errors occur when deviations from the true values go in a certain direction and consistently deviates from the true values, making interpretation of results problematic (299). In contrast to random errors, systematic errors will not be minimized by increasing the sample size. A systematic error or bias reflects a problem of validity, and most violations of internal validity can be classified as selection bias, information bias, or confounding (309).

6.1.3.1 Selection bias

Selection bias can occur when the study population is not representative for the target population to which conclusions are being extended (303). A low attendance rate typically increases the risk of a non-representable study sample (310). In the Young-HUNT3 study, nearly 80% of the adolescent population in the county of Nord-Trøndelag participated. This high attendance rate reduces the probability of selection bias, although the possibility that the adolescents who did not attend are systematically different from the participants cannot be ruled out.

A potential source of selection bias in this study is the lower participation rate among senior high school students compared to junior highs school students. This is particularly relevant in Paper II where differences in the relationships between PA/sport participation and mental health outcome between these two age groups were examined.

Absence from school the day the study was conducted was the main reason for non-participation (269). As musculoskeletal pain or mental health problems may be a reason for not going to school, the prevalence of these health problems might be higher among those with school absence compared to those who were at school and participated in the study. Also, the participation rate was particularly low among adolescents who had dropped out or were not enrolled in school, which may have caused differential participation, particularly in the oldest age group. It is conceivable that these adolescents may have a higher frequency of musculoskeletal pain, mental health problems and unhealthy lifestyle factors. However, less than 5% of the total population of Young-HUNT3 did not attend school (269), and we therefore do not expect our results to be significantly affected by this possible selection bias.

Although the participation rate in Young-HUNT1 was high, the participation in HUNT3 11 years later was much lower (follow-up in Paper III). By the time of the HUNT3 data collection, those who had participated in Young-HUNT1 had become young adults aged 23-31 years, an age when many leave the county for educational purposes or for work, and only 60% were eligible for invitation to HUNT3. Nevertheless, no major differences in baseline PA level or mean BMI in Young-HUNT1 was found between those who participated in HUNT3 and those who did not (269), reducing the potential for selection bias. Further investigation of possible selection biases between these two groups was conducted in our study sample for Paper III. We found no significant differences in the baseline values of these two groups for the other exposure variables in Paper III (musculoskeletal pain and psychological distress).

An important note is that differences in characteristics between participants and non-participants in a study do not necessarily cause selection bias in the estimation of associations. For selection bias to occur, these differences need to affect the exposure-outcome association of interest (311). The risk of selection bias is found to be larger for prevalence estimates than for exposure-outcome associations (311, 312), supporting the belief that non-participation in our study has not substantially influenced the conclusions we have drawn in Papers I-III.

6.1.3.2 Information bias

Information bias refers to bias in an estimate arising from measurement errors (313), and often occurs when self-reported information from study participants is incorrect (299). Information bias may lead to misclassification if study participants have been placed in an incorrect category, altering the observed research outcome thereby. Differential misclassification can occur when the probability of being misclassified differs between groups of participants in a study, while non-differential misclassification can occur if the probability of misclassification is equal across all groups in the study (313).

As the present study mainly relied on self-reported data collected from respondents, error due to inaccurate measures may have led to information bias, especially in Papers I and II were both exposures and outcomes were self-reported. In Paper III, however, the outcome BMI $\geq$ 30 kg/m^2 (obesity) was calculated based on height and weight measured by trained nurses, and potential information bias from self-reported BMI was avoided. Objectively measured BMI, as in the HUNT studies, is important, since people tend to both overestimate height and underestimate weight (314).

Self-reported data can be affected by external bias caused by *social desirability* or approval (315), which is the tendency of respondents to answer questions in a manner that will be viewed favorably by others (316). In the Young-HUNT studies, adolescents may have underreported their health problems, while social desirability among respondents to be viewed as “physically active” may have led to over-reporting of physical activity behaviors (305). There is, however, no apparent reason why such under- or over reporting should be different among exposure groups in Papers I-III, suggesting that this type of potential misclassification may not be of a major concern. However, it has been suggested that reports of PA levels may vary between people with musculoskeletal pain and healthy controls, which could be a potential source of differential misclassification in Paper I. Specifically, LBP patients were found to have more trouble estimating their levels of PA (317). In contrast, another study found that both patients with LBP and healthy controls tended to over report their levels of PA (318). Although considered less serious, information bias due to misclassification of the outcome variables should also be considered, and we cannot exclude the possibility that the degree of misclassification in the outcomes musculoskeletal pain (Paper I) and mental health problems (Paper II) may vary to some degree between those with different levels of PA.

Another challenge may be differences between groups in *response styles* (319), relating to the possibility that some individuals for instance tend to systematically report higher values (320). However, evidence on the potential impact of different response styles in population-based studies is limited, and rating behavior was found to be of little importance in an epidemiological study of patients with musculoskeletal disorders (321).

Recall bias is another form of information bias created by differences in accuracy of recall between study participants (322). However, most of the self-reported variables used in this study assessed recent behaviors or health problems (PA as an average peer week, musculoskeletal pain on average the last three months, psychological distress past 14 days), minimizing this potential bias. An exception is the musculoskeletal pain exposure variable in Paper III which may be prone to inaccurate responses due to the long recall period of 12 months. However, inaccurate recall may not have differed between study groups as having difficulty remembering affects everyone (303). This potential misclassification therefore tends to be non-differential to some extent, which is considered less serious as results usually lead to an underestimation of the strength of the association between the exposure and the outcome (i.e. in our studies the odds ratio could be biased towards 1.0) (307, 323).

Differential misclassification may, however, have occurred in Paper II if, for example, social desirability, response styles, or recall bias differed between genders or adolescent age groups (junior- and senior high school). As the ability to recall and report PA is a challenging cognitive task, it might be that questions were interpreted differently across these age groups. Younger adolescents have more frequent, short bursts of intense PA, but may be less active in structured activities, which may also influence the accuracy of responses (46).

Despite the sources of systematic misclassification as discussed above, we have no information indicating that major information biases affect our conclusions.

6.1.3.3 Confounding

A fundamental shortcoming of causal inference from observational data is bias caused by confounding (324). Confounding, as defined by Porta (2008) is,*"bias of the estimated effect of an exposure on an outcome due to the presence of a common cause of the exposure and the outcome"*(313). Hence, a confounder variable is associated with both the exposure and the outcome, but not an effect of the exposure, and adjusting for it reduces the overall bias in the estimation of a causal effect. In the HUNT studies, comprehensive information about socioeconomic conditions and health related behaviors and conditions is available, allowing and enabling adjustment for many potential confounding factors.

In Paper I, analyses were stratified by gender, and the final multiple models were adjusted for age, socioeconomic status, and psychological distress. Age and sex are well-known confounders in the relationship between PA and musculoskeletal pain. Psychological distress has not been accounted for in comparable population-based studies examining relationships between sport participation and musculoskeletal pain (147, 325), its inclusion as a confounder is therefore a strength in this study. Additionally, we adjusted for BMI as it was identified as a potential confounder based on previous findings. However, analyses additionally adjusted for BMI did not attenuate the results, indicating that associations between PA, sport participation, and musculoskeletal pain were likely to be independent of BMI.

In Paper II, analyses were stratified by gender and school level (junior and senior high school). In order to control for confounding, adjustments in the multiple models included age, puberty development (PDS), socioeconomic status, prior violence, sexual abuse (by peer or adult) and bullying. The latter three factors have, to our knowledge, not been taken into consideration in previous population-based studies in this field. Further, biological development has been accounted for by using a validated measure of puberty development. However, it is possible that the associations between PA and sport participation and musculoskeletal pain (Paper I) and mental health problems (Paper II) could be biased due to factors which were not adjusted for (unmeasured confounders), or residual confounding due to imprecise measures.

In Paper III, potential confounding factors in the relationship between the studied health problems in adolescence and obesity in young adulthood were not considered, as the regression analysis was done for prediction purposes (see 6.1.1 Design).

6.1.4 External validity - generalizability

External validity concerns generalization, and refers to the extent to which results from a study can be generalized outside of the study population (297). This study used data from a large population of adolescents and young adults in the Nord-Trøndelag county in Norway. In terms of age, mortality, and health status, the county is fairly similar to the rest of Norway. However, the county is mostly rural with no big cities, and income and education levels are slightly below the national average (269, 270).

In addition to the high participation rate in the Young-HUNT studies, the large study population makes the results and inferences drawn from the current study relatively representative of the adolescent population in Norway. Nevertheless, caution is warranted in generalizing the results to other nations and cultures due to differences in factors such as health care systems, socioeconomic status, or the degree of urban areas and living.

As previously mentioned, participants in Young-HUNT3 mainly consisted of adolescents attending school, and this must be considered when applying our results to those who are not part of the school system. Further, despite the high number of participants in Young-HUNT1, participation in HUNT3 11 years later was low among young adults. This may indicate that those who participated at both times and were included in our study (Paper III) were a select group, and thereby be a threat to the generalizability of the study findings (326). However, as discussed under selection bias (6.1.3.1), there seems to be no systematic selection of subjects.

6.2 Prevalence

Although prevalence estimations were not a specific aim in these papers, the prevalence rates of the outcome measures of musculoskeletal pain (Paper I), mental health problems (Paper II), and obesity in young adulthood (Paper III), and their comparability with other studies, will be discussed in the following section.

6.2.1 Musculoskeletal pain (Paper I)

Making direct comparisons of the prevalence rates with previous findings is difficult due to differences in definitions of pain, including frequency of pain and prevalence period, study methodologies, and samples of adolescents studied (105, 107). As emphasized in the Introduction, the fluctuating and multidimensional nature of musculoskeletal pain also represents a challenge when obtaining prevalence rates (110, 153).

Despite this heterogeneity among studies, our findings seems to coincide with the results of other population-based studies. In our study, the neck and shoulders were the most frequently reported pain locations, which is in line with findings from other studies conducted in the general adolescent population (129, 276, 327). NSP, defined as persistent and weekly, was reported by 17% of participants in our study. In another study of Norwegian adolescents, 20% reported persistent weekly NSP (132), although participants were older (17-19 years) and were asked to report pain during the last six months, in contrast to our study recording pain in the last three months. In our study persistent weekly LBP was reported by 14% of the adolescents. A meta-analysis of prevalence rates of LBP reported a point prevalence of 12% and a one-year prevalence of 34% among children and adolescents (109), although pain frequency and severity varied between studies. LEP (persistent weekly) was reported by 11% of adolescents in our study, which is lower than reported in a review including population-based samples (111), as well as in the adolescent athlete population (113). However, severity measures are not directly comparable as some of these studies lack information on frequency and severity of pain or complaints (111).

It should be noted, however, that pain in our study was assessed using respondents' reports of how often they had experienced pain unrelated to any known disease or acute injury during the last three months. Our case definition of musculoskeletal pain therefore includes non-traumatic and not-disease related pain. The wording of the questionnaire in Young-HUNT3 thereby limits reports of pain to either overuse problems/injuries or pain without a clear etiology. Many of the abovementioned studies have not excluded pain related to acute injuries, which may be another explanation for the lower rate of LEP found in our study, especially since a high proportion of acute injuries occur in the lower limbs (328). Nevertheless, there are other more valid measures for examining the extent of overuse injuries. For example, Clarsen (2020) and colleagues at Oslo Sports Trauma Research Center (OSTRC) have developed a questionnaire to register overuse injuries with emphasis on reports of symptoms and pain, an improvement on the traditional time-loss registration of overuse injuries (329).

Musculoskeletal pain was more frequently reported among girls in our study, which is a consistent finding in the literature (5), and the observed gender difference was most apparent for NSP. Other population-based studies have reported higher prevalence of NSP among girls than boys (124, 132, 134, 330). These results coincide with the general pattern of musculoskeletal pain being more frequently reported by females as opposed to males, beyond the onset of puberty (331, 332). A number of factors and mechanisms may contribute to this gender difference in pain, including variations in genetics, physiology including hormone profiles and variation, pain coping, and catastrophizing, as well as gender roles (332, 333). The underlying potential biopsychosocial mechanisms responsible for the gender difference is, however, somewhat unclear (332).

Despite the limited comparability with previous studies due to methodological considerations discussed above, it is clear that musculoskeletal pain is frequently experienced by adolescents, with apparent gender differences, as well as differences according to localization of pain.

6.2.2. Mental health problems (Paper II)

Psychological distress was reported by 19% of girls and 6% of boys in our study, which is comparable to results reported from Ungdata (179, 334), a comprehensive study on adolescent health and well-being using data from a large sample of Norwegian adolescents.

More girls than boys reported mental health problems in our study, including psychological distress, low self-esteem, and low life satisfaction. This gender difference is in agreement with the existing epidemiological literature (184, 187-189, 335). One suggested explanation for the gender differences is girls' greater need for affiliation, which means that they may be more vulnerable to interpersonal negative events (336). In terms of self-esteem, it has been argued that girls may be generally more dependent on others and thereby need a higher level of approval and success in order to feel confident compared to men (337). Higher scores of symptoms of depression among adolescent girls than boys may as well be influenced by differences in biological and hormonal changes during adolescent years (338).

As described in the Introduction, the prevalence of mental health problems in adolescence seems to increase with age. In our study, only psychological distress was significantly more prevalent in the older group (≥16 years), in line with previous findings of an increase in psychological distress or depressive symptoms throughout adolescence (33, 34, 192). In particular the mid-teens (14-16 years) are shown to be a period of marked increase in symptoms of depression (33, 192). Low self-esteem and low life satisfaction, however, were broadly unchanged by increasing age in our study. This may reflect the fact that self-esteem and satisfaction in life are outcomes that are more related to subjective well-being (289, 339), and that these traits change less than proxy measures for aspects of mental health, such as depressive symptoms or anxiety levels. Hence, our results indicate divergent patterns depending on the outcome measures of mental health, in line with other findings (208).

6.2.3 Obesity in young adulthood (Paper III)

The prevalence rate of obesity in young adulthood (17%, HUNT3) is in compliance with results from the European Health Interview Survey showing that about one in six adults in Europe is considered obese (340). The HUNT studies have reported a large increase in the prevalence of obesity among young adults from the 1980s (233), which corresponds with the global obesity trend (341, 342).

6.3 Discussion of the main findings

In this section, some of the main findings of the thesis will be discussed in relation to previous literature and theoretical frameworks. I will begin with a discussion of age and gender differences in PA levels and sport participation among adolescents (Paper II), followed by a discussion of the relationships between PA, sport participation, and musculoskeletal pain (Paper I) and mental health (Paper II). Finally, the potential impact of PA, musculoskeletal pain, and psychological distress in adolescence on the probability of obesity in young adulthood will be considered (Paper III).

6.3.1 Physical activity and sport participation among adolescents – gender and age differences (Paper II)

In Paper II, significantly lower PA levels and sport participation rates were seen among senior high school students compared to junior high school students, among both girls and boys, indicating that a large proportion of adolescents drop out of regular activities and sports.

These results were expected as several studies have found a decline in PA levels throughout adolescence (31, 33, 80, 89, 92), with the most dramatic decrease in PA occuring from the age of 15 (33, 343).

Further, girls reported being less physically active and less engaged in sports than boys, a gender difference also reported in other large population-based studies (33, 78, 83, 85, 92, 344-346). The magnitude of the difference in PA levels between girls and boys differs across studies, but a large pooled investigation of European children and adolescents found that boys had higher levels of total daily PA, and spent about 55% more of an average daytime in moderate to vigorous physical activity (MVPA), compared to girls (344).

This gender gap seems to start as early as in childhood (347). In our study we observed that differences between boys' and girls' PA level and sports participation rates were larger among the older adolescents in senior high school than among younger junior high school students, suggesting a widening of the gender gap with increasing age throughout adolescence. Although WHO's goal of lowering rates of insufficiently active by 15% by 2030 (67) appears to be difficult to achieve for both boys and girls, this gender gap in PA levels has been highlighted as a major inequity that needs to be addressed. Policy action aimed specifically at promoting PA among girls is needed (78, 348, 349).

Factors underlying the observed age and gender differences in PA and sport participation among adolescents are multifactorial and interacting, including individual, social, and environmental, as well as biological factors (350). The transition from junior high to senior high school (ages 15-16 years) involves changes in the educational context and social environment. In this period, adolescents' lives may become more complicated, with competing demands. In particular, the increased demands from both sport participation and school may be important causes for the decline in PA and drop-out from sports in this age group (59, 351).

Other reasons for this decline are connected to experiences and emotions related to the performance of sports activities as well as their organization. Crane & Temple (2015) reported in a systematic review that lack of enjoyment was a major contributing factor in drop out from organized sports, and thereby lower levels of PA among adolescents (351). Furthermore, low perceived competence is found to be a key determinant, as those who do not perceive themselves as having adequate skills to participate will be less likely to enjoy performing sports and thus drop out (351, 352). There is evidence that girls generally feel less competent in performing sports than boys (353, 354), leading to higher rates of dropout among girls. Further, fear of being judged by others, feelings of inadequacy, and a lack of self-esteem are found to be important barriers for sport participation among women in particular (355). Differences in individuals' motivations for being active and engaging in sports may also be a reason. For instance, achievement and competition seem to be important motives for boys to participate in sports, while they tend to be of less importance for girls (356, 357). Girls may also receive less social support or encouragements from parents to engage in PA and sport compared to boys (358-360). In our study, lower participation rates among older adolescents (senior high school students) was found particularly in team sports and technical sports, and this was most evident among girls. These results highlight the importance of actions aimed at encouraging girls to participate in these types of sports to maintain or prevent a large decline in their PA level throughout adolescence.

The lower participation rates in sports in the older age group found in our study could, however, in part be due to a sampling effect as younger adolescents may participate in many types of sports, while older adolescents tend to specialize in one or a few sports. However, not only sport participation rates, but also levels of PA, were lower among older adolescents in our study, suggesting that PA actually decreases with increasing age. Whether high numbers of dropout from sports may be attributable to a "sampling to specialization"effect has recently been more closely investigated by Eime et al. (2019). They found that dropout during adolescence persisted after adjustment for change in behavior from performing multiple sports before specializing, confirming that dropout is a real concern and not simply a result of increased sport specialization (353).

From a public health perspective, it is, however, also important to discuss the challenges and barriers which may prevent older adolescents from continuing to participate in sports and stay active. Dropout from sports often occurs when adolescents transition from a junior level, where play is an important component, to a higher level, with an increasing focus on specialization to a single sport, and competition. It is clear that this transition may make continued participation difficult, especially for those with insufficient ability or low self-confidence (361). Thus, opportunities for participation and diversified sports experiences will be fewer for older adolescents due to increased specialization. Finding from Paper II did, however, reveal that a larger proportion of students in senior high school (≥16 years of age) performed strength sports, compared to those in junior high school. This indicates a shift towards more unorganized activities in late adolescence, which is supported by the Norwegian Ungdata report showing that the proportion of gym and fitness center membership is almost twice as high among adolescents in senior high school compared to junior high school (69, 93).

It should be noted that despite the observed age and gender differences in PA levels and sport participation, a large proportion of the adolescents in our study reported a high PA level (45% of boys and 35% of girls). As this group comprises all those who reported playing sports or exercising at least four days a week, some still may fall short according to the recommendation for daily activity. However, activities within school hours were not covered in the HBSC assessment of PA. For adolescents in Norway, a minimum of 2 school hours per week is allocated for physical education. The focus on leisure time activities may have led to an underestimation of the "overall" PA level of the participants in this study. Still, the complexity of assessing PA and the limitations of self-reported measures, as highlighted in the Introduction and in the discussion about information bias (6.1.3.2), must be taken into consideration when making assumptions about PA levels reported in our study as compared to the PA recommendations.

Further, the percentage of adolescents who reported engagement in sports, and in particular in team sports, was high by international standards. This may partly be a reflection of the Norwegian sport culture and sport policies that promote: "joy of sport for all". Youth sports are strongly supported and prioritized among stakeholders in Norway, and it was the first country in the world to develop the Children's Rights in Sport, a declaration made by the Norwegian Olympic and Paralympic Committee and Confederation of Sports. This document describes positive experiences of sports participation that every child and adolescent in the country should have access to, from good training environments and venues to activities that promotes and facilitate friendship (362).

6.3.2 Physical activity and sport participation in relation to musculoskeletal pain (Paper I)

The findings of this cross-sectional study (Paper I) revealed that moderate levels of PA (2-3 days/week) were associated with reduced odds of NSP and LBP. The associations between sport participation and musculoskeletal pains (NSP, LBP and LEP) differed according to type of sport participation and pain localization.

As pointed out in the Introduction, other population-based studies using a cross-sectional design have also indicated that a moderate level of PA seems to be most beneficial in reducing the odds of NSP (132) and LBP (151) among adolescents. However, results are inconclusive as no or weak associations between PA and NSP or LBP have also been reported in cross-sectional studies (146-148, 150, 330), and longitudinal studies have found PA at baseline to not be associated with back pain at follow-up (149). Further, a systematic review including six cross-sectional and two longitudinal studies from adolescent samples concluded with conflicting evidence for an association between PA and neck pain and LBP (363).

After the publication of Paper I, the potential relationships between PA and NSP and LBP have been summarized in other review studies. Results from a meta-analysis of prospective cohort studies suggest that leisure time PA may reduce the risk of chronic LBP (26), which is in support of our findings. However, few of the included studies used data from adolescent samples (26). Further, reviews of studies examining risk factors for back pain in adolescent samples have concluded with mixed evidence for PA as a potential risk factor (364, 365).

In our study, a high level of PA was significantly associated with pain in the lower extremities. Overuse problems/injuries were included in our definition of musculoskeletal pain. In Paper I, the high rate of overuse injuries occurring in the lower extremities among active adolescents (104, 154, 155) is discussed as a possible explanation for the current findings. Adolescents that experience overuse problems or injuries often continue to train and compete without restrictions (115), and the results from our paper highlight the importance of PA modification for adolescents who report pain in the lower extremities in particular.

A U-shaped curve relationship between PA and musculoskeletal pain, i.e. that both too little and too much PA present an increased risk for pain, has been suggested, mostly from studies in the LBP research field including adult samples (366, 367). However, the evidence seems to be inconsistent (26, 368, 369), and there is considerable uncertainty about the levels or threshold for unhealthy PA levels among adolescents. The notion of a potential U-shaped relationship is partly supported by our study as a moderate level of PA seems to be more beneficial for NSP and LBP than both a low or high level of PA. A thorough investigation into such dose and response relationships would, however, require a more extensive categorization of PA into several different levels, preferably with a separate category for those with a very high PA level, exercising at least every day. In our study, the sport participation exposures (seven types of sports) were dichotomized, preventing further analysis of these relationships. In a study of Japanese adolescents, Kamada et al. (2016) found no evidence of a dose response relationship between time spent playing sports and musculoskeletal pain in adolescents, but differences between types of sports were not taken into account (370).

Thus, this inconsistency in the literature may well result from variability in the type of sport practiced by adolescents. Another important contribution from Paper I is therefore the findings concerning the potential contribution of different types of sport participation and how this seems to impact pain differently depending on pain location. Our results in Paper I revealed that participation in endurance sports, such as cross-country skiing, swimming, and running seems to be most beneficial in terms of reducing NSP and LBP. As these finding also finds support in previous studies of adolescent samples (137, 325, 371, 372), we have argued that these types of sports could be recommended for the prevention and management NSP and LBP.

Further, participation in technical sports, such as track and field, alpine skiing, and snowboarding, was associated with increased odds of LBP, while team sport participation was associated with increased odds of pain in the lower extremities. As discussed in Paper I, these results are also supported by previous findings, although mostly in studies of carefully selected samples of adolescents, except from the cross-sectional population-based study from Auvinen et al. (2008) (325). Compared to the latter study, we additionally adjusted for psychological distress in the estimation of the relationship between sport participation and musculoskeletal pain. The results revealed that the relationship was attenuated but remained statistically significant when controlling for these factors.

It should be noted that multi-site pain is not addressed in Paper I, although it should be seen as part of the larger research field that deals with adolescent musculoskeletal health in a public health perspective. As mentioned, musculoskeletal pain in multiple locations is common among adolescents (105, 106, 108, 120-122), and multisite pain is found to be more strongly associated with psychosocial and mental health problems than localized pain (100, 106, 373, 374). Thus, the influence of psychological distress in the relationship between PA and musculoskeletal pain may be stronger among those who experience pain in multiple locations. To further address this dimension, more epidemiological research is needed on the potential impact of PA on musculoskeletal pain, assessing both localized and multisite pain.

In summary, results from this study indicate that different types of sport participation can either be a potentially risky activity or a preventive activity in regard to musculoskeletal pain. Our findings contribute to the literature and expand our understanding of how PA and sport participation may be differently related to musculoskeletal pain depending on type of sport performed, as well as pain localization. *Type of sport participation* should therefore be considered by healthcare professionals when they evaluate musculoskeletal pain among active adolescents.

6.3.3 Physical activity and sport participation in relation to mental health (Paper II)

This study detected that higher levels of PA were associated with reduced odds of low self-esteem and low life satisfaction throughout adolescence. Further, a high PA level was associated with reduced odds of psychological distress in the oldest age group, consisting of senior high school students (≥16 years). Other population-based, cross-sectional studies with data from large, population-based adolescent samples have reported higher PA levels to be associated with lower levels of psychological distress and depressive symptoms (33, 85, 212, 375, 376), less anxiety, greater well-being (85), and higher self-esteem (377).

Several systematic reviews and meta-analyses have attempted to summarize the literature examining the relationship between PA and various mental health outcomes in adolescence, including both observational studies (cross-sectional and longitudinal design) and randomized controlled trials (208-211, 378-382). Based on these reviews there is a growing body of literature supporting the benefits of PA in children and adolescents, particularly in reducing psychological distress and depression/depressive symptoms (209-211, 378, 381, 382).

In a synthesis of review studies, Biddle & Asare (2011) concluded that PA among adolescents is associated with mental health benefits, most notably higher self-esteem (208). This review of reviews was updated in 2019 when the authors concluded that higher levels of PA were most strongly associated with better cognitive functioning. Further, they found partial evidence for a causal association between PA and depression, while associations between PA and reduction of anxiety and improvement in self-esteem were more uncertain (380).

Another review published in 2019 synthesized and updated the evidence from observational studies and analyzed effects of PA interventions among children and adolescents (381). It reported that both cross-sectional and longitudinal studies demonstrated significant associations between higher PA levels and lower levels of mental health problems, including depression, stress and psychological distress, and greater well-being, self-image, and satisfaction with life. Further, findings from the meta-analysis of intervention studies suggested that PA interventions can improve mental health among adolescents (381). A Cochrane review of studies evaluating exercise interventions among adolescents also showed a small effect of exercise on reduction in depression and anxiety scores (24). Another Cochrane review found exercise interventions to have positive short-term effects on self-esteem among adolescents (383). Other more recently published reviews of intervention studies have also revealed that PA may be relevant in the treatment of depressive symptoms in adolescents and young adults (20, 21). In summary, our findings that higher levels of PA are favorably associated with various dimensions of mental health is therefore supported both by other population-based cohort studies and intervention studies, and generally supports the evidence from recent reviews on the relationship between PA and mental health in adolescents.

Additionally, in terms of the potential impact of sport participation, our results support previous research findings showing that engagement in sports is associated with improved health outcomes (42, 85, 210, 219, 384). The comprehensive information about sport participation from the Young-HUNT3 study provided us with the opportunity to expand our understanding of how different types of sport participation can be related to various dimensions of mental health. In our study we found that team sport participation seems to be especially beneficial, consistent with previous evidence derived from adolescent cohorts (42, 85, 385). Another possible explanation is that adolescents who are struggling with mental health problems or poor self-esteem commonly drop out of team sports. As discussed in Paper II, the social aspect of being part of a team seems to be a key component that contributes to better mental health (42, 219). Whatever the underlying cause, being engaged in a team sport alongside their peers increases adolescents' social exposure and opportunities for positive peer relationships, and may create a support network that they wouldn't otherwise have. Importantly, if only a selection of adolescents with good mental health join in and continue to participate in these sports, this may contribute to maintain and increase social disparity among adolescents. Potential barriers, i.e. that team sports are more inaccessible to those struggling with metal health problems, may increase the differences between those adolescents who are part of a team, and thus get to experience social cohesion, play, and fun, and those not taking part in such health-promoting physical activities.

After the publication of Paper II, a few studies have further supported the mental health benefits of team sport participation, and contributed new knowledge to this research field. Oberle et al. (2019) examined participation in different types of extracurricular activities from childhood to early adolescence (grades 4 and 7 in Canada), and whether participation or non-participation over time was related to their mental health. New to this study was that peer belonging was considered as a mediator. They found that a shift towards participation in team sports was more strongly related to mental health benefits, including less anxiety and depressive symptoms, compared to non-participation or participation in individual sports or other individual extracurricular activities. Of particular interest was the finding that shifting from non-participation to engagement in team sports was associated with improved mental health, and that this relationship was found to be fully mediated by a stronger sense of peer belonging. The authors emphasizes the social context of extracurricular participation and highlight the need to encourage inactive children and adolescents to become involved in activities such as team sports (386). The important role of team sports in improvement of mental health has also been highlighted in a recent study examining long-term mental health outcomes among those with adverse childhood experiences (387). This study reported that for those with adverse childhood experiences, participation in team sports during adolescence was significantly associated with better mental health, including reduced odds of depression, in early adulthood (387). The results of these studies further support the importance of making team sports more accessible to all adolescents, and of creating an environment of social inclusion and positive peer relationships in all types of sports participation during adolescent years.

A unique contribution of our study (Paper II) is the stratified analysis that takes potential gender and age differences during adolescence into account. While a lower likelihood of low self-esteem and low life-satisfaction was apparent among those with a high PA level in both age groups, among both girls and boys, a significant association between a high PA level and reduced psychological distress was observed only in senior high school students. Further, team sport participation was associated with reduced psychological distress among senior high school girls only, implying that these types of sports may provide greater mental health benefits for girls in this age group. As pointed out in the article, we expected stronger associations among high school students and team sport participants as peer support and peer interaction become more salient during adolescence (57), and the transition from junior high to senior high school creates changes in social contexts and norms that may enhance the importance of peer relationships. During adolescence, at the same time as PA levels and sport participation begin to decline (31, 33, 80, 89), high school students may begin to experiment with alcohol, smoking, or other risk behaviors, which can increase the burden on their health. Maintaining structure and social meeting places through participation in team sports may therefore be particularly beneficial for adolescents in this age group.

The present study addresses a potential limitation in previous studies concerning inadequate adjustment for confounding factors. Exposure to interpersonal violence, including violence, sexual abuse, and bullying, may heavily impact both PA behaviors and mental health. Long-term planning, coping, and hope for the future may be hindered following exposure to violence, and this is found to be strongly associated with the onset of psychological distress (221). Adolescents exposed to interpersonal violence may also find it particularly difficult to maintain a healthy lifestyle, and may feel unmotivated to schedule and participate in PA after school (222, 223). To the best of our knowledge, this is the first population-based study to show that PA is associated with mental health benefits in adolescence after adjusting for exposure to interpersonal violence.

To clarify, we did not investigate the mechanisms of how PA or sport participation may affect depressive symptoms or self-esteem in Paper II. As mentioned in the Introduction, PA can have an impact on mental health outcomes through biological mechanisms, but may also influence mental health more indirectly through its impact on both psychological and social factors (388). Moreover, we did not have information about adolescents' motives for sport participation. Clearly, individuals will vary in the types of sports they like and wish to engage in. Thus, as the mental health benefits of sport participation may be a consequence of participation in something fun and enjoyable, one should not be too prescriptive when it comes to the type of sports one recommends adolescents to participate in to improve mental health (389).

Despite the abovementioned evidence on the mental health benefits of PA and sport participation, it is important to mention that a high volume of activities and sports may also compromise mental health. A very high degree of sports participation is found to be a risk factor for poor well-being (390) and is associated with overtraining and increased likelihood of depressive symptoms (391). It is nevertheless in young athletes who perform very intensive training that most of the harmful consequences of sports participation have been observed (392-394).

Overall, the lower sport participation rates among late-teens found in this study are of concern because of the potential benefits of sports on mental health reported in the current and previous studies, but also because sport participation increases overall PA and long-term maintenance of PA into adulthood (59, 60). Creating opportunities to participate in activities and sports, at different skill levels and just for fun, will probably lead to more adolescents experiencing sports participation as motivating and meaningful. Our findings therefore underline the critical importance facilitating access to and building motivation for sports participation among adolescents. Moreover, this study points to the importance of efforts to ensure and strengthen the social aspect of sports activities for adolescents to increase health benefits and to prevent dropout from sports during adolescence.

6.3.4 The impact of PA, musculoskeletal pain, and psychological distress in adolescence on obesity into young adulthood (Paper III)

In Paper III we found that lower levels of PA in adolescence increased the probability of obesity in young adulthood, with an additive adverse effect of adolescent musculoskeletal pain which indicated a strong tendency for increased probability of obesity for both genders.

As highlighted in the Introduction, the potential weight-related consequences of physical inactivity, musculoskeletal pain, and mental health problems in adolescence, and their co-occurrence, has, to our knowledge, not been studied in population-based cohorts. In line with our findings, others have found associations between physical inactivity in adolescence and obesity in young adulthood (247, 248), although systematic reviews have reported inconclusive results (246, 250, 251). Further, an adverse impact of pain on development of obesity has previously been suggested based on the evidence of a high prevalence of obesity in clinical samples of adolescents with chronic pain (252, 257). Psychological distress/depressive symptoms in adolescence have also been suggested as predictive factors for development of obesity into young adulthood (263, 265, 395). Our study did not support these findings as we found that the additional adverse impact of psychological distress on the probability of obesity into young adulthood was low. More specifically, psychological distress in adolescence did not contribute substantially to higher probability of obesity when accounting for PA and musculoskeletal pain. Our study findings did, however, indicate that psychological distress among girls, compared to boys, may be more strongly related to obesity in adulthood. This is in line with findings from a meta-analysis (265) and a systematic review (266).

In summary, as inactive adolescents seem to be more susceptible to obesity in young adulthood, our findings emphasizes adolescence as an important period for establishing good habits for engagement in PA, and provide support for strategies focusing on PA promotion for adolescents in order to reduce development of obesity. Further, our findings point to adolescent musculoskeletal pain as a contributing factor to increased probability of obesity in young adulthood, and provide evidence of a cumulative effect of low PA and musculoskeletal pain, potentially accelerating the development of obesity. The clinical implication of these findings is that treatment and prevention of musculoskeletal pain, along with PA promotion and interventions to increase PA and sport participation in adolescence, may be important factors in the prevention of obesity in young adulthood. Our results indicate that assessment of weight development may be particularly important in inactive adolescents with musculoskeletal pain, as obesity prevention efforts should be initiated at an early stage. The identification of these subgroups of adolescents with a higher probability of obesity into young adulthood may provide new perspectives in our understanding of the multidimensional nature of development of obesity, and emphasizes the importance of studying the accumulation of adverse health factors in adolescence.

7. Conclusions and implications

This thesis expands our knowledge of how PA and sports participation may be related to musculoskeletal pain and mental health in adolescence, and, further, how the co-occurrence of these factors can affect the probability of obesity into young adulthood. The following conclusions and implications can be drawn:

- **Paper I:** A moderate level of PA was associated with reduced odds of persistent weekly NSP and LBP, and a high level of PA was associated with increased odds of persistent weekly LEP. The association between sport participation and persistent weekly musculoskeletal pain depended on type of sport participation and localization of pain. Evaluation of musculoskeletal pain among active adolescents should account for type of sport participation, and modification of PA and athletic activity may be particularly important for those who report pain in the lower extremities.

  Paper II: PA level and sport participation rates were lowest among girls in senior high school. Higher levels of PA were favorably associated with various dimensions of mental health, especially for adolescents in senior high school. Team sport participation may be particularly beneficial to mental health. These findings emphasize the need for greater efforts to identify barriers to sports participation to prevent a decline in PA levels and dropout from sports during adolescent years.

- **Paper III:** Co-occurrence of physical inactivity and musculoskeletal pain in adolescence increased the probability of obesity in young adulthood. Efforts to increase PA participation whilst addressing, treating, and preventing musculoskeletal pain in adolescence may be key to prevention of obesity in adulthood.

Suggestions for future research

This thesis supports the evidence that a physically active lifestyle in adolescence will likely benefit both musculoskeletal and mental health, and elaborates on how participation in sports relates to these health outcomes in a general population of adolescents. To better quantify PA levels, objective measurements of PA would be preferable in future studies examining these relationships. However, findings from Papers I and II also emphasize the importance of further research into the role of different types of sport participation, particularly when evaluating localized musculoskeletal pain outcomes. Further research is needed to identify barriers to sport participation, especially for adolescents who are struggling with pain and mental health problems.

Although results from **Paper I** provide knowledge that can be helpful in the detection and prevention of musculoskeletal pain among adolescents who are active in sports, it is important to note that adolescents usually engage in a broad range of activities and sports. We still do not know how the sum of these activities can impact or balance the risk. For those sports found to be associated with increased odds of pain in this study, development and better adaption of sport-specific training methods will most likely be important initiatives. However, further research into how sport-specific loading of the musculoskeletal system may have an impact on localized pain will be needed to better identify appropriate preventive interventions. Continued research on this topic should involve the use of clear definitions of musculoskeletal pain, distinguishing between traumatic and non-traumatic pain or injuries, to allow for comparisons between studies. Longitudinal studies are particularly warranted in order to provide a stronger evidence-base for temporal relationships. From a public health perspective, more attention to the potential impact of PA and sports on multisite pain is also warranted, preferably accounting for a broad range of biopsychosocial factors.

An interesting finding in **Paper II**, which requires further research, was that the relationship between a high PA level and psychological distress was more striking in the older group (≥16 years). We found favorable associations between higher levels of PA and various dimensions of mental health, in agreement with a growing body of evidence. Nevertheless, more research is needed on the effects of interventions aimed at increasing PA and sport participation among adolescents and their impact on mental health problems. Longitudinal studies examining whether the positive health outcomes related to PA during adolescence carry on into adulthood would be of great value from a preventive health perspective, and should preferably involve frequent follow-ups.

Our study results from **Paper III** highlight the need for future longitudinal studies examining both the individual and the combined impact of multiple factors. Further work is needed to understand the long-term weight-related implications of these common adverse health problems and their co-occurrence, including more comprehensive assessment of the exposures and their combinations throughout different phases of adolescence.

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Appendix

Young-HUNT3 questionnaire

Physical activity and sport participation:

OM IDRETT OG MOSJON

51. Utenom skoletida: **Hvor mange dager i uka driver du idrett, eller mosjonerer du så mye at du blir andpusten og/eller svett?** *Sett bare ett kryss*

- Hver dag ☐
- 4-6 dager i uka ☐
- 2-3 dager i uka ☐
- 1 dag i uka ☐
- Sjeldnere enn en gang i uka ☐
- Sjeldnere enn en gang i måneden ☐
- Aldri ☐

52. Utenom skoletida: **Til sammen hvor mange timer i uka driver du idrett eller mosjonerer du så mye at du blir andpusten og/eller svett?** *Sett bare ett kryss*

- Ingen ☐
- Omtrent ½ time ☐
- Omtrent 1-1½ time ☐
- Omtrent 2-3 timer ☐
- Omtrent 4-6 timer ☐
- 7 timer eller mer ☐

53. Tenk på de siste 7 dagene: Hvor lang tid brukte du på å sitte en vanlig hverdag?
Dette kan være tiden du sitter ved PC, gjør lekser, er hos venner, mens du sitter eller ligger og leser eller ser på TV. Regn med tiden du bruker både på skolen og i fritida.

☐ antall timer

54. Trener du på helsestudio? Ja ☐ Nei ☐

55. Hvor ofte har du drevet med følgende treningsaktiviteter de siste 12 månedene?
Sett ett kryss for hver linje

	Aldri	Under en gang i uka	En gang i uka	Flere ganger i uka
Utholdenhetsidrett (f.eks. løp, langrenn, sykling, svømming)	☐	☐	☐	☐
Lag/ballidretter (f.eks. fotball, vollyball, håndball, ishocky, squash)	☐	☐	☐	☐
Estetisk idrett (f.eks. dans, turn, aerobics)	☐	☐	☐	☐
Styrkeidrett (f.eks. vektløfting, bryting, bodybuilding)	☐	☐	☐	☐
Kampsport (f.eks. judo, karate, taekwondo, boksing)	☐	☐	☐	☐
Tekniske idretter (f.eks. ridning, friidrett, alpint, hopp, snowboard, rullebrett)	☐	☐	☐	☐
Risikosport (f.eks. elvepadling, fjellklatring, paragliding)	☐	☐	☐	☐
Lett jogging eller gange/turgåing	☐	☐	☐	☐
Annet	☐	☐	☐	☐

56. Hvis du ikke har drevet med noen av disse idrettene de siste 12 månedene, men gjorde det tidligere, hvor gammel var du da du sluttet?

☐ år gammel

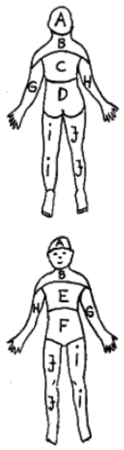
57. Deltar du i idrettskonkurranser, kamper? *Sett ett kryss*

Ja ☐ Nei, men jeg deltok før ☐ Nei ☐

The section on pain:

OM SMERTER

31. Hvor ofte har du hatt noen av disse plagene i løpet av de siste 3 månedene?
(Uten at du har skadet deg eller har en kjent sykdom som er årsak til smertene)
Se på figurene og sett ett kryss for hver linje



	Aldri/ sjelden	Omtrent en gang i måneden	Omtrent en gang i uka	Flere ganger i uka	Nesten hver dag
A. Hodepine/migrene	☐	☐	☐	☐	☐
B. Nakke-/skuldersmerter	☐	☐	☐	☐	☐
C. Smerter i øvre del av ryggen	☐	☐	☐	☐	☐
D. Smerter i nedre del av ryggen/setet	☐	☐	☐	☐	☐
E. Smerter i brystkassen	☐	☐	☐	☐	☐
F. Magesmerter	☐	☐	☐	☐	☐
G. Smerter i venstre arm	☐	☐	☐	☐	☐
H. Smerter i høyre arm	☐	☐	☐	☐	☐
I. Smerter i venstre bein	☐	☐	☐	☐	☐
J. Smerter i høyre bein	☐	☐	☐	☐	☐
Andre smerter	☐	☐	☐	☐	☐

HVIS DU HAR SVART **«ALDRI/SJELDEN»** PÅ ALT: GÅ TIL SPØRSMÅL **34**

Hvis du har hatt smerter i løpet av de siste 3 månedene:

32. Stemmer noe av det som står nedenfor på deg? *Sett ett kryss for hver linje*

	Stemmer	Stemmer ikke
• Smerter gjør det vanskelig for meg å sove	☐	☐
• Smerter forstyrrer den gode nattesøvnen min	☐	☐
• Smerter gjør det vanskelig å sitte i skoletimen	☐	☐
• Smerter gjør det vanskelig for meg å gå mer enn en kilometer	☐	☐
• På grunn av smerter har jeg problemer i gymtimen	☐	☐

33. Har smertene alt i alt hindret deg i å utføre daglige aktiviteter? *Sett ett kryss for hver linje*

	Nei	Ja, av og til	Ja, ofte
• På skolen	☐	☐	☐
• I fritida	☐	☐	☐

Hvis ja, **hva slags smerter hindret deg i å utføre daglige aktiviteter?** *Sett ett eller flere kryss*

Hodepine/migrene ☐ Magesmerter ☐ Muskel-/leddsmerter ☐ Andre smerter ☐

Parts of the section on mental health:

Self-esteem (RSES)

73. **Når du tenker på hvordan du har det for tida, er du stort sett fornøyd eller er du stort sett misfornøyd?** *Sett ett kryss*

- Svært fornøyd .... ☐
- Meget fornøyd .... ☐
- Ganske fornøyd .... ☐
- Både og .... ☐
- Nokså misfornøyd .... ☐
- Meget misfornøyd .... ☐
- Svært misfornøyd .... ☐

Psychological distress (SCL-5)

76. **Nedenfor er en liste over noen problemer eller plager. Har du vært plaget av noe av dette <u>de siste 14 dagene</u>?** *Sett ett kryss for hver linje*

	Ikke plaget	Litt plaget	Ganske plaget	Veldig plaget
• Vært stadig redd og engstelig	☐	☐	☐	☐
• Følt deg anspent eller urolig	☐	☐	☐	☐
• Følt håpløshet når du tenker på framtida	☐	☐	☐	☐
• Følt deg nedfor eller trist	☐	☐	☐	☐
• Bekymret deg for mye om forskjellige ting	☐	☐	☐	☐

Life satisfaction

77. **Hva slags oppfatning har du av deg selv?** Kryss av for hver av setningene under ettersom du er enig eller uenig i at de passer for deg. *Sett ett kryss for hver linje*

	Svært enig	Enig	Uenig	Svært uenig
• Jeg har en positiv holdning til meg selv	☐	☐	☐	☐
• Jeg føler meg virkelig ubrukelig til tider	☐	☐	☐	☐
• Jeg føler at jeg ikke har mye å være stolt av	☐	☐	☐	☐
• Jeg føler at jeg er en verdifull person, i hvert fall på lik linje med andre	☐	☐	☐	☐

Young-HUNT1 questionnaire

Physical activity

OM IDRETT OG MOSJON

50. Utenom skoletida: **Hvor mange dager i uka driver du idrett, eller mosjonerer du så mye at du blir andpusten og/eller svett?**
(Sett bare ett kryss)

- *Hver dag* .... ☐
- *4-6 dager i uka* .. ☐
- *2-3 dager i uka* ... ☐
- *1 dag uka* .... ☐
- *Ikke hver uke, men minst en dag hver 14.dag* . ☐
- *Ikke hver 14.dag, men minst en dag i måneden* ☐
- *Sjeldnere enn en dag i måneden* .... ☐
- *Aldri* .... ☐

51. Utenom skoletida: **Til sammen hvor mange timer i uka driver du idrett eller mosjonerer du så mye at du blir andpusten og/eller svett?**
(Sett bare ett kryss)

- *Ingen* .... ☐
- *Omtrent ½ time* .. ☐
- *Omtrent 1 time* ... ☐
- *Omtrent 2-3 timer* .... ☐
- *Omtrent 4-6 timer* .... ☐
- *7 timer eller mer* .... ☐

Psychological distress (SCL-5)

65. **Nedenfor er en liste over noen problemer eller plager. Har du vært plaget av noe av dette de siste 14 dagene ?** (Sett ett kryss for hver linje)

	Ikke plaget	Litt plaget	Ganske plaget	Veldig plaget
Vært stadig redd og engstelig	☐	☐	☐	☐
Følt deg anspent eller urolig	☐	☐	☐	☐
Følt håpløshet når du tenker på framtida	☐	☐	☐	☐
Følt deg nedfor eller trist	☐	☐	☐	☐
Bekymret deg for mye om forskjellige ting	☐	☐	☐	☐

Pain (including musculoskeletal pain)

12. **Har du hatt noen av disse plagene i løpet av de siste 12 månedene ?**
(Sett ett kryss på hver linje)

	Aldri	Sjelden	Av og til	Ofte
A *Hodepine (uten kjent medisinsk årsak)*	☐	☐	☐	☐
B *Nakke og skuldersmerter*	☐	☐	☐	☐
C *Ledd og muskelsmerter*	☐	☐	☐	☐
D *Magesmerter (uten kjent medisinsk årsak)*	☐	☐	☐	☐
E *Kvalme*	☐	☐	☐	☐
F *Treg mage*	☐	☐	☐	☐
G *Diare, magesyke*	☐	☐	☐	☐
H *Hjertebank*	☐	☐	☐	☐
I *Bronkitt eller lungebetennelse*	☐	☐	☐	☐
J *Ørebetennelse*	☐	☐	☐	☐
K *Bihulebetennelse*	☐	☐	☐	☐

I

Original Research

Physical Activity Level and Sport Participation in Relation to Musculoskeletal Pain in a Population-Based Study of Adolescents

The Young-HUNT Study

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Background: Prevalence of musculoskeletal pain among adolescents is high, and pain in adolescence increases the risk of chronic pain in adulthood. Studies have shown conflicting evidence regarding associations between physical activity and musculoskeletal pain, and few have evaluated the potential impact of sport participation on musculoskeletal pain in adolescent population samples.

Purpose: To examine the associations between physical activity level, sport participation, and musculoskeletal pain in the neck and shoulders, low back, and lower extremities in a population-based sample of adolescents.

Study Design: Cross-sectional study; Level of evidence 4.

Methods: Data from the Nord-Trøndelag Health Study (Young-HUNT3) were used. All 10,464 adolescents in the Nord-Trøndelag county of Norway were invited, of whom 74% participated. Participants were asked how often they had experienced pain, unrelated to any known disease or acute injury, in the neck and shoulders, low back, and lower extremities in the past 3 months. The associations between (1) physical activity level (low [reference], medium or high) or (2) sport participation (weekly compared with no/infrequent participation) and pain were evaluated using logistic regression analyses, stratified by sex, and adjusted for age, socioeconomic status, and psychological distress.

Results: The analyses included 7596 adolescents (mean age, 15.8 years; SD, 1.7). Neck and shoulder pain was most prevalent (17%). A moderate level of physical activity was associated with reduced odds of neck and shoulder pain (OR = 0.79 [95% CI, 0.66-0.94]) and low back pain (OR = 0.75 [95% CI, 0.62-0.91]), whereas a high level of activity increased the odds of lower extremity pain (OR = 1.60 [95% CI, 1.29-1.99]). Participation in endurance sports was associated with lower odds of neck and shoulder pain (OR = 0.79 [95% CI, 0.68-0.92]) and low back pain (OR = 0.77 [95% CI, 0.65-0.92]), especially among girls. Participation in technical sports was associated with increased odds of low back pain, whereas team sports were associated with increased odds of lower extremity pain. Strength and extreme sports were related to pain in all regions.

Conclusion: We found that a moderate physical activity level was associated with less neck and shoulder pain and low back pain, and that participation in endurance sports may be particularly beneficial. Our findings highlight the need for health care professionals to consider the types of sports adolescents participate in when evaluating their musculoskeletal pain.

Keywords: musculoskeletal pain; physical activity; sport participation; adolescents; overuse problems; epidemiology

There is growing awareness of the challenges created by the increasingly high prevalence of musculoskeletal pain among adolescents.[7,15,21] Musculoskeletal pain may result in reduced quality of life, absence from school, and increased use of pharmaceuticals and health care.[11,32] In most studies, girls report higher prevalence of pain symptoms.[2,3,30,33] Adolescents with musculoskeletal pain tend to have a higher risk of chronic pain in adulthood,[18,41]

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emphasizing the importance of forming a better understanding of potential determinants of pain.

It is well documented that engagement in sports increases the risk of acute injuries. High levels of physical activity (PA) and sports participation have also been suggested as risk factors for nontraumatic musculoskeletal pain; however, the evidence is inconsistent.[42] Some studies have found an increased risk of musculoskeletal pain in adolescents with high levels of PA.[2,24,33,36] Others have reported that PA is associated with reduced risk of musculoskeletal pain,[30,44,47] and some report no association between PA and back pain[1,5,29,48] or other musculoskeletal pain.[9] It is difficult to compare results from various studies as definitions of pain and distinctions between traumatic and nontraumatic musculoskeletal pain vary. Furthermore, few have differentiated according to localization of musculoskeletal pain. Previous studies have primarily been conducted in selected samples, and evaluation of PA has been limited; most studies capture the frequency of PA but lack information about type of sport participation.

As different sports are likely to have diverse effects on the etiology and pathogenesis of musculoskeletal pain due to variations in physical strain and loading, it is important to evaluate these relationships. Knowledge about the potentially positive or negative impact of different types of sports on musculoskeletal pain, and how this may vary between different pain locations, will help guide and develop future preventive strategies.

To our knowledge, only 1 former population-based study has evaluated the potential impact of sports on musculoskeletal pain in an adolescent population sample. They found that participation in gym training, downhill skiing, snowboarding, and gymnastics was related to neck, shoulder, and low back pain.[3] More research is available on overuse injuries potentially causing long-term pain in adolescent athlete populations, with the highest prevalence reported in sports requiring repetitive movements of the lower extremities such as track and field and soccer.[38,40] In addition to pain conditions in the lower extremities, the low back and shoulders are the most commonly reported pain locations in adolescents participating in sports.[8,26]

As the relationship between PA and musculoskeletal pain in each of these 3 common pain locations has not previously been explicitly studied, we wanted to explore these relationships while taking into account the specific types of sports adolescents reported performing.

The aim of this study was to examine the association between level of leisure time PA or sport participation and musculoskeletal pain, unrelated to any known disease or acute injury, in the neck and shoulder (NSP), low back (LBP), and lower extremities (LEP) among adolescents in a population-based sample.

METHODS

Study Sample

All adolescents (N = 10,464) aged 13 to 19 years in the Nord-Trøndelag county of Norway were invited to participate in the third population-based Nord-Trøndelag Health Study (Young-HUNT3), conducted from 2006 to 2008. Attendees completed a comprehensive health-related questionnaire during school hours. The questionnaire included an invitation to a subsequent clinical examination. Adolescents who were absent from school were invited to participate via post. A total of 7716 (74%) adolescents responded to the questionnaire and attended the clinical examination. Of these, 120 participants were excluded due to age $\geq$20 years or because they did not respond to the pain questions of interest (Appendix Figure A1).

Exposure Variables

The level of leisure time PA was assessed by asking: "Not during the average school day; how many days a week do you play sports or exercise to the point where you breathe heavily and/or sweat?" The 7 response alternatives were the following: every day, 4 to 6 d/wk, 2 to 3 d/wk, 1 d/wk, less than every week, less than every month, and never. The responses were divided into 3 categories of PA, regardless of type of sport: "Low activity" represented 1 day a week or less, "moderate activity" represented 2 to 3 days a week, and "high activity" represented 4 days a week or more. The question was adopted from the World Health Organization Health Behaviour in Schoolchildren (HBSC) questionnaire and has been found to hold acceptable reliability and validity.[35]

Sport participation was assessed by asking: "How often have you participated in the following activities/sports in the past 12 months?": endurance sports, team sports, strength sports, technical sports, esthetic sports, martial arts, extreme sports, jogging or walking/hiking, and other (Table 1). The response options were not mutually exclusive. Frequency of each sport/activity was measured according to the answer options: never, <1, 1, or several times per week. A dichotomous variable was created for each of the sport categories, where a frequency of "$\geq$1 time per week" was defined as active participation in the respective sport. Participants who responded "never" or "<1 time per week" in each of the sport categories were used as reference groups. As a vast majority of individuals in our sample engaged in jogging and hiking, these common activities were not regarded as individual sport exposures.

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Ethical approval for this study was obtained from Regional Committee for Medical Research Ethics (2014/1228/REK Sør-Øst A).

TABLE 1
Characteristics of the Study Sample (N = 7596)

Variables	Girls (n = 3831)	Boys (n = 3765)
Age, y, mean (SD)	15.8 (1.7)	15.8 (1.7)
Physical activity, n (%)		
High physical activity	1379 (36.0)	1717 (45.6)
Moderate physical activity	1441 (37.6)	1179 (31.3)
Low physical activity	962 (25.1)	834 (22.2)
Missing	48 (1.3)	35 (0.9)
Sport participation,[a] n (%)		
Endurance sports[b]	1756 (45.8)	1924 (51.1)
Team sports[c]	2251 (58.8)	2354 (62.5)
Strength sports[d]	928 (24.2)	1482 (39.4)
Technical sports[e]	905 (23.6)	924 (24.5)
Esthetic sports[f]	1009 (26.3)	218 (5.8)
Martial arts[g]	149 (3.9)	286 (7.6)
Extreme sports[h]	35 (0.9)	174 (4.6)
Psychological distress,[i] mean (SD)	1.6 (0.6)	1.3 (0.4)
Missing, n (%)	77 (2.0)	142 (4.0)
Family economy, n (%)		
Above average	565 (14.7)	722 (19.2)
Average	2721 (71.0)	2471 (65.6)
Below average	355 (9.3)	276 (7.3)
Missing	190 (5.0)	296 (7.9)
Body mass index, kg/m^2, mean (SD)	22.2 (3.7)	22.1 (3.9)

[a]Participation in each of the sport categories ≥1 d/wk.
[b]For example, cross-country skiing, swimming, running.
[c]For example, soccer, volleyball, handball.
[d]For example, weightlifting, bodybuilding.
[e]For example, track and field, Alpine skiing, snowboarding.
[f]For example, dance, gymnastics.
[g]For example, judo, karate, boxing.
[h]For example, rafting, rock climbing, paragliding.
[i]Range of possible scores is 1 to 4.

Outcome Variables

The outcomes of interest in the present study were NSP, LBP, and LEP. Musculoskeletal pain was assessed using respondents' reports of how often they had experienced pain unrelated to any known disease or acute injury during the past 3 months. Pain in the neck and shoulders, low back, and lower extremities were listed among several possibilities. The frequency of pain in each location was specified using 5 alternatives ranging from "never or seldom" to "almost every day." Reported pain frequency of "≥1 day per week" was used as a cutoff point to distinguish between the adolescents who experienced pain frequently and those who experienced pain rarely. The reference group in the analyses was adolescents who reported experiencing musculoskeletal pain "never or seldom" or "less than once a month." Good test-retest reliability (kappa [κ] = 0.9) evaluated by repeating the questions about occurrence of musculoskeletal pain (≥1 day per week) at a 1-week interval, as well as good concurrent validity investigated by comparisons with interviews (κ = 0.7), have previously been demonstrated for the pain questionnaire.[28]

Background Variables and Confounders

Data on sex and age were obtained from the Norwegian National Population Registry. Socioeconomic status was based on perceived family economy (above average, average, or below average). Psychological distress, including symptoms of anxiety and depression, was measured using a validated 5-item short version of the Hopkins Symptom Check List (SCL-5).[43] Responses to various mental health complaints fear or anxiety; tension, distress, or restlessness; hopelessness about the future; sadness; and excessive worry during the past 2 weeks) were scored according to 4 alternatives ranging from "not at all bothered" (1) to "extremely bothered" (4), and a mean score was calculated (1.6 for girls and 1.3 for boys). Body mass index (BMI) was used as a continuous variable.

Ethics

The HUNT studies are approved by the Data Inspectorate of Norway and by the Regional Committee for Medical Research Ethics, and all information from HUNT is treated according to the guidelines of the Data Inspectorate. Participation is based on informed consent from participants aged 16 years or older. In accordance with Norwegian law, parents of those younger than 16 years consented on behalf of their child.

Statistical Analysis

Continuous variables were described with means and standard deviations (SDs) and categorical variables using counts and percentages. Differences in distribution of the baseline characteristics of girls and boys were calculated using the chi-square test for categorical variables and the Student *t* test for continuous variables.

Logistic regression analyses were used to estimate the association between (1) level of PA (low [reference], medium, or high) or (2) weekly sport participation compared with no or infrequent participation and NSP, LBP, and LEP. Analyses were stratified by sex. The results were reported as crude and adjusted odds ratios (ORs) with 95% confidence intervals (CIs). Potential confounders were selected based on a priori knowledge and previous studies. Adjustments were made for age, BMI, socioeconomic status, and psychological distress. However, BMI did not alter the magnitude or direction of the associations between PA or sport participation and pain and was therefore removed from the final model. The exposure variables (1) level of PA and (2) type of sport participation were analyzed in separate models. The 7 categories of sport participation were all adjusted for each other. Sports performed by fewer than 30 participants in each of the 3 pain categories were excluded in the presentation of the results (extreme sports for girls and esthetic sports for boys). Some individuals reported pain in more than 1 location, thus introducing statistical dependencies into our data. Therefore, we performed additional sensitivity analyses for participants reporting pain in only 1 of the pain locations (NSP, LBP, or LEP). *P* values <.05 were considered statistically significant. All tests were

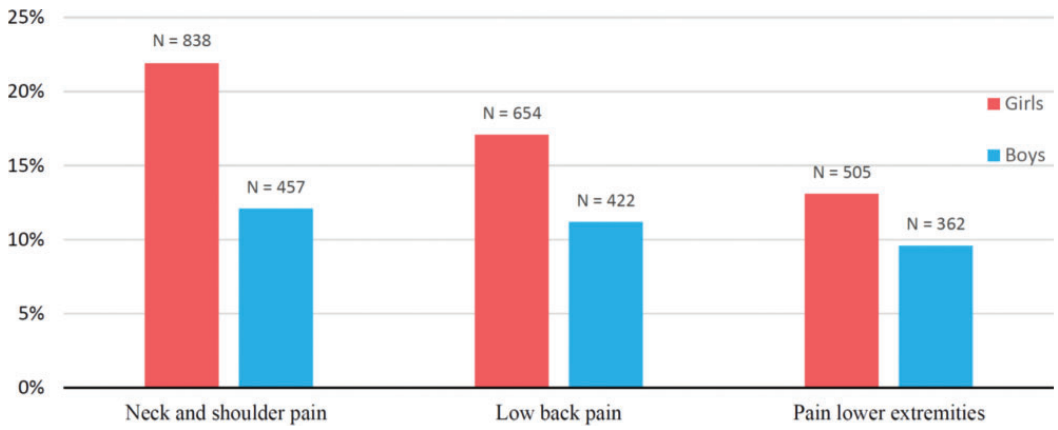

Figure 1. Reported frequency of persistent weekly pain in the neck and shoulders (NSP), low back (LBP), and lower extremities (LEP), stratified by sex (n = 7596).

2-sided. All analyses were performed using SPSS version 21 (IBM Corp).

RESULTS

The analyses included 3831 girls and 3765 boys, with a mean age of 15.8 years (SD, 1.7).

In total, 84% reported participating in some sort of sport at least once a week. Boys reported a higher participation rate in all sports except for esthetic sports. High or moderate levels of PA were reported by 75% of participants, with more boys than girls reporting a high level of PA ($P < .001$) (Table 1). More girls than boys reported pain in each of the body locations ($P < .001$), and NSP was the most frequent pain location reported for both sexes (Figure 1). The majority of both boys and girls (62%) reported pain in only 1 of the 3 body locations. However, 17% of girls and 12% of boys reported both NSP and LBP.

Associations Between PA Level and Pain Outcomes

Compared with a low PA level in crude and adjusted analyses, a moderate PA level was significantly associated with decreased odds of NSP among both girls and boys (OR = 0.79 [95% CI, 0.63-0.99] and OR = 0.74 [95% CI, 0.55-1.00], respectively), and decreased odds of LBP (OR = 0.77 [95% CI, 0.60-0.98] and OR = 0.70 [95% CI, 0.51-0.95], respectively). A high PA level was associated with slightly decreased odds of NSP and LBP, although results were not significant. In contrast, a high PA level was significantly associated with increased odds of LEP among both girls (OR = 1.39 [95% CI, 1.05-1.85]) and boys (OR = 2.06 [95% CI, 1.44-2.95]) (Appendix Table A1). The sensitivity analyses of those reporting only 1 pain outcome revealed similar results.

Associations Between Sport Participation and Pain Outcomes

Neck and Shoulder Pain. Weekly participation in endurance sports, compared with infrequent or no participation, was associated with reduced odds of NSP for both sexes. Among boys, team sports were related to reduced odds of NSP, whereas strength sports (OR = 1.32 [95% CI, 1.03-1.71]) and extreme sports were associated with increased odds of NSP (OR = 2.31 [95% CI, 1.40-3.82]) (Figure 2).

Low Back Pain. Among girls, weekly participation in endurance sports, as compared with infrequent or no sport participation, was related to decreased odds of LBP (OR = 0.70 [95% CI, 0.56-0.88]). Technical sports were the only type of sport associated with LBP (OR = 1.43 [95% CI, 1.11-1.83] in girls and OR = 1.33 [95% CI, 1.00-1.76] in boys) (Figure 3). In unadjusted analyses, however, performing strength sports, martial arts, and extreme sports also significantly increased the odds of LBP among boys (OR = 1.36 [95% CI, 1.08-1.72], OR = 1.54 [95% CI, 1.06-2.24], and OR = 1.78 [95% CI, 1.11-2.85], respectively).

Lower Extremity Pain. None of the sports were significantly associated with reduced odds of LEP. Participation in strength sports and technical sports, versus no or infrequent participation, was associated with increased odds of LEP among girls. Among boys, participating in team sports was associated with LEP (OR = 1.69 [95% CI, 1.24-2.30]), while those participating in extreme sports were more than twice as likely to experience LEP compared with nonparticipants (Figure 4).

Sensitivity analyses of those reporting only NSP, LBP, or LEP confirmed the results presented above. However, the analysis of participants with “only LEP” did reveal stronger and significantly increased odds of LEP in both girls (OR = 1.41 [95% CI 1.02-1.94]) and boys (OR = 1.91 [95% CI, 1.25-2.91]) who participated in team sports.

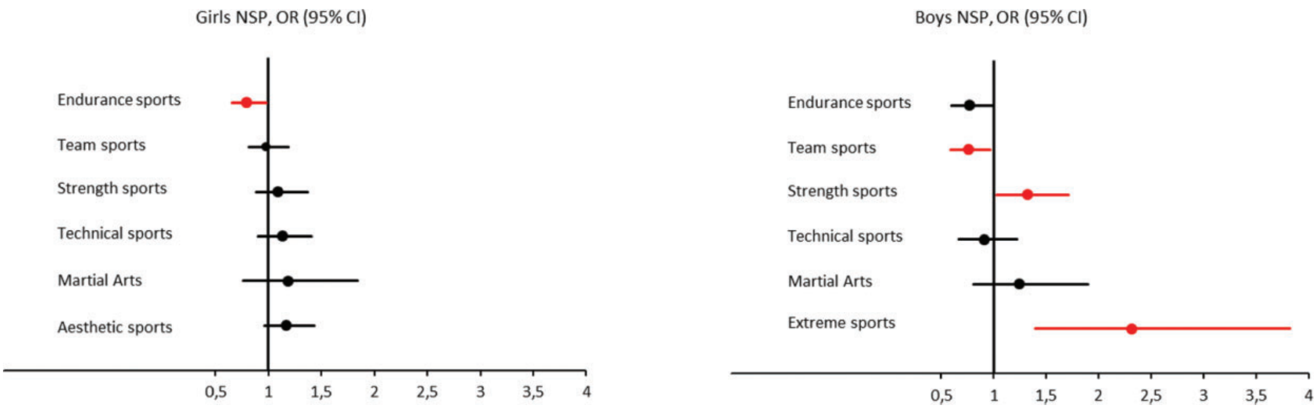

Figure 2. The odds ratio (OR) with 95% CI of persistent weekly neck and shoulder pain (NSP) related to sport participation in girls and boys. Analyses adjusted for age, socioeconomic status, psychological distress, and participation in other sports. Reference groups were participants who responded "never" or "≤1 time per week" in each of the sport categories.

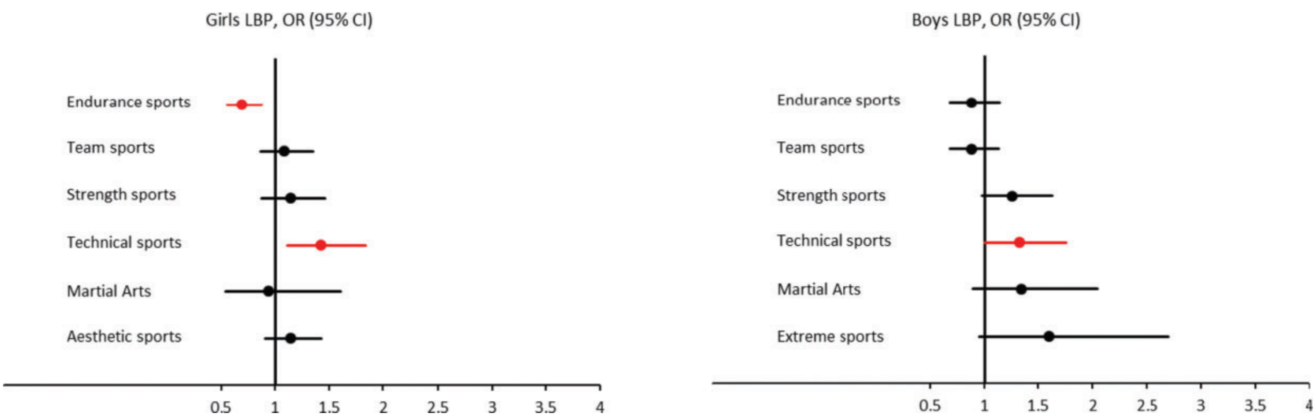

Figure 3. The odds ratio (OR) with 95% CI of persistent weekly low back pain (LBP) related to sport participation in girls and boys. Analyses adjusted for age, socioeconomic status, psychological distress, and participation in other sports. Reference groups were participants who responded "never" or "≤1 time per week" in each of the sport categories.

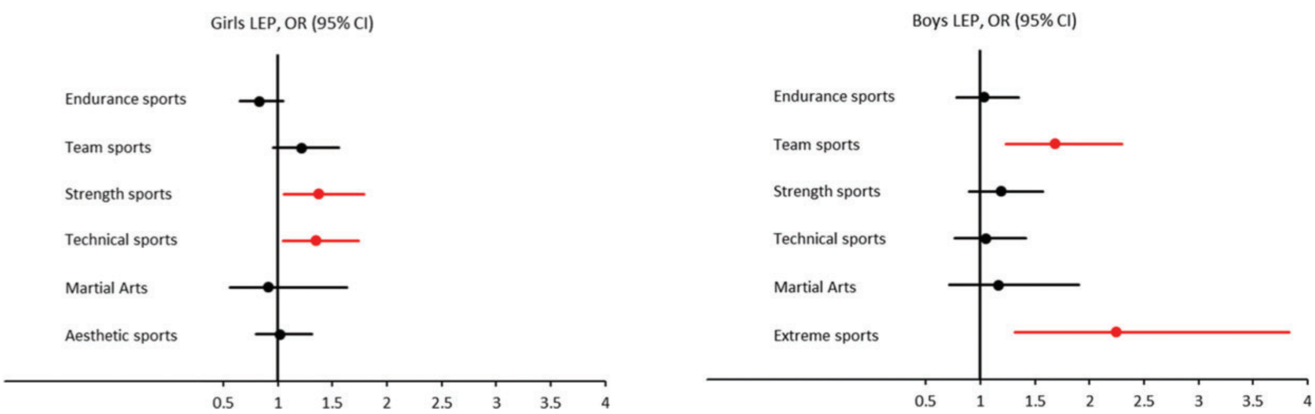

Figure 4. The odds ratio (OR) with 95% CI of persistent weekly lower extremity pain (LEP) related to sport participation in girls and boys. Analyses adjusted for age, socioeconomic status, psychological distress, and participation in other sports. Reference groups were participants who responded "never" or "≤1 time per week" in each of the sport categories.

DISCUSSION

In this population-based study of adolescents, we found that a moderate PA level was associated with reduced odds of NSP and LBP, whereas a high level of PA was associated with increased odds of LEP. Endurance sports were found to be associated with reduced odds of NSP and LBP, especially among girls. Team sport participation was associated with increased odds of LEP, whereas technical sports were related to greater odds of LBP for both sexes.

In line with previous results from adolescent population-derived cohorts,[2,30] a moderate level of PA was associated with reduced odds of NSP and LBP for both sexes. However, in a population-based sample of Danish adolescents, self-reported PA was not associated with LBP.[5]

In the current study, a high level of PA was associated with LEP but not NSP or LBP. Most sports-related overuse injuries occur in the lower extremities[10,38] and are typically due to repetitive submaximal loading of the musculoskeletal system without adequate rest to allow for structural adaptation to take place.[6,10] In a large study of adolescent athletes, overuse injuries in the lower extremities accounted for 62.6% of all overuse injuries.[40] It is well documented that young athletes often continue with training and competition without reductions in training volume, despite the existence of overuse problems.[8] Thus, one should be aware that the threshold to reduce the frequency of PA might be high for active adolescents who are experiencing musculoskeletal pain due to overuse. Based on the current results, and due to the higher risk of overuse-related problems in the lower extremities, it may be particularly important for coaches and health care professionals to provide information regarding PA modifications to adolescents who report pain in the lower extremities.

Regarding the potential contribution of various types of sports, we found that participation in endurance sports was associated with reduced odds of NSP. The only former population-based study within the field[3] found that cross-country skiing, a typical endurance sport in Norway, was associated with lower prevalence of both NSP and LBP. They argued that this beneficial effect was due to the versatile nature of the sport. Furthermore, participating in sports loading the upper extremities has been associated with low prevalence of NSP, as reported in both cross-sectional[31] and longitudinal[41] studies.

Endurance sports were also significantly associated with reduced prevalence of LBP among girls in the current study. Auvinen et al[3] found that cross-country skiing specifically could protect against LBP. Furthermore, Clarsen et al[8] reported a low rate of low back problems among adolescent cross-country skiers compared with athletes in other sports. As back pain has been associated with low isometric muscle endurance in the back extensors among adolescents,[5] this could be part of the explanation for the possible beneficial effect of endurance sports. Even at a high level, endurance sports do not seem to be harmful to the back. Among former elite endurance athletes (cross-country skiing, rowing, and orienteering), LBP was no more common than among nonathletes, and orienteering was found to be protective.[14]

Auvinen et al[3] reported that strength training was associated with increased LBP in adolescents. The same association was found among boys in the current study, although results were not significant in the adjusted analysis. Several studies have reported that LBP is the most frequent complaint in adolescent athletes who participate in strength training,[12] and the use of weight training machines in particular has been found to increase the risk of LBP.[39] Furthermore, hyperextension or rotational motions causing repetitive stress to the spine are reported to be risk factors for back pain among adolescents participating in various technical sports.[17] In line with this, performing technical sports was associated with increased odds of LBP for both sexes in the current study.

In the current study, participation in team sports was associated with increased odds of LEP. A study among Norwegian adolescent athletes found that 20% of handball players and 36% of volleyball players reported overuse knee problems.[8] In particular, patellofemoral pain is one of the most common complaints observed in adolescent athletes.[16] Patellar tendinopathy and Osgood-Schlatter syndrome are examples of overuse injuries shown to be of major concern for athletes in team sports that require a high volume of jumping and speed training and are especially frequent among volleyball players.[46]

Overuse injuries of the lower extremities are also commonly reported in sports requiring repetitive movements of the lower extremities such as track and field, with girls having higher injury rates than boys.[34,38] These results are consistent with the increased odds of LEP among girls who reported performing technical sports in this study. Reasons for higher susceptibility to overuse injuries and pain conditions in girls performing technical sports may include differences between sexes in anatomy, joint laxity, muscle strength, and neuromuscular and biomechanical factors, which affect physiological responses to excessive training loads and microtrauma.[38]

Concerning the interpretation of these results, it is important to emphasize that adolescents often participate in more than 1 type of sport. However, as the aim was to explore selective sport activities as potential contributing factors of musculoskeletal pain, we adjusted for participation in all other sports in order to minimize limitations related to overlapping sport exposures (and introduction of statistical dependency). Additionally, some participants reported pain in more than 1 body location, which should be considered when interpreting the results. However, sensitivity analyses of those reporting only NSP, LBP, or LEP confirmed the results from the main analyses. Identification of potential confounders and mediators was based on prior knowledge and assumed causal associations from results in previous studies. Anxiety and depression are strongly related to musculoskeletal pain,[19,23,33] and these health complaints may also increase the risk of inactivity due to low motivation for sport participation and social activities.[22] Unlike previous studies,[3,29] adjustment for symptoms of anxiety and depression was therefore conducted to reduce the overall bias in estimation of the relationship between PA/sports and musculoskeletal pain.

The knowledge gained through this study's identification of PA levels and sports associated with pain within the various body locations creates the potential for prevention or earlier detection of musculoskeletal pain among adolescents. Based on our findings, it would seem that it is important for health care professionals who encounter active adolescents with pain to consider not only the general PA level (days of PA per week) but to identify types of sport participation as well. Sports found to be associated with a decreased likelihood of musculoskeletal pain could probably be recommended as part of primary preventive strategies. Furthermore, our results can provide coaches and health professionals with a better basis for understanding the potential risks associated with different sports, thus increasing their awareness and opportunities to guide and adapt athletic activity to prevent development of long-term pain conditions. Launay[25] emphasizes that young athletes must learn to listen to their bodies in order to be able to adapt, change, or stop painful exercise before overuse injuries become chronic. To assist active adolescents, one should be aware of the early signs of overuse and be prepared to raise questions about sport participation and the frequency and type of exercise.[25] However, to develop and implement guidelines for coaches, health professionals, and athletes, more longitudinal studies providing evidence about the causal relationships between different types of sport participation and various locations of musculoskeletal pain outcomes will be needed.

Nevertheless, one also needs to recognize that in most cases, long-lasting pain among adolescents is the result of multifactorial conditions, and several studies have demonstrated a strong association between mental health problems and NSP and LBP.[30,37] This is also a factor in LEP; for example, patellofemoral pain is one of the frequent complaints for which clinicians are strongly recommended to address potential psychosocial factors interacting with the patient's presentation of pain.[4] Clinical assessment of adolescents with pain complaints should therefore include both physical and psychological symptoms.[37] It is also important to balance the adverse health outcomes inherent in any type of sport with the risks associated with a more sedentary lifestyle. Sedentary behavior is found to be strongly associated with adverse health outcomes, including obesity, cardiovascular and metabolic diseases, psychological problems, antisocial behavior, and decreased academic achievement.[45] Hence, from a public health perspective, the numerous benefits of regular PA to physical, mental, and social health may outweigh the negative aspects of pain related to some types of sports in this study.

Taken together, our results suggest that strategies for prevention of musculoskeletal pain should include consideration of types of sport participation in addition to the overall level of PA, as well as the location of pain and sex differences. However, further studies on the impact of type and frequency of sport participation on musculoskeletal pain, as well as age and sex differences, will be necessary to develop targeted and effective prevention strategies for adolescents.

Study Strengths and Limitations

Strengths of this study are the large sample size and the information regarding pain location and frequency of pain, as well as the information about sport participation. Since previous findings on the relationship between PA and musculoskeletal pain have been inconsistent, the ability to investigate the association between various levels of PA and a range of sports activities and the 3 most common pain locations is the major strength of the study.

The cross-sectional design is the main limitation of this study as it prevented us from making valid causal inferences from these observational data. The outcome of pain was defined as musculoskeletal pain unrelated to any known disease or acute injury, restricted to pain reported at a frequency of $\geq$1 day per week during the past 3 months. A limitation, however, is the lack of specific information about pain severity. Nevertheless, a high number of pain-associated disabilities, including sleep problems and limitations in activities of daily living, have previously been found among adolescents reporting musculoskeletal pain with a frequency of at least once a week.[19,20] It should be noted that pain potentially caused by overuse-related injuries, typically characterized by a gradual and cumulative process of tissue damage without a single definable event associated with their onset,[8,13] was included in our case definition of musculoskeletal pain. The wording of the pain question in our questionnaire should minimize the possibility of reporting musculoskeletal pain resulting from acute injuries with a specific, clearly identifiable injury event. However, we cannot exclude the possibility that some of the adolescents might have misunderstood this question about pain. Furthermore, the outcome in this study was pain experienced during the previous 3 months, which might have introduced recall bias. It has, however, been shown that adolescents are able to accurately recall and report pain experienced during a 3-month period.[27]

Both exposure and outcome variables were self-reported, making them susceptible to information bias. Even though self-reports of PA have been criticized, the questions used in this study have been shown to provide reliable and valid measurements for physical fitness.[35]

CONCLUSION

In a large population-based sample of adolescents, we found that PA at a moderate level was associated with reduced likelihood of NSP and LBP and that endurance sports may be particularly beneficial. Participation in technical sports was associated with increased odds of LBP, whereas participation in team sports was associated with increased odds of LEP. Our findings highlight the need for health care professionals to consider the types of sports adolescents participate in and not only their overall level of PA when evaluating their musculoskeletal pain.

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APPENDIX

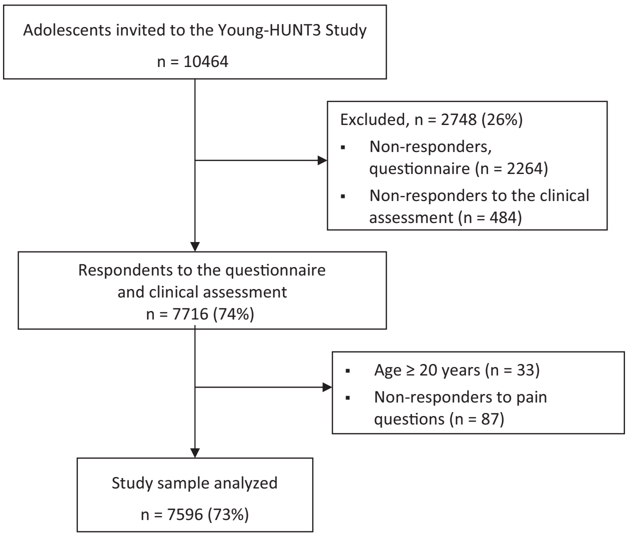

Figure A1. Flowchart of the study sample.

TABLE A1
Odds of Persistent Weekly Pain Related to Level of Physical Activity, Crude Analyses, and Analyses Adjusted for Age, Socioeconomic Status, and Psychological Distress[a]

	OR [95% CI] for Persistent Weekly Pain[b]		OR [95% CI] for Persistent Weekly Pain[b]	
	Crude	Adjusted[c]	Crude	Adjusted[c]
	NSP—Girls		NSP—Boys	
Low PA (≥1 d/wk)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA (2-3 d/wk)	**0.66 [0.54-0.80]**	**0.79 [0.63-0.99]**	**0.73 [0.56-0.95]**	**0.74 [0.55-1.00]**
High PA (≥4 d/wk)	**0.60 [0.49-0.74]**	0.84 [0.67-1.06]	**0.72 [0.56-0.92]**	0.80 [0.61-1.06]
	LBP—Girls		LBP—Boys	
Low PA (≥1 d/wk)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA (2-3 d/wk)	**0.66 [0.53-0.82]**	**0.77 [0.60-0.98]**	**0.66 [0.50-0.88]**	**0.70 [0.51-0.95]**
High PA (≥4 d/wk)	**0.69 [0.55-0.86]**	0.94 [0.73-1.20]	0.81 [0.63-1.04]	0.92 [0.70-1.21]
	LEP—Girls		LEP—Boys	
Low PA (≥1 d/wk)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA (2-3 d/wk)	0.89 [0.68-1.16]	0.99 [0.75-1.33]	1.38 [0.97-1.96]	1.48 [1.00-2.18]
High PA (≥4 d/wk)	1.22 [0.95-1.57]	**1.39 [1.05-1.85]**	**1.93 [1.40-2.66]**	**2.06 [1.44-2.95]**

[a]Values in boldface indicate statistically significant associations ($P < .05$). LBP, low back pain; LEP, lower extremity pain; NSP, neck and shoulder pain; OR, odds ratio.
[b]Reported pain ≥1 d/wk the previous 3 months.
[c]Adjusted for age, socioeconomic status, and psychological distress.

II

BMJ Open

Physical activity and sport participation among adolescents: associations with mental health in different age groups. Results from the Young-HUNT study: a cross-sectional survey

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ABSTRACT

Objectives Knowledge of how physical activity (PA) and sport participation are related to mental health throughout adolescence is scarce. Our objective was to describe PA levels and sport participation in a population-based sample of adolescents, and to explore how they relate to mental health in different age groups.

Design A population-based cross-sectional study.

Setting and participants The adolescent part of the Nord-Trøndelag Health Study, a Norwegian population-based health survey, conducted from 2006 to 2008. Of 10 464 invited participants (age 13–19 years), 7619 (73%) participated, of whom 3785 (50%) were boys.

Outcome measures Mental health outcomes included psychological distress assessed using a short version of the Hopkins Symptom Check List Five items, self-esteem assessed using a short version of the Rosenberg Self-Esteem Scale and life satisfaction assessed with a single-item satisfaction with life measure.

Method Logistic regression models were used to estimate the likelihood of psychological distress, low self-esteem and low life satisfaction, according to self-reported PA level and type of sport participation, stratified by gender and school level (junior vs senior high school).

Results Fewer senior high school students participated in team sports compared with junior high school students (p<0.001). Physically active adolescents and participants in team sports had higher self-esteem and life satisfaction. A high PA level, compared with a low PA level, was associated with reduced odds of psychological distress among senior high school students (OR 0.63, 95% CI 0.46 to 0.86 for girls and OR 0.46, 95% CI 0.27 to 0.79 for boys). Team sport participation was associated with reduced odds of psychological distress in senior high school girls.

Conclusion A high PA level was favourably associated with various dimensions of mental health, especially for adolescents in senior high school. Team sport participation may have a positive impact on mental health and should, therefore, be encouraged.

Strengths and limitations of this study

- ► Large population-based sample of adolescents with a high participation rate.
- ► Comprehensive information about sport participation and validated measures of mental health across adolescent age groups.
- ► Stratified analysis that takes potential age and gender differences during adolescence into account, and adjustments for possible confounders including exposure to interpersonal violence (physical violence, bullying and sexual abuse).
- ► The main limitation of this study is the cross-sectional study design.
- ► Measures of physical activity were self-reported.

INTRODUCTION

Physical activity (PA) and psychological well-being are essential to healthy development and quality of life in adolescence.[1–3] Health behaviours, including the habit of engaging in regular PA, are often established during this period,[4 5] paving the way for long-term health prospects.

Maintenance of PA throughout adolescence is of major importance in a public health perspective. Engaging in PA and sports during adolescence is associated with the development of lifelong PA[6–8] and psychological well-being.[1 9] Yet adolescents tend to be less physically active with increasing age.[10] The most dramatic decrease in PA is found to occur between the ages of 15 and 16, around the transition from junior to senior high school.[11] Although few adolescents are satisfying the recommended 60 min of moderate to vigorous PA per day worldwide,[12 13] sport participation is found to be high in some population-based studies.[6 14] However, the information about participation rates in various type of sports throughout adolescence is lacking.

Mental health problems are another major challenge among adolescents; currently, the leading cause of health-related disability within this age group, affecting up to 20% of adolescents worldwide.[15 16] Prevalence rates of psychological distress, such as anxiety and depression, increase with age, especially from the mid-teens (14–16 years).[11 17] Poor mental health also tends to carry over into adulthood,[17 18] highlighting the importance of preventive efforts during adolescence. Currently, the evidence indicates that PA may have a positive impact on anxiety, depression and self-esteem among adolescents, although our knowledge is limited.[1] Studies commonly assess these relationships without considering different developmental stages during adolescence. Further, the need for PA measures that account for various types of sports/activities has been emphasised.[1] No large population-based studies have evaluated PA levels and type of sport participation in relation to mental health among girls and boys in different adolescent age groups. Identification of these relationships could have implications for preventive programmes and may contribute to more accurate strategies for increasing engagement in PA and improving mental health among adolescents.

The aim of this study was to describe PA levels and the frequency of sport participation in a large population-based sample of adolescents stratified by age group (junior vs senior high school students) and gender. Further, to explore associations between PA level, type of sport participation and mental health, including psychological distress, self-esteem and life satisfaction, among boys and girls across adolescent age groups. As early adolescent stage versus mid-late adolescence is characterised by a major shift in psychosocial development tasks, where peer relationships become more salient,[19 20] the social benefits of sports participation may be of greater importance with increasing age through adolescence. We, therefore, hypothesised that a high level of PA and participation in sports would be associated with lower levels of psychological distress, higher self-esteem and greater life satisfaction, particularly among high school students and participants in team sports.

METHODS

Study sample

From 2006 to 2008, all adolescent residents (age 13–19 years) of the Nord-Trøndelag county in Norway (n=10 464) were invited to participate in the third wave of the population-based Nord-Trøndelag Health Study (Young-HUNT3). The attendees completed a comprehensive health-related questionnaire during school hours. Of those invited, 7716 (74%) adolescents responded to the questionnaire and attended a clinical examination. The response rate was 82% among junior high school students and 69% among senior high school students. Participants not enrolled in school (n=84) and participants ≥20 years of age (n=13) were excluded from the analyses in this study. Thus, the study sample comprised 7619 participants (73%) (online supplementary appendix), of whom 4615 (61%) went to junior high school. All participants in senior high school were ≥16 years old.

Exposure variables

Leisure time PA level was assessed by a validated question on frequency of PA from WHO Health Behavior in Schoolchildren (WHO HBSC) Survey Questionnaire[21 22]: Outside school hours: ‘How often do you usually exercise in your free time so much that you get out of breath or sweat?’. The level of intensity during exercise where you breathe heavily and/or sweat refers to moderate to vigorous activity. Response alternatives were: every day, 4–6 days/week, 2–3 days/week, 1 day/week, less than every week, less than every month and never. Responses were categorised into three levels of PA: ‘low PA’ (≤1 day/week) (reference group), ‘moderate PA’ (2–3 days/week) and ‘high PA’ (≥4 days/week).

Type and frequency of sport participation was assessed by the question: ‘How often have you participated in the following activities/sports in the last 12 months?’; endurance sports (eg, cross-country skiing, swimming, running), team sports (eg, soccer, volleyball, handball), strength sports (eg, weightlifting, body-building), technical sports (eg, track and field, alpine skiing, snowboard), aesthetic sports (eg, dance, gymnastics), martial arts (eg, judo, karate, boxing), extreme sports (eg, rafting, rock climbing, paragliding), jogging/walking and other. Four alternatives were given for describing the frequency of participation in each of the sport categories: never, less than once a week, once a week, several times a week. A frequency of ‘at least once a week’ was defined as active participation. Furthermore, adolescents were classified by their participation in sports into team sports (eg, soccer, volleyball, handball) or individual sports (all other sports). The reference group consisted of those with no or infrequent participation in all the sport categories, as well as those who reported a low level of PA. The groups were mutually exclusive. Responses to ‘jogging/walking’ were not defined as separate sport activities/participation, as they may also be performed in non-sport contexts. The activity ‘jogging/walking’ was, however, included in all exposure categories; ‘jogging/walking’ at least once a week was reported among 61% of those participating in individual sports, among 71% of those participating in team sports and among 33% of those with no/infrequent sport participation or low PA level.

Outcome variables: mental health

Psychological distress was assessed using a validated short version of the Hopkins Symptom Check List Five-item (SCL-5),[23 24] including the phrases: ‘During the last 14 days: I have been constantly afraid and anxious; I have felt tense or uneasy; I have felt hopeless about the future; I have felt dejected or sad; I have worried too much about various things’. Responses were scored according to four response alternatives ranging from 'not at all bothered' (1) to 'extremely bothered' (4). A mean score was calculated, and a cut-off for symptoms of anxiety and depression was set at a mean score above two.[23] The SCL-5 version has shown high correlation with the 25-item SCL-25 (r=0.92)[24] and good internal consistency (Cronbach's alpha 0.87).[23]

Self-esteem/feelings of self-worth was measured using a short version of the Rosenberg Self-Esteem Scale (RSES) (original 10 items),[25] including four statements: 'I have a positive attitude toward myself', 'I feel rather useless at times', 'I feel that I don't have much to be proud of', and 'I feel that I am a valuable person, at least equal to other people'. Response alternatives were measured on a 4-point scale ranging from 'I strongly agree' (1) to 'I strongly disagree' (4). For the first and last items, the scores were inversed. A mean score was calculated (range 4–16), with higher scores indicating higher levels of self-esteem. A cut-off was set at a mean score of 10 (midpoint of the scale) to separate low and high self-esteem, corresponding to the recommended cut-off at 25 on the original 10-item RSES (range 10–40).[26] The four-item version of the RSES is found to correlate at 0.95 with the full scale and to explain 0.90% of the full-scale variance, and has good internal consistency (Cronbach's alpha 0.80).[27]

Life satisfaction was measured with the question: 'Thinking about your life at the moment, would you say that you by and large are satisfied with life, or are you mostly dissatisfied?' Response alternatives were measured on a 7-point scale ranging from 'very satisfied' (1) to 'very dissatisfied' (7), and were coded into a dichotomous outcome variable where adolescents who responded 1–3 were classified as 'high life satisfaction', and those who responded 4–7 were classified as 'low life satisfaction'. A single-item life satisfaction measure is shown to perform almost as well as the multiple-item Satisfaction with Life Scale (SWLS).[28 29]

Potential confounders

Data on gender and age were obtained from the Norwegian National Population Registry. Socioeconomic status was based on participants' reports of perceived family economy. Pubertal development was assessed by self-reported pubertal status using the validated Pubertal Development Scale (PDS).[30] Participants were asked to rate their own growth and to assess pubic hair growth. Further, boys were asked to assess changes in voice and facial hair growth, while girls were asked about age at menarche and breast development. Pubertal changes were reported on scales ranging from 1 (has not begun) to 4 (development completed). Menarche was dichotomised into yes (coded 4) and no (coded 1). The items were summed up and an average PDS score was calculated.

Exposure to interpersonal violence was assessed with questions derived from The University of California at Los Angeles Post-traumatic Stress Disorder Reaction Index Reaction Index[31]: 'Have you ever experienced any of these events?' (no or yes): (1) Been subjected to violence (beaten or injured), (2) Been subjected to unpleasant/disagreeable sexual acts by someone approximately your own age, (3) Been subjected to unpleasant/disagreeable sexual acts by an adult and (4) Been threatened or physically harassed by fellow students at school over a period of time. Responses were categorised as 'prior violence', 'prior sexual abuse' (by peer or adult) and 'prior bullying'.[32]

Statistical analyses

Categorical variables were described with counts and percentages, and continuous variables with mean and SD. Possible associations between gender and age distribution were assessed with X^2 tests.

The associations between (1) PA level and (2) type of sport participation and the mental health outcomes were evaluated using multiple logistic regression models. The results are expressed as ORs with 95% CIs. Analyses were stratified by gender and school level (junior and senior high school). To adjust for potential confounding, age, puberty development (PDS), socioeconomic status, prior violence, sexual abuse (by peer or adult) and bullying were all included in the multiple models. All tests were two sided, and the significance level was set to 5%. Analyses were performed using SPSS V.25 (SPSS).

Due to missing data on pubertal development (PDS score) (13% in girls, 15% in boys), a model-based imputation for this variable was performed. Linear regression models stratified by gender were fitted with age and body mass index. Residuals for both models followed standard normal distribution and the model fit was very good. The missing values were replaced with the predicted values. The predicted variables and the original variables for both genders were highly correlated, r=0.75 and r=0.85 for boys and girls, respectively.

Patient and public involvement

When preparing for the Young-HUNT3 survey, the HUNT research centre appointed reference groups consisting of student representatives (13–19 years), as well as representatives from the county school authorities and county doctors. Content of the questionnaires, clinical examination, implementation of results and protection of privacy have been discussed with these representatives. Results from the current study have been presented and discussed with the Youth Panel for Research at the Research and Communication Unit for Musculoskeletal Health, Oslo University Hospital. The HUNT research centre has an active information policy and publishes annual newsletters for participants as well as regular reports on the HUNT website (https://www.ntnu.no/hunt/om).

RESULTS

Characteristics of the study sample

In total, 3785 boys and 3834 girls were included in the analyses. Characteristics of the study sample are summarised in table 1. The mean age was 15.8 years (SD 1.7). About 10% reported living in families with an economy below average, and reports of exposure

Table 1 Characteristics of the study sample (n=7619)

Characteristics	Girls (%) Junior high n=2298	Girls (%) Senior high n=1536	Boys (%) Junior high n=2317	Boys (%) Senior high n=1468
Age, mean (SD)	14.6 (0.89)	17.6 (0.86)	14.6 (0.89)	17.5 (0.84)
Socioeconomic status; family economy, n (%)				
Above average	297 (12.9)	264 (17.2)	402 (17.4)	319 (21.7)
Average	1644 (71.5)	1077 (70.1)	1521 (65.6)	939 (64.0)
Below average	204 (8.9)	144 (9.4)	141 (6.1)	136 (9.3)
Missing	153 (6.7)	51 (3.3)	253 (10.9)	74 (5.0)
Puberty (PDS score), mean (SD)	2.90 (0.68)	3.49 (0.51)	2.56 (0.61)	3.34 (0.47)
Missing	10 (0.4)	5 (0.3)	–	1 (0.0)
Interpersonal violence, n (%)				
Physical violence	122 (5.3)	138 (9.0)	200 (8.6)	246 (16.8)
Missing	96 (4.2)	34 (2.2)	167 (7.2)	65 (4.4)
Sexual abuse	123 (5.4)	169 (11.0)	50 (2.2)	44 (3.0)
Missing	103 (4.5)	32 (2.1)	170 (7.3)	58 (4.0)
Bullying	140 (6.1)	129 (8.4)	183 (7.9)	117 (8.0)
Missing	107 (4.7)	32 (2.1)	170 (7.3)	58 (4.0)
Mental health outcomes				
Psychological distress (SCL-5)*, n (%)				
SCL-5 ≥2	350 (15.2)	362 (23.6)	111 (4.8)	110 (7.5)
SCL-5 <2	1892 (82.3)	1138 (74.1)	2093 (90.3)	1302 (88.7)
Missing	56 (2.4)	36 (2.3)	113 (4.9)	56 (3.8)
Self-esteem (RSES)†, n (%)				
RSES <10	660 (28.7)	442 (28.8)	304 (13.1)	192 (13.1)
RSES ≥10	1499 (65.2)	1029 (67.0)	1847 (79.7)	1199 (81.7)
Missing	139 (6.0)	65 (4.2)	166 (7.2)	77 (5.2)
Life satisfaction, n (%)				
Low life satisfaction	722 (31.4)	469 (30.5)	373 (16.1)	223 (15.2)
High life satisfaction	1525 (66.4)	1050 (68.4)	1872 (80.8)	1212 (82.6)
Missing	51 (2.2)	17 (1.1)	72 (3.1)	33 (2.2)

*Range 1–4.
†Range 4–16.
PDS, Pubertal Development Scale; RSES, Rosenberg Self-Esteem Scale; SCL-5, Symptom Check List Five item.

to interpersonal violence was higher among senior as compared with junior high school students, with physical violence being more common in boys, sexual violence more common in girls, and bullying more evenly distributed between the sexes. Girls reported more mental health problems than boys, with the highest levels of psychological distress found among girls in high school (table 1).

PA level and sport participation

More boys reported a high level of PA (45.2%) compared with girls (35.4%) (p<0.001). For both genders, junior high school students reported significantly higher levels of PA than senior high school students (table 2). Of the various sports, team sports were most commonly reported by both girls and boys, with about 60% of the adolescents participating in such sports at least once a week (table 2). For both genders, participation in team and technical sports was less common among senior high school students as compared with junior high school students (p<0.001). In contrast, a significantly higher proportion of both girls and boys in senior high school were engaged in strength sports compared with those in junior high school. Significantly, more girls than boys participated in aesthetic sports, while a higher proportion of boys participated in strength sports and extreme sports, in both age groups (table 2).

PA and mental health

A high level of PA, compared with a low level of PA, was significantly associated with reduced odds of low

Table 2 Physical activity (PA) level and sport participation rates in relation to gender and school level

	Girls (%)			Boys (%)		
	Junior high	Senior high	P value	Junior high	Senior high	P value
PA level						
High PA	38.4	32.4		46.5	43.8	
Moderate PA	39.9	34.3		33.1	28.0	
Low PA	20.2	31.6	**<0.001***	18.5	27.2	**<0.001***
Missing	1.5	1.6		1.9	1.0	
Sport participation (≥1 day/week)						
Team sports	**64.7**	**49.9**	**<0.001**	**65.8**	**56.7**	**<0.001**
Endurance sports	46.0	45.5	0.63	51.4	49.4	0.06
Aesthetic sports	25.9	27.3	0.43	6.0	5.2	0.25
Strength sports	**20.5**	**29.7**	**<0.001**	**33.8**	**47.6**	**<0.001**
Martial arts	3.5	4.4	0.17	7.6	7.6	0.85
Technical sports	**28.0**	**16.7**	**<0.001**	**26.8**	**20.8**	**<0.001**
Extreme sports	1.0	0.8	0.71	4.6	4.7	0.99

Low PA=≤1 day/week, moderate PA=2–3 days/week, high PA=≥4 days/week.
Bold numbers, statistically significant, p<0.05.
*X^2 test for trend.

self-esteem and low life satisfaction among all students (table 3). In senior high school students, a high level of PA was significantly associated with reduced odds of psychological distress (OR 0.63, 95% CI 0.46 to 0.86 for girls and OR 0.46, 95% CI 0.27 to 0.79 for boys).

Sport participation and mental health

Participation in team sports, compared with no/infrequent sport participation, was significantly associated with reduced odds of low self-esteem for girls, both in junior high school (OR 0.45, 95% CI 0.32 to 0.64) and senior high school (OR 0.57, 95% CI 0.39 to 0.84). A similar non-significant trend was observed in boys (table 4). Participation in individual sports was significantly associated with reduced odds of low self-esteem among senior high school boys (OR 0.37, 95% CI 0.18 to 0.76).

Participation in team sports was associated with reduced odds of low life satisfaction, among all girls and among junior high school boys (table 4). Among girls in senior high school, team sport participation was also significantly associated with reduced odds of psychological distress (OR 0.70, 95% CI 0.49 to 1.00). In boys and junior high school girls, no statistically significant associations between sport participation and psychological distress were revealed in the adjusted models (table 4).

DISCUSSION

In this population-based sample of adolescents, PA levels and participation rates in sports were lower among girls, and lower among senior high school students compared with junior high school students. Our results showed that higher levels of PA were favourably associated with self-esteem and life satisfaction throughout adolescence, as well as with reduced likelihood of psychological distress in senior high school students. Further, team sport participation was associated with mental health benefits, especially for girls.

Strengths and limitations

The main strengths of our study include the large sample size of adolescents from an unselected general population, a high participation rate (73%) and the information including frequency of participation in sports. To our knowledge, such comprehensive information about sport participation in relation to gender and age differences has not previously been presented. This information enabled us to examine the relationship between sport participation and mental health outcomes, including the aspect of various types of sports, in contrast to most studies on this topic which mainly focus on general PA. We used validated measures of mental health outcomes. Another strength is that we were able to adjust for a variety of possible confounders, as well as including exposures to interpersonal violence as these exposures may have an impact on both PA behaviours and mental health.[33–35]

The main limitation of this study is the cross-sectional study design, and the resultant inability to demonstrate the direction of the association. Further, as measures were self-reported, the included variables are susceptible to information bias. We have used a single item measure to assess PA, and the variable used to describe sport participation exposure provides a crude measure of frequency of participation. However, WHO HBSC question of PA used in this study has been found to hold acceptable reliability and validity in adolescent samples.[21 22] It should be noted that a proportion of the 'high PA' group in this

Table 3 Associations between levels of physical activity (PA) and mental health problems (psychological distress, low self-esteem and low life satisfaction) among girls and boys in junior and senior high school

	Outcome			
	Junior high school		Senior high school	
PA level	Unadjusted	Adjusted‡	Unadjusted	Adjusted‡
	OR (95% CI) for psychological distress*			
Girls				
Low PA	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA	0.80 (0.59 to 1.07)	0.86 (0.62 to 1.21)	**0.68 (0.51 to 0.90)**	**0.73 (0.54 to 0.99)**
High PA	**0.67 (0.49 to 0.91)**	0.88 (0.63 to 1.24)	**0.53 (0.39 to 0.72)**	**0.63 (0.46 to 0.86)**
Boys				
Low PA	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA	**0.54 (0.32 to 0.90)**	**0.56 (0.31 to 0.99)**	0.78 (0.49 to 1.23)	0.89 (0.53 to 1.49)
High PA	**0.58 (0.56 to 0.91)**	0.70 (0.41 to 1.18)	**0.38 (0.23 to 0.62)**	**0.46 (0.27 to 0.79)**
	OR (95% CI) for low self-esteem †			
Girls				
Low PA	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA	**0.63 (0.48 to 0.82)**	**0.65 (0.49 to 0.87)**	**0.68 (0.30 to 0.93)**	**0.72 (0.52 to 0.99)**
High PA	**0.53 (0.40 to 0.70)**	**0.59 (0.44 to 0.80)**	**0.43 (0.31 to 0.61)**	**0.49 (0.34 to 0.70)**
Boys				
Low PA	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA	**0.37 (0.24 to 0.58)**	**0.32 (0.20 to 0.53)**	0.66 (0.38 to 1.15)	0.67 (0.37 to 1.20)
High PA	**0.31 (0.20 to 0.48)**	**0.33 (0.21 to 0.52)**	**0.41 (0.24 to 0.71)**	**0.44 (0.25 to 0.79)**
	OR (95% CI) for low life satisfaction			
Girls				
Low PA	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA	**0.60 (0.48 to 0.76)**	**0.59 (0.45 to 0.76)**	**0.66 (0.51 to 0.85)**	**0.68 (0.52 to 0.89)**
High PA	**0.43 (0.34 to 0.55)**	**0.49 (0.37 to 0.63)**	**0.45 (0.34 to 0.59)**	**0.51 (0.38 to 0.69)**
Boys				
Low PA	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Moderate PA	**0.67 (0.51 to 0.90)**	**0.65 (0.47 to 0.90)**	0.76 (0.53 to 1.08)	0.73 (0.50 to 1.08)
High PA	**0.42 (0.32 to 0.56)**	**0.44 (0.32 to 0.60)**	**0.44 (0.31 to 0.62)**	**0.43 (0.30 to 0.63)**

Bold numbers: statistically significant associations, $p<0.05$.
Low PA=≤1 day/week, moderate PA=2-3 days/week, high PA=≥4 days/week.
*SCL-5 ≥2 (range 0–4).
†RSES <10 (range 4–16).
‡Adjusted for age, puberty score (PDS), socioeconomic status, prior physical violence, prior bullying, prior sexual abuse.
PDS, Pubertal Development Scale; RSES, Rosenberg Self-Esteem Scale; SCL-5, Symptom Check List Five items.

study may not fulfil the recommended levels of daily PA according to WHO guidelines,[36] as this group includes all those who played sports or exercised at least 4 days/week. Although measures of psychological distress (SCL-5) and self-esteem (RSES) were shortened versions of the original instruments, the measurement precision of these versions is found to be high and sufficient for use in population-based studies.[23 24 27] Furthermore, dichotomisation of the mental health outcomes makes them prone to misclassification. However, the cut-off values to distinguish those with high versus low degree of psychological distress (SCL-5) and low self-esteem (RSES) have both been shown to be clinically relevant cut-points.[23 26] In contrast to psychological distress, low self-esteem and low life satisfaction were not more prevalent in the older age group, reflecting the measurement of different phenomena. Psychological distress is found to function as a proxy measure of symptoms of anxiety and depression,[23 24] while self-esteem and life satisfaction are more closely related to subjective well-being,[28 37] which may be more stable traits.

Table 4 Associations between sport participation and mental health problems (psychological distress, low self-esteem and low life satisfaction) among girls and boys in junior and senior high school

	Outcome			
	Junior high school		Senior high school	
Sport participation	Unadjusted	Adjusted‡	Unadjusted	Adjusted‡
	OR (95% CI) for psychological distress*			
Girls				
No sport	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Individual sports	1.06 (0.70 to 1.60)	1.09 (0.68 to 1.73)	0.87 (0.61 to 1.22)	0.93 (0.64 to 1.35)
Team sports	0.78 (0.53 to 1.14)	1.02 (0.66 to 1.56)	**0.56 (0.40 to 0.78)**	**0.70 (0.49 to 1.00)**
Boys				
No sport	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Individual sports	1.04 (0.56 to 1.95)	1.04 (0.52 to 2.09)	0.85 (0.49 to 1.49)	0.98 (0.51 to 1.88)
Team sports	**0.55 (0.31 to 0.99)**	0.60 (0.31 to 1.15)	**0.57 (0.34 to 0.96)**	0.93 (0.50 to 1.70)
	OR (95% CI) for low self-esteem†			
Girls				
No sport	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Individual sports	**0.52 (0.37 to 0.75)**	**0.55 (0.37 to 0.81)**	0.77 (0.53 to 1.11)	0.81 (0.55 to 1.20)
Team sports	**0.42 (0.30 to 0.57)**	**0.45 (0.32 to 0.64)**	**0.50 (0.35 to 0.71)**	**0.57 (0.39 to 0.84)**
Boys				
No sport	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Individual sports	1.11 (0.62 to 1.99)	1.43 (0.73 to 2.79)	**0.42 (0.22 to 0.82)**	**0.37 (0.18 to 0.76)**
Team sports	**0.53 (0.30 to 0.92)**	0.72 (0.38 to 1.36)	**0.47 (0.27 to 0.81)**	0.57 (0.32 to 1.03)
	OR (95% CI) for low life satisfaction			
Girls				
No sport	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Individual sports	**0.70 (0.51 to 0.96)**	0.71 (0.50 to 1.00)	**0.66 (0.48 to 0.91)**	**0.65 (0.46 to 0.91)**
Team sports	**0.46 (0.34 to 0.61)**	**0.51 (0.37 to 0.70)**	**0.48 (0.36 to 0.65)**	**0.55 (0.40 to 0.76)**
Boys				
No sport	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)	1.0 (Reference)
Individual sports	1.00 (0.68 to 1.46)	0.99 (0.65 to 1.52)	0.84 (0.55 to 1.29)	0.80 (0.50 to 1.28)
Team sports	**0.56 (0.39 to 0.79)**	**0.63 (0.43 to 0.93)**	**0.62 (0.42 to 0.92)**	0.72 (0.47 to 1.12)

Bold numbers: statistically significant associations, p<0.05.
*SCL5 ≥2 (range 0–4).
†RSES <10 (range 4–16).
‡ Adjusted for age, puberty score (PDS), socioeconomic status, prior physical violence, prior bullying, prior sexual abuse.
PDS, Pubertal Development Scale; RSES, Rosenberg Self-Esteem Scale; SCL-5, Symptom Check List Five items.

Although the response rate in Young-HUNT3 was high, the lower response among senior high school students compared with junior high school students may represent a selection bias. In Norway, most adolescents start senior high school the year they turn 16. Differences in school systems in other countries, as well as differences related to opportunities for engagement in sports and the organisation of various youth sports may limit the generalisability of the results from this study. Norwegian society is rooted in egalitarian ideals, with 'Sport for All' as a high priority and policy aim[38]; this may be part of the reason why sport participation found in this study is high by international standards. Lastly, the results of this study should be interpreted with caution due to multiple testing, and replication of results is warranted.

Our results according to previous findings and interpretation of findings

The findings from this study confirmed the gender differences in PA levels found in other population-based studies, with girls being less physically active than boys.[11–13] Also in line with reports from other studies, fewer girls were involved in sports.[7 13 14 39] The lower levels of PA and sport participation found among senior high school students confirm findings from previous studies reporting a decline in PA during adolescence,[10 11 40 41] especially between the ages of 15 and 16 years.[11] Drop-out from sports for adolescents at this age may be related, in part, to the difficulty of meeting the increasing demands of participation in both school and sport.[7 42] However, a systematic review of factors associated with drop-out from organised sports reported that lack of enjoyment and perceptions of competence are the two most dominant factors related to drop-out from sports among adolescents.[42]

The current findings are in line with previous studies reporting associations between adolescents' PA and mental health, including lower likelihood of depressive symptoms,[1 11 13 43 44] as well as greater well-being[13] and higher self-esteem among those who are physically active.[1 44] Longitudinal studies also indicate that PA may protect against the development of depression.[45 46] Furthermore, PA may be a helpful intervention for adolescents struggling with depressive symptoms.[47 48] Regarding engagement in sports, the results of the present study are in accordance with the literature indicating a positive relationship between sport participation and mental health.[9 13 49–51]

The findings from this study make several contributions to the body of research on the impact of PA and sports on mental health among adolescents. First, age differences were revealed in these relationships, as a high PA level was associated with reduced psychological distress in high school students only. Explanations for why PA and sport participation may be of greater importance in reducing psychological distress among older adolescents could relate to how peer support and interaction play an increasingly important role during adolescence.[19 20] Thus, social and PAs with peers may be particularly beneficial for older adolescents, helping to distract them from depressive thoughts and to reduce the sense of isolation.

Second, this study shows that the potential beneficial effects related to mental health vary across various types of sport. Participation in team sports, compared with no participation, was more strongly related to beneficial mental health outcomes than individual sports compared with no participation, especially in high school girls. Other studies have reported that organised sports had a greater impact on depressive symptoms among girls than boys,[11] and that team sports may confer mental health benefits for girls in particular.[13] A systematic review of the psychological and social benefits of sport participation argued that team sports seem to be associated with more beneficial outcomes compared with individual sports due to the social aspect of being part of a team.[9] In a recent study of a large representative sample of European adolescents, lower levels of anxiety and depression and higher levels of well-being were found among team sport participants.[13] Team sport participation during adolescence has also been shown to be associated with lower levels of depressive symptoms in early adulthood.[50 52] In line with this, our findings highlight that the type of sport, including the social aspect of participation, should be considered when examining the impact of sports on mental health among adolescents.

Overall, adolescents with a high PA and team sport participation had lower odds of having low self-esteem than of having psychological distress. These results are in accordance with findings from a review study showing that, of the several mental health outcomes associated with PA in young people, the strongest association was with self-esteem.[1] It may be that experiences of low self-esteem occur earlier than symptoms of anxiety and depression and that low self-esteem may trigger poor coping behaviour and risk behaviour that subsequently increases the likelihood of mental disorders.[53] A Cochrane review reports that exercise interventions have positive short-term effects on self-esteem that may help prevent the development of psychological and behavioural problems.[54]

This study contributes to our understanding of the implications lower levels of PA may have on mental health in different phases of adolescence. Regardless of the direction of the association between PA and mental health, inactive adolescents may carry a 'double health burden', with both physical and mental health challenges. To help more adolescents increase or maintain their levels of PA, interventions could include facilitation of a wider variety of sports activities, and at different skill levels, to reach and engage more adolescents. As lack of enjoyment has previously been found to be the most dominant factor related to drop-out from sports[42], increased focus on the joy of sports may be important in order to reduce drop-out rates during adolescence. In efforts to reduce mental health problems, our results suggest that girls in particular should be a target group for promotion of team sport participation.

CONCLUSION AND IMPLICATIONS

This study identified gender and age differences in PA and sport participation across adolescent age groups, with the lowest engagement in PA and sports found among girls in senior high school. Our results indicate that a high PA level and sport participation have a positive impact on various dimensions of mental health throughout adolescence, highlighting the importance of continuing with sports in the late teens. The findings underline a need for interventions aimed at maintaining or increasing PA and sport participation, especially for girls around the transition to senior high school. Initiatives to help adolescents continue in team sports may be particularly advantageous. Future studies should examine the effect of interventions for encouraging and increasing PA and sport participation among adolescents, as well as their potential mental health benefits.

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Contributors MHG processed, analysed and interpreted the data and drafted the initial manuscript. SØS, KS and J-AZ were involved in the conception and design of the manuscript, as well as data interpretation and critical review and revision of the manucript. MCS supervised the statistical analyses. MCS and MBJ were involved in critical review and revision of the manucript. All authors have read and approved the final manuscript.

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Patient consent for publication Not required.

Ethics approval Participationin the study was voluntary. Inclusion in Young-HUNT was based on written consentfrom participants 16 years of age or older, and from the parents of those under16 years of age, in accordance with Norwegian law. The current study has been approved by the Regional Committee for Medical Research Ethics (2014/1228/REK Sør-Øst A). The Young-HUNT Studies have been approved by REK and the Data Inspectorate of Norway.

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Data sharing statement The data set analysed belongs to a third party, the Nord-Trøndelag Health Study (HUNT Study). The authors of the current manuscript have been given permission to analyse the data after obtaining the necessary Norwegian permits. Research groups that wish to analyse data from the HUNT study may apply to the HUNT organisation to get access to the data (https://www.ntnu.no/hunt/datatilgang). HUNT databank online provides a complete overview of the research variables, as well as metadata (https://hunt-db.medisin.ntnu.no/hunt-db/#/survey/YH3). The general health questionnaire used in the study is accessible from the HUNT Bio-And-Databank (http://www.ntnu.edu/hunt/data/que).

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III

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Article

Obesity in Young Adulthood: The Role of Physical Activity Level, Musculoskeletal Pain, and Psychological Distress in Adolescence (The HUNT-Study)

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Abstract: The global obesity epidemic raises long-term health concerns which underline the importance of preventive efforts. We aimed to investigate individual and combined effects of common health problems in adolescence on the probability of obesity in young adulthood. This prospective population-based study included data from participants in the Nord-Trøndelag Health Study in Norway (Young-HUNT1 (1995–1997), age 13–19, baseline) who participated in HUNT3 as young adults 11 years later (age 23–31). Exposure variables at baseline included self-reported physical activity, musculoskeletal pain, and psychological distress. We examined associations between exposure variables and the main outcome of obesity in young adulthood (BMI ≥ 30 kg/m^2) using univariate and multiple logistic regression, stratified by sex. Probabilities of obesity for given combinations of the exposure variables were visualized in risk matrixes. The study sample consisted of 1859 participants (43.6% boys). Higher probabilities of obesity in young adulthood were found across combinations of lower physical activity levels and presence of musculoskeletal pain in adolescence. Additional adverse effects of psychological distress were low. Proactive intervention strategies to promote physical activity and facilitate sports participation for all adolescents, whilst addressing musculoskeletal pain and its potential individual causes, could prove helpful to prevent development of obesity in young adulthood.

Keywords: obesity; prevention; adolescence; young adulthood; physical activity; musculoskeletal pain

1. Introduction

Obesity is a major public health concern worldwide, and is associated with increased risk of chronic morbidity and mortality [1]. A substantial rise in the prevalence of obesity during the last three decades [1,2], along with an increase in related comorbidities and disease burden [2], has made the prevention of obesity a global public health priority [3]. Adolescence, and the subsequent transition into young adulthood, have been recognized as critical periods for weight-related behavior change to prevent the development of obesity [4,5].

A lifestyle characterized by low levels of physical activity (PA), musculoskeletal pain, and psychological distress are three common and related factors adversely affecting the health and well-being of adolescents worldwide [6–10]. The cumulative presence of these factors could be of particular importance for the development of overweight and obesity over time. Particularly, regular PA is considered one of the most important lifestyle factors in the prevention and management of obesity [11] and long-term morbidity [12]. Young people commonly drift away from engagement in regular physical activity throughout their adolescent years [13], and the majority of adolescents worldwide (81%) do not adhere to the current recommendations of daily PA [6]. Emerging unhealthy adolescent behavior patterns, such as no or infrequent engagement in PA, could affect the development of obesity into adulthood [14,15]. However, there is a lack of knowledge about the impact of early regular PA on later risk of obesity. More specifically, results from systematic reviews are inconsistent and have provided limited evidence for the contribution of PA in adolescence on development of obesity [14–16], with few studies covering the transition period from adolescence to young adulthood.

Further, musculoskeletal pain and mental health problems frequently take place in adolescence, and are among the top causes of functional impairments [7,8,10,17]. Estimations indicate that between one third and one half of adolescents worldwide report musculoskeletal pain monthly or more [7], and up to one in five children and adolescents experience mental health problems [8,18]. Moreover, these problems commonly co-occur [19,20]. In a national representative cohort from the United States, 26% of adolescents reported that they had experienced both chronic pain and mental health problems during their lifetime [21]. Both musculoskeletal pain and mental health problems are known to be leading causes of health-related disability [8,10,22], associated with impairments in daily activities, in social relationships and in extracurricular activities, as well as sleep disturbances and absence from school [7,19,23].

There is a possibility that these commonly persistent health problems, alongside lack of PA, could impact heavily on young people's capability to pursue healthy lifestyles. The potential adverse impact of pain on the development of obesity has been raised as a concern based on the high prevalence of obesity seen in adolescents with chronic pain [24,25]. Further, results from systematic reviews have found psychological distress or depression/depressive symptoms in adolescence being predictive for development of obesity [26–29]. Limited evidence, however, exists on individual and combined effects of these common health problems from population-based cohorts with follow-up into young adulthood.

Young adults of this generation appear to be particularly affected by the global obesity epidemic [30], highlighting the importance of addressing the weight-related consequences of the potential risk factors. However, the question of whether the co-occurrence of physical inactivity and these health problems in adolescence may play a role in the development of obesity has received little attention. As current preventive efforts to reduce obesity seem to be insufficient [31], there is need for further exploration of factors that may be helpful in guiding intervention strategies. Particularly, future prospective studies assessing the combination of multiple potential risk factors for obesity are warranted [32]. Early intervention is a key in the prevention of obesity [31,33,34], and knowledge about the potential impact of the co-existence of health challenges in adolescence may make a valuable contribution to this initiative. Physical activity habits, as well as musculoskeletal pain and mental health challenges, are likely to be less ingrained in adolescence than in adulthood, emphasizing the importance of preventive efforts during the adolescent years when these potential risk factors are more malleable [35]. Identifying groups of adolescents potentially at risk for the development of obesity could help to provide early, targeted preventive interventions.

To the best of our knowledge, it has not been examined in large population-based samples whether the joint impact of physical inactivity, musculoskeletal pain, and psychological distress in adolescence increases the probability of obesity. Thus, the aim of this prospective study with 11-year follow-up was to examine the impact of the individual and combined occurrence of PA levels, musculoskeletal pain, and psychological distress in adolescence on the probability of obesity in young adulthood. We hypothesized that physical inactivity, musculoskeletal pain, and psychological distress in adolescence would contribute additively to adverse impact on the probability of obesity in young adulthood.

2. Materials and Methods

2.1. Study Sample

All adolescents aged 13–19 years living in the county of Nord-Trøndelag in Norway (n = 10,202) were invited to participate in the first adolescent phase of the Nord-Trøndelag Health Study, the Young-HUNT1 study, conducted in 1995–1997. During school hours, the adolescents completed a comprehensive health-related questionnaire about lifestyle factors, health, and quality of life, including the exposure variables described below (Section 2.3 Exposures). In addition, nurses performed health examinations that included measurement of height and weight at school visits. In total, 8983 adolescents responded the questionnaire in Young-HUNT1 (response rate 88%). These adolescents were also invited as young adults 11 years later, in 2006–2008, to participate in the HUNT3 study. Of the invited young adults who had participated in the Young-HUNT1 (n = 5353), 36% participated in the 11-year follow-up in HUNT3 [36]. Participants in HUNT3 completed a comprehensive health-related questionnaire at home, and attended screening stations for clinical examinations, including measurement of weight and height. In total, 1919 individuals participated in the Young-HUNT1 (baseline) as adolescents and in HUNT3 as young adults (age 23–31) 11 years later. We excluded participants ≥20 years of age at baseline (n = 10) according to the World Health Organization (WHO)'s definition of adults, and participants in HUNT3 who did not attend the clinical examination (n = 11) or did not have available BMI measures (n = 10). Those classified as underweight in HUNT3 (BMI < 18.5) were also excluded (n = 29) as these individuals are considered at higher risks of serious illness, leaving N = 1859 for the analysis (Appendix A).

The majority of the population in the Nord-Trøndelag County is Caucasian. In terms of sex, age distribution, mortality and health status, the population is representative of Norway [36,37], and the development of obesity in Nord-Trøndelag is comparable to the global trend [1]. The Norwegian society is a socioeconomically stable society with a high degree of equity among students and young people [38]. A more comprehensive description of the data collection in the HUNT studies can be found elsewhere [36,37]. Participation in the study was voluntary. Inclusion was based on written consent from participants 16 years of age or older, and from the parents of those under 16 years of age, in accordance with Norwegian law. The Regional Committee for Medical Research Ethics (REK) has approved the current study (2014/1228/REK Sør-Øst A). The HUNT Studies have been approved by REK and the Norwegian Data Inspectorate of Norway. The Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines were used to ensure the reporting of this observational study.

2.2. Variables

Data on gender and age were obtained from the Norwegian National Population Registry. BMI was calculated by dividing body weight in kilograms by the squared value of body height in meters (kg/m^2). The BMI-derived categorization of obesity for adolescents at baseline was defined in accordance with the extended International Obesity Task Force (IOTF) classification according to age and sex specific cut-off points [39].

2.3. Exposures

2.3.1. Physical Activity Level (Young-HUNT1)

A validated question on frequency of PA from the World Health Organization Health Behavior in Schoolchildren (WHO HBSC) Survey Questionnaire was used to assess leisure time PA level [40]: "Outside school hours, how often do you usually exercise in your free time so much that you get out of breath or sweat?". Response options were: every day, 4–6 days/week, 2–3 days/week, 1 day/week, less than every week, less than every month, and never. These seven categories were combined into three levels: "Low PA" (≤1 days/week) (reference group), "moderate PA" (2–3 days/week), and "high PA" (≥4 days/week).

2.3.2. Musculoskeletal Pain (Young-HUNT1)

Musculoskeletal pain was assessed by questions regarding occurrence of neck or shoulder pain and joint or muscle pain in the past 12 months. Response options for frequency of pain were: "never", "seldom", "sometimes", and "often". Those who reported experiencing pain "sometimes" or "often" were classified as having musculoskeletal pain.

2.3.3. Psychological Distress (Young-HUNT1)

A validated short version of the Hopkins Symptom Checklist Five items (SCL-5) was used to assess symptoms of psychological distress [41]. The statements included in SCL-5 were: "During the last 14 days: I have been constantly afraid and anxious; I have felt tense or uneasy; I have felt hopeless about the future; I have felt dejected or sad; I have worried too much about various things". The four response options ranged from 1 = "not at all bothered" to 4 = "extremely bothered". A mean score was calculated, with a cut-off for symptoms of psychological distress set at a mean score of two [41].

2.4. Outcome

Obesity (BMI ≥ 30 kg/m^2) in Young Adulthood (at 11 Years Follow-Up, HUNT3)

Height and weight were measured by nurses. Height was measured to the nearest centimeter, and weight to the nearest half kilogram with light clothes, without shoes, jacket, or outdoor clothing. BMI was calculated (kg/m^2), and those with BMI ≥ 30 were categorized as obese according to the definition of adult obesity adopted from the WHO.

2.5. Data Analyses

Categorical variables were reported as counts and percentages, and continuous variables as means and standard deviations (SDs). Analyses were stratified by gender. Differences in distribution of exposure variables at baseline between girls and boys were assessed using the Chi-square test for categorical variables and the Student's t-test for continuous variables.

The risk matrixes were constructed by first performing univariate logistic regression analyses to estimate the odds for the main outcome of obesity for each of the exposure variables; PA level (low, moderate, high), musculoskeletal pain (yes/no), and psychological distress (yes/no). Reference groups in the logistic regression analyses were young adults with BMI 18.5–29.9 kg/m^2. The results were expressed as crude and adjusted odds ratios (ORs) with 95% confidence intervals (CIs).

In our study, the aim was to develop a prediction model, not to reveal variables which would be independently associated with the outcome. Some variables might be statistically significant only when other variables are included in the multiple model, so we did not want to rule out such possible interactions. We therefore chose to include variables from the univariate analyses with p-values ≤ 0.2 into a multiple logistic regression model in order to evaluate whether their inclusion improved the overall model fit and the prediction abilities of the model. Thus, PA level and musculoskeletal pain for both sexes, in addition to psychological distress for girls, were included in multiple logistic regression models which formed the basis for calculations of the risk matrixes. The coefficients derived from the multiple models were used to compute probabilities for obesity in young adulthood given different combinations of the exposure variables at baseline. Risk matrixes for girls and boys were constructed separately to visualize the results. Sensitivity analyses were performed by limiting the reference group to participants within a normal weight range in young adulthood (BMI 18.5–24.9 kg/m^2), excluding overweight participants (BMI 25–30 kg/m^2). Statistical differences in exposure variables at baseline between Young-HUNT1 participants who also participated at HUNT3 (11-year follow-up) and those who did not participate in HUNT3 were calculated with the Chi square test. All analyses were considered exploratory so no correction for multiple testing was done and p-values < 0.05 were considered statistically significant. All tests were two-sided. Statistical analyses were performed with SPSS version 25 (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Characteristics of the Study Sample

The study sample consisted of 1859 participants, of whom 810 (43.6%) were males. Characteristics of the study participants at baseline (Young-HUNT1) by gender are presented in Table 1. Mean age was 16 years (SD 1.8). About one third of the adolescents reported a low level of PA (≤1 day/week). Musculoskeletal pain was frequently reported among both girls (36%) and boys (26%). The rate of psychological distress was twice as high in girls compared to boys (Table 1).

Table 1. Participants' characteristics at baseline–nord-trøndelag health study in norway (Young-HUNT1).

Variables	Girls (N = 1049)	Boys (N = 810)	*p*-Value
Age (years), mean (SD)	16.0 (1·8)	16.0 (1.8)	
Physical activity, N (%)			
High PA	245 (23.4)	239 (29.5)	
Moderate PA	449 (42.8)	321 (39.6)	
Low PA	347 (33.1)	237 (29.3)	0.005 *
Missing	8 (0.8)	13 (1.6)	
Musculoskeletal pain, N (%)			
Yes	379 (36.1)	213 (26.3)	
No	638 (60.8)	568 (70.1)	$p < 0.001$
Missing	32 (3.1)	29 (3.6)	
Psychological distress, (SCL5), N (%)			
SCL5 ≥ 2	123 (11.7)	46 (5.7)	
SCL5 < 2	890 (84.8)	735 (90.7)	$p < 0.001$
Missing	36 (3.4)	29 (3.6)	
BMI, mean (SD)	21.5 (3.2)	21.1 (3.2)	0.012
Obese †, N (%)	16 (1.5)	24 (3.0)	0.027

Boys and girls analysed separately; * Chi-square test for trend; High physical activity (PA) = ≥4 days/week, Moderate PA = 2–3 days/week, Low PA = ≤1 day/week; SCL5 = Hopkins Symptom Checklist Five Items (range 0–4); † BMI-derived categorization of obesity defined by the International Obesity Task Force (IOTF); criteria for adolescents.

3.2. Probability of Obesity in Young Adulthood

In total, 165 (15.7%) girls and 146 (18.0%) boys were obese at 11 years follow-up (young adulthood, HUNT3). Results from univariate and multiple logistic regression analyses of PA level, musculoskeletal pain, and psychological distress in adolescence assessing potential predictors of obesity in young adulthood are listed in Table 2. A high PA level was the one of the selected covariates that was most strongly associated with reduced odds for obesity for both sexes.

Table 2. Results from logistic regression analysis with obesity (BMI ≥ 30) in young adulthood as dependent variable.

Variables	Univariate Analysis			Multiple Analysis		
	OR	95% CI	*p*-Value	OR	95% CI	*p*-Value
Girls						
PA level						
Low PA		1.0 (Reference)			1.0 (Reference)	
Moderate PA	0.67	0.46–0.98	0.04	0.67	0.45–0.99	0.05
High PA	0.64	0.41–1.00	0.05	0.61	0.38–0.97	0.04
Musculoskeletal pain						
No		1.0 (Reference)			1.0 (Reference)	
Yes	1.53	1.09–2.16	0.02	1.55	1.08–2.22	0.02
Psychological distress *						
No		1.0 (Reference)			1.0 (Reference)	
Yes	1.41	0.87–2.28	0.17	1.09	0.65–1.82	0.76
Boys						
PA level						
Low PA		1.0 (Reference)			1.0 (Reference)	
Moderate PA	0.70	0.46–1.07	0.10	0.67	0.44–1.02	0.06
High PA	0.56	0.35–0.90	0.02	0.55	0·35–0.89	0.02
Musculoskeletal pain						
No		1.0 (Reference)			1.0 (Reference)	
Yes	1.30	0.88–1.93	0.19	1.30	0.87–1.93	0.20
Psychological distress *						
No		1.0 (Reference)			1.0 (Reference)	
Yes	1.12	0.53–2.38	0.77	-		-

High PA = ≥4 days/week, Moderate PA = 2–3 days/week, Low PA = ≤1 day/week; * SCL-5 ≥ 2, SCL5 = Hopkins Symptom Checklist Five Items (range 0–4).

Adolescent girls with a high level of PA, and no musculoskeletal pain or psychological distress, had the lowest probability of developing obesity as young adults (11%, 95% CI (6% to 16%)) (Table 3). The probability of obesity among girls was the highest among those with low PA in combination with musculoskeletal pain and psychological distress (25%, 95% CI (11% to 39%)). The risk matrix for boys, including PA level and musculoskeletal pain, showed similar results. Boys with a high PA level and no musculoskeletal pain had the lowest probability of obesity in young adulthood with 14% (95% CI (9% to 19%)), compared to 27% (95% CI (16% to 38%)) in boys with low PA who reported musculoskeletal pain (Table 4). Overall, about one in four adolescents with a low PA level in combination with musculoskeletal pain had developed obesity by young adulthood, compared to one in seven to nine adolescents with a high PA level and absence of musculoskeletal pain.

Results from sensitivity analyses, with normal weight, rather than both normal and overweight individuals, as the reference group, suggested stronger predictive value of tested risk factors, thus supporting the main results (Appendix B; Table A1, Table A2, Table A3).

Table 3. Risk matrix model for girls. Probability of obesity (BMI ≥ 30 kg/m^2) (percentage, (95% confidence interval (CI)) in young adulthood.

		PA Level		
		Low PA	**Moderate PA**	**High PA**
MS pain	**Psychol. distress**	25% (11–39%)	18% (3–33%)	17% (1–33%)
	No psychol. distress	24% (15–33%)	17% (10–24%)	16% (8–24%)
No MS pain	**Psychol. distress**	18% (1–35%)	13% (0–32%)	12% (0–35%)
	No psychol. distress	17% (11–23%)	12% (8–16%)	11% (6–16%)

Physical activity (PA) level (low PA = ≤1 day/week, moderate PA = 2–3 days/week, high PA = ≥4 days/week), presence of musculoskeletal (MS) pain (never/seldom or sometimes/often) and psychological distress (SCL5, <2 points or ≥2 points). Red = highest risk profile.

Table 4. Risk matrix model for boys. Probability of obesity (BMI ≥ 30 kg/m^2) (percentage, (95% CI)) in young adulthood.

	PA Level		
	Low PA	**Moderate PA**	**High PA**
MS pain	27% (16–38%)	20% (12–28%)	17% (7–27%)
No MS pain	22% (16–28%)	16% (11–21%)	14% (9–19%)

Physical activity (PA) level (low PA = ≤1 day/week, moderate PA = 2–3 days/week, high PA = ≥4 days/week), presence of musculoskeletal (MS) pain (never/seldom or sometimes/often) and psychological distress (SCL5, <2 points or ≥2 points). Red = highest risk profile.

4. Discussion

In this prospective population-based study we found that low levels of PA in adolescence increased the probability of obesity in young adulthood. Early musculoskeletal pain, in combination with low PA, contributed consistently and additively to the adverse effect. A low PA level in combination with musculoskeletal pain doubled adolescents' risk of developing obesity by young adulthood, as compared to their physically active peers without musculoskeletal pain.

These results are in line with findings from prior studies where longitudinal relationships between physical inactivity in adolescence and obesity in young adulthood have been reported [42]. The current study adds to previous knowledge by estimating the probability of obesity in young adulthood given combinations of PA levels and two of the most common and burdensome health challenges among adolescents, musculoskeletal pain and psychological distress [7,8]. Our results indicate that the presence of musculoskeletal pain in adolescence predicts development of obesity by young adulthood. Thus, adolescents' pain may precede obesity, rather than vice versa. This finding may challenge our current belief that pain is often a consequence of obesity. As an example, increased clinical attention to weight status among adolescents with pain has previously been emphasized based on the high rate of obesity (1/3) found among adolescents with chronic pain who have been consulting pain clinics [24,25]. Thus, the current study adds valuable knowledge to existing research from pediatric pain clinics by demonstrating how musculoskeletal pain reported in a population-based sample of adolescents may contribute to long-term weight-related consequences into young adulthood.

We further anticipated higher probability of obesity among adolescents struggling with both psychological distress and musculoskeletal pain as the co-occurrence of these health challenges is linked to worse pain and decreased functioning [19]. However, in our study we did not find support for an added effect of early psychological distress on adult obesity when accounting for PA level and musculoskeletal pain. This finding contrasts with results from prior studies that have reported an increased risk of obesity in adulthood among those with depressive symptoms in adolescence [26,43,44]. There is a possibility that pain and withdrawal from social contexts, including regular sports activities, may represent the active agents driving or mediating the previously found adverse effect of psychological distress on development of obesity. A reason for the lack of associations between psychological distress in adolescence and later onset obesity in the present study might, however, also be a lack of statistical power due to the sample size and the relatively few cases of obesity in our material.

Prospective studies that examine multiple potential risk factors for obesity, as well as their co-occurrence, in diverse samples of adolescents are needed to enhance our understanding of the complexity of factors that may contribute to the development of obesity [32]. Taken together, findings from this study support the need for public health efforts to focus on proactive strategies to promote and customize sports activities for all adolescents. Early identification of pain and subsequent implementation of need-based treatment may represent an opportunity to prevent the development of obesity, as the additional adverse effect of musculoskeletal pain on lower PA levels indicated a strong tendency towards increased probability of obesity. Further, our findings pointed in the same direction for both genders, which strengthens our confidence in the results. Sensitivity analyses, where the reference groups were limited to participants within a normal weight range in young adulthood, revealed even higher probabilities of obesity across combinations of lower levels of PA and occurrence of musculoskeletal pain, and thus confirmed the robustness of the results from our main analysis.

The results of this study suggest that health care professionals should be aware of the potential increased likelihood of future obesity among adolescents with low levels of PA who also report musculoskeletal pain. In particular, adolescents who are at risk of being obese or having difficulty with weight management may require greater attention in examinations of musculoskeletal pain, assessment of potential underlying causes, and implementation of need-based treatment, in addition to the emphasis on providing information on the benefits of PA and activity guidance.

Of the three exposure factors examined in this study, a low level of PA in adolescence was most strongly associated with obesity in young adulthood. PA is probably the most modifiable of the factors examined, as getting adolescents to be more physically active and to participate in sports and activities may be easier than treating anxiety, depression, and musculoskeletal pain. Additionally, an increase in PA may lead to higher levels of socialization through inclusion in community activities, thereby creating opportunities for development of social skills and social competence, which in turn may provide benefits for musculoskeletal health and mental health [45,46]. Further, based on the current findings, musculoskeletal pain appears to be a stronger predictor than psychological distress. This might be of special importance as musculoskeletal pain could be easier to detect and to modify through interventions than psychological distress.

Although there is existing evidence to suggest that low levels of PA [11,32], musculoskeletal pain [24,25], and psychological distress [26–28] are factors to consider in the prevention of obesity, this study is unique in examining the potential long-term impact of combinations of these adverse health factors on the probability of obesity. The study uses a representative population-based sample of adolescents with an 11-year follow-up period capturing the transition period from adolescence into young adulthood.

A limitation of our study is that our exposure measures were self-reported. However, PA has been assessed using the WHO HBSC measure of frequency of PA, which has been validated for use in adolescent samples [40,47]. We have used a validated measure to assess psychological distress (SCL-5), with a cut-off point shown to be clinically relevant [41]. The questions about musculoskeletal pain only provided information about pain frequency, not severity, and may be prone to recall bias due to the 12-month recall period. Reports of "neck or shoulder pain" and "joint or muscle pain" were combined into one category of musculoskeletal pain due to the lack of statistical power to analyze them separately, and a drawback may be that information about pain localization is not taken into account. Another limitation is the low follow-up participation rate from the Young-HUNT1 study to the HUNT3 study, which may represent a selection bias. Many young adults had moved out of the county for educational purposes and were not eligible for invitation at follow-up. However, baseline values were comparable between participants and non-participants in the 11-year follow-up from the Young-HUNT1 study to the HUNT3 study regarding PA level and mean BMI [36], indicating that the drop out is unlikely to substantially influence the results. Further, comparisons between these groups showed no significant differences in occurrence of musculoskeletal pain or psychological distress at baseline.

Although the probability estimates indicated a strong pattern of increased probability of obesity across lower levels of PA in combination with musculoskeletal pain in both genders, the relatively low number of obese young adults resulted in low precision as reflected in the wide 95% CIs, especially for girls where three factors (PA level, musculoskeletal pain, and psychological distress) were included into the final regression model. Hence, we emphasize the patterns in our findings, and recommend caution in the interpretation of the single probability estimates. Further research assessing the combined effects of these health challenges in adolescence on the probability of obesity is needed to confirm the findings, ideally with more frequent follow-ups and improved measurement methods, including more detailed assessment of pain location and severity.

Lastly, as regression analyses for prediction purposes were conducted to identify subgroups of adolescents at high risk of obesity focusing on the three aforementioned factors, other health risk factors that might make additional contributions to PA limitations and the risk of obesity, such as diet, smoking, alcohol and drug use, have not been taken into account. Further, BMI status at baseline was not considered. However, only 40 adolescents (2%) were obese at baseline.

5. Conclusions

The study shows that adolescents with a low PA level may have a higher probability of obesity in young adulthood, and that co-occurrence of musculoskeletal pain further increases the probability of later obesity. Our findings support proactive strategies to make regular sports activities more inclusive and accessible for all adolescents in order to reduce risk of becoming obese in young adulthood. Interventions targeting adolescents' musculoskeletal pain and underlying causes could make an important contribution in hindering the development of obesity in adolescents at risk.

Author Contributions: All authors collaboratively conceived the present study in the following roles: Conceptualization, M.H.G., S.Ø.S., M.C.S., J.-A.Z. and K.S.; Formal analysis, M.H.G. and M.C.S.; Methodology, M.H.G., M.C.S. and K.S.; Project administration, M.H.G., K.S. and J.-A.Z.; Supervision, S.Ø.S., M.C.S., J.-A.Z. and K.S.; Visualization, M.H.G. and M.C.S.; Writing—original draft, M.H.G.; Writing—review & editing, M.H.G., S.Ø.S., M.C.S., M.B.J., I.H., J.-A.Z. and K.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

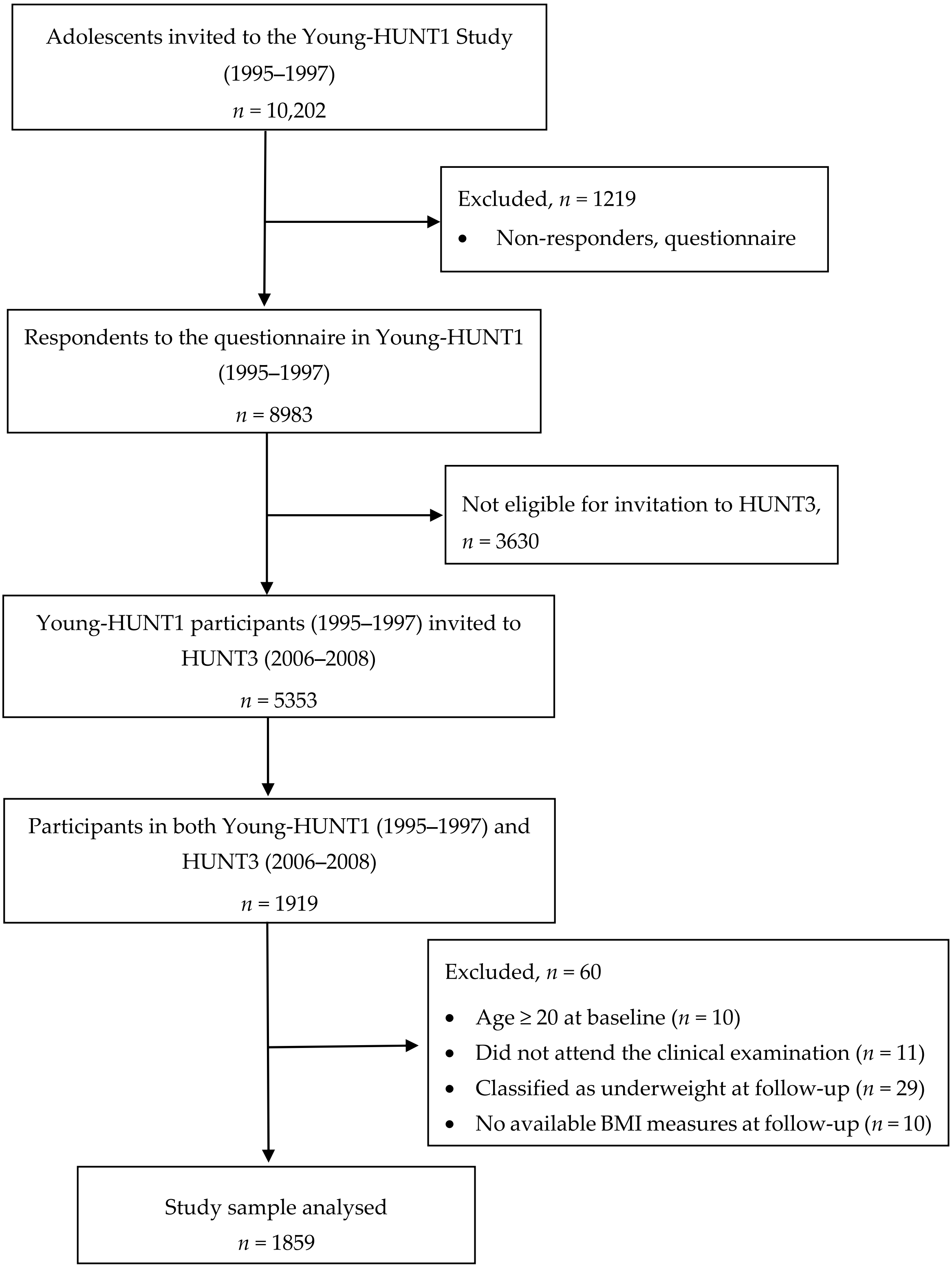

Figure A1. Flow Chart of the Study Sample.

Appendix B

Table A1. Results from logistic regression analysis with obesity (BMI ≥ 30) as dependent variable, with the reference group restricted to individuals within normal weight (BMI 18.5–24.9 kg/m^2).

Variables	Univariate Analysis			Multivariate Analysis		
	OR	95% CI	p-Value	OR	95% CI	p-Value
Girls						
PA level						
Low PA		1.0 (Reference)			1.0 (Reference)	
Moderate PA	0.69	0.46–1.02	0.06	0.68	0.45–1.03	0.07
High PA	0.63	0.39–1.01	0.05	0.59	0.36–0.97	0.04
Musculoskeletal pain						
No		1.0 (Reference)			1.0 (Reference)	
Yes	1.56	1.09–2.22	0.02	1.58	1.08–2.31	0.02
Psychological distress *						
No		1.0 (Reference)			1.0 (Reference)	
Yes	1.46	0.88–2.42	0.15	1.11	0.65–1.90	0.71
Boys						
PA level						
Low PA		1.0 (Reference)			1.0 (Reference)	
Moderate PA	0.66	0.41–1.04	0.07	0.61	0.38–0.97	0.04
High PA	0·45	0.27–0.75	<0.01	0.43	0.26–0.72	<0.01
Musculoskeletal pain						
No		1.0 (Reference)			1.0 (Reference)	
Yes	1.26	0.82–0.93	0.28	1.28	0.83–1.97	0.27
Psychological distress *						
No		1.0 (Reference)			1.0 (Reference)	
Yes	1.33	0.58–3.07	0.50	-		-

High PA = ≥4 days/week, Moderate PA = 2–3 days/week, Low PA = ≤1 day/week; * SCL-5 ≥ 2, SCL5 = Hopkins Symptom Checklist Five Items (range 0–4).

Table A2. Sensitivity analyses, risk matrix model for girls. Probability of Obesity (BMI ≥ 30) (percentage, (95% CI)) in young adulthood, with the reference group restricted to individuals within a normal weight range (BMI 18·5–24·9 kg/m^2).

		PA Level		
		Low PA	**Moderate PA**	**High PA**
MS pain	**Psychol. distress**	35% (20–50%)	27% (10–44%)	24% (5–43%)
	No psychol. distress	32% (23–41%)	25% (17–33%)	22% (12–32%)
No MS pain	**Psychol. distress**	25% (6–44%)	19% (0–41%)	17% (0–43%)
	No psychol. distress	23% (17–29%)	17% (13–21%)	15% (9–21%)

Physical activity (PA) level (low PA = ≤1 day/week, moderate PA = 2–3 days/week, high PA = ≥4 days/week), presence of musculoskeletal (MS) pain (never/seldom or sometimes/often), and psychological distress (SCL5, <2 points or ≥2 points). Red = highest risk profile.

Table A3. Sensitivity analyses, risk matrix model for boys. Probability of Obesity (BMI ≥ 30) (percentage, (95% CI)) in young adulthood, with the reference group restricted to individuals within a normal weight range (BMI 18·5–24·9 kg/m^2).

	PA Level		
	Low PA	**Moderate PA**	**High PA**
MS pain	43% (31–55%)	32% (22–42%)	25% (14–36%)
No MS pain	37% (30–44%)	27% (21–33%)	20% (14–26%)

Physical activity (PA) level (low PA = ≤1 day/week, moderate PA = 2–3 days/week, high PA = ≥4 days/week), presence of musculoskeletal (MS) pain (never/seldom or sometimes/often), and psychological distress (SCL5, <2 points or ≥2 points). Red = highest risk profile.

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Errataliste

Navn kandidat: Maren Hjelle Guddal

Avhandlingstittel: Physical activity and sport participation in adolescence. Health implications related to musculoskeletal pain, mental health and obesity. The HUNT Study

Forkortelser for type rettelser:

Cor – korrektur

Celtf – endring av sidelayout eller tekstformat

Side	Orginaltekst	Type rettelse	Korrigert tekst
100, Appendix	Self-esteem (RSES) 73. Når du tenker på hvordan du har det for tida, er du stort sett fornøyd eller er du stort sett misfornøyd?...	Celtf	Self-esteem (RSES) 77. Hva slags oppfatning har du av deg selv?...
100, Appendix	Life satisfaction 77. Hva slags oppfatning har du av deg selv?...	Celtf	Life satisfaction 73. Når du tenker på hvordan du har det for tida, er du stort sett fornøyd eller er du stort sett misfornøyd?...
29	…perception of painand emotional stress…	Cor	...perception of pain and emotional stress…