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ACTA UNIVERSITATIS OULUENSIS

Soile Puhakka

NATURAL RESIDENTIAL ENVIRONMENT AND PHYSICAL ACTIVITY IN ADOLESCENCE AND MIDLIFE – THE ROLE OF GREENNESS, LANDSCAPE DIVERSITY, AND NATURE RELATEDNESS

UNIVERSITY OF OULU GRADUATE SCHOOL;
UNIVERSITY OF OULU,
FACULTY OF MEDICINE;
FACULTY OF SCIENCE;
OULU DEACONESS INSTITUTE FOUNDATION SR.;
MEDICAL RESEARCH CENTER OULU

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Academic dissertation to be presented with the assent of the Doctoral Programme Committee of Health and Biosciences of the University of Oulu for public defence in the Wegelius Auditorium of Oulu Deaconess Institute (Albertinkatu 16), on 26 January 2024, at 12 noon

UNIVERSITY OF OULU, OULU 2024

Acta Univ. Oul. D 1765, 2024

Supervised by
Professor Raija Korpelainen
Doctor Tiina Lankila

Reviewed by
Docent Riikka Puhakka
Associate Professor Erja Portegijs

Opponent
Professori Liisa Tyrväinen

ISBN 978-952-62-3965-1 (Paperback)
ISBN 978-952-62-3966-8 (PDF)

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

Cover Design
Raimo Ahonen

PUNAMUSTA
TAMPERE 2024

Puhakka, Soile, Natural Residential Environment and Physical Activity in Adolescence and Midlife – The Role of Greenness, Landscape Diversity, and Nature Relatedness.
University of Oulu Graduate School; University of Oulu, Faculty of Medicine; Faculty of Science; Oulu Deaconess Institute Foundation sr; Medical Research Center Oulu
Acta Univ. Oul. D 1765, 2024
University of Oulu, P.O. Box 8000, FI-90014 University of Oulu, Finland

Abstract

Physical activity reduces the risk of non-communicable disease by improving physiological and psychological health. Still, many adults and adolescents worldwide are physically inactive. Recently, epidemiological studies have noted the positive impact of natural residential environments on physical activity among youth and adults. Also, research has suggested that strong nature relatedness could be one of the motivating factors for physical activity among young adults. The associations of natural environments, nature relatedness, and physical activity have not been comprehensively studied in large population-based settings.

The purpose of this study was to investigate the association between residential greenness, residential landscape diversity, and accelerometer-measured physical activity at midlife. The data were collected in the population-based Northern Finland Birth Cohort 1966 (n = 5,433). In addition, this study aimed to explore the connection between nature relatedness and self-reported physical activity in the population-based MOPO study (n = 914) among adolescent men. Participants in both studies completed comprehensive health and behaviour questionnaires and went through clinical examinations. Multiple linear regressions and generalized additive models were used to study the associations between explanatory and outcome variables.

A positive association was found between residential greenness and light physical activity, especially in middle-aged men. A positive association was also found between landscape diversity (combination of forests, fields, wetlands, and landforms) and total physical activity in middle-aged men and women. In adolescent men, nature relatedness, current physical activity and physical activity in childhood were positively associated.

As a conclusion, residential greenness and landscape diversity can possibly have a positive effect on physical activity. Nature relatedness can support the physical activity of adolescent men.

Keywords: geographic information systems, greenness, landscape, nature relatedness, physical activity

Puhakka, Soile, Luonnollinen asuinympäristö ja fyysinen aktiivisuus nuoruudessa ja keski-iässä – Vihreyden, maiseman monimuotoisuuden ja luontosuhteen rooli.
Oulun yliopiston tutkijakoulu; Oulun yliopisto, lääketieteellinen tiedekunta; luonnontieteellinen tiedekunta; Oulun Diakonissalaitoksen Säätiö sr; Medical Research Center Oulu
Acta Univ. Oul. D 1765, 2024
Oulun yliopisto, PL 8000, 90014 Oulun yliopisto

Tiivistelmä

Fyysinen aktiivisuus on yhteydessä parempaan fyysiseen ja psyykkiseen terveyteen. Siitä huolimatta suuri osa nuorista ja aikuisista ja ei liiku terveytensä kannalta riittävästi. Luonnollisten asuinympäristöjen merkitys asukkaiden fyysiselle aktiivisuudelle on tunnistettu epidemiologisissa tutkimuksissa. On myös havaittu, että vahva luontosuhde voi kannustaa nuoria aikuisia liikkumaan. Luontoympäristöjen, luontosuhteen ja fyysisen aktiivisuuden yhteyksiä ei ole kuitenkaan tutkittu laajoissa, väestöpohjaisissa aineistoissa.

Tämän tutkimuksen tarkoituksena oli tutkia asuinympäristön vihreyden sekä maiseman yhteyttä keski-ikäisten suomalaisten (n= 5433) kiihtyvyysanturilla mitattuun fyysiseen aktiivisuuteen. Tutkimusaineisto kerättiin väestöpohjaisessa Pohjois-Suomen syntymäkohortti 1966- tutkimuksessa. Tässä tutkimuksessa selvitettiin myös luontosuhteen yhteyttä nuorten miesten (n= 914) itse arvioituun fyysiseen aktiivisuuteen (väestöpohjainen MOPO-tutkimus). Molemmissa aineistoissa tutkittavat täyttivät laajat terveyttä ja terveyskäyttäytymistä koskevat kyselyt ja osallistuivat kliiniseen mittauksiin. Aineisto analysoitiin käyttäen lineaarista monimuuttujaregressiomallinnusta ja yleistettyä additiivista mallia.

Asuinympäristön vihreys oli positiivisesti yhteydessä erityisesti keski-ikäisten miesten kevyeen fyysiseen aktiivisuuteen. Maiseman monimuotoisuus (metsien, peltoalueiden, suoalueiden ja geomorfologisten muodostumien yhdistelmä) oli yhteydessä keski-ikäisten fyysiseen kokonaisaktiivisuuteen. Vahva luontosuhde sekä vanhempien kanssa nykyään ja lapsuudessa yhdessä liikkuminen olivat tilastollisesti merkitsevästi yhteydessä suurempaan fyysisen aktiivisuuden määrään.

Asuinympäristön vihreys ja maiseman monimuotoisuus voivat edistää keski-ikäisten fyysistä aktiivisuutta. Vahva luontosuhde voi puolestaan kannustaa nuoria miehiä liikkumaan enemmän.

Asiasanat: fyysinen aktiivisuus, luontosuhde, maisema, paikkatieto, vihreys

To my dear children Leonardo and Elisabet

"It's a dangerous business, going out your door. You step onto the road, and if you don't keep your feet, there's no knowing where you might be swept off to."
Adapted from The Lord of the Rings by J. R. R. Tolkien

Acknowledgements

This doctoral dissertation was conducted at the Department of Sports and Exercise Medicine at the Oulu Deaconess Institute Foundation, at the Geography Research Unit at the University of Oulu, and at the Research Unit of Population Health at the University of Oulu.

This beginning of my research career would not have been possible without my excellent supervisors, colleagues, friends, and family. Raija Korpelainen, you used to say that ‘Soile’s thoughts fly so high somewhere in the atmosphere that she needs somebody to hold the strings, or she will be lost somewhere in the stratosphere’. That is very true; thank you for holding the strings. Thank you for trusting me and giving me the opportunity to start my career in your team back in 2015. Tina Lankila, thank you for encouraging and supporting me through the journey. We have had so many nice conversations, and I really appreciate all your help and wise words. Jarmo Rusanen, I wanted especially to thank you for introducing me to Raija’s team as a trainee candidate on Labour Day 2015.

I would like to express my gratitude for my excellent colleagues and co-authors Maija Korpisaari, Riitta Pyky, Katja Kangas, Mikko Kärmeniemi, Maisa Niemelä, Tiina Ikäheimo, Helena Tukiainen, Janne Alahuhta, Jan Hjort, Vahid Farrahi, Pekka Korpelainen, Maarit Kangas, Simo Näyhä, and Heli Koivumaa-Honkanen. I really appreciate your help and effort for this thesis. I also want to thank all the people of ODL Liikuntaklinikka. You are simply the best team to work with! I wish to thank the participants of the NFBC1966 46-year follow-up and the participants of the MOPO study for their commitment to this study. Thank you to the funders for supporting this study.

Thank you, mom and dad, for everything. You have always supported me and offered me the best circumstances for my life and studies. I want to thank my children Leonardo and Elisabet for being the inspiration of my life – I’m doing this especially for you. Thank you Tapio for supporting me when I was struggling with the writing process. Thank you, my friends, for taking my thoughts somewhere else than just the academic world. I’m very grateful that I have people like you in my world. Finally, since the past years have been very busy, I want to thank my dear horses Geysir, Pete, and Elmeri and my ‘supervisor’ Viiru the cat for being my sincere friends through the journey. Nothing makes you forget your worries better than ‘muzzle and paw therapy’.

Date

August 2023 Soile Puhakka

Abbreviations

BMI	Body mass index
EE	Energy expenditure
GAM	Generalized additive model
GIS	Geographic information system
LPA	Light physical activity
LTPA	Leisure time physical activity
MET	Metabolic equivalent of task
MPA	Moderate physical activity
MVPA	Moderate to vigorous physical activity
N	Number of participants
NDVI	Normalized difference vegetation index
NFBC1966	Northern Finland Birth Cohort 1966
NR	Nature relatedness
PA	Physical activity
SES	Socioeconomic status
VPA	Vigorous physical activity
VPA/VVPA	Vigorous/very vigorous physical activity
WHO	World Health Organization

Original publications

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

I Puhakka, S., Lankila, T., Pyky R., Kärmeniemi, M., Niemelä, M., Kangas, K., Rusanen, J., Kangas, M., Näyhä, S., & Korpelainen, R. (2019). Satellite imaging-based residential greenness and accelerometry measured physical activity at midlife – Population-based Northern Finland Birth Cohort 1966 study. *International Journal of Environmental Research and Public Health, 17*(24), 9202. https://doi.org/10.3390/ijerph17249202

II Puhakka, S., Kangas, K., Lankila, T., Niemelä, M., Kärmeniemi, M., Tukiainen, H., Alahuhta, J., Hjort, J., & Korpelainen, R. (2022). Association between Residential Natural Landscape Diversity and Accelerometer-measured Physical Activity in adults: Population-based Northern Finland Birth Cohort 1966 Study. (*Manuscript*)

III Puhakka, S., Pyky, R., Lankila, T., Kangas, M., Rusanen, J., Ikäheimo, T. M., Koivumaa-Honkanen, H., & Korpelainen, R. (2018). Physical activity, residential environment and nature relatedness in young men – A population-based MOPO study. *International Journal of Environmental Research and Public Health*, *15*(10), 2322. https://doi.org/10.3390/ijerph15102322

Contents

1 Introduction

Physical inactivity is a global pandemic that is associated with the risk of many non-communicable diseases such as cardiovascular diseases, musculoskeletal and connective tissue disorders, type 2 diabetes, colon and breast cancer, and mental health problems (Katzmarzyk et al., 2022; Lee, 2012). In addition to causing unnecessary deaths, physical inactivity is a huge burden for public health care, costing more than $67.5 billion internationally (Ding et al., 2016). In Finland, the cost of physical inactivity is estimated to be approximately 3.2 billion (Kolu et al., 2022). The World Health Organization (2020) has provided guidelines for weekly physical activity (PA). The latest PA recommendations in the US and in Finland replace sedentary time with light-intensity activities (UKK Institute, 2019; US Department of Health and Human Services, 2018). In 2020, the World Health Organization recommended that adults do at least 150–300 minutes of moderate-intensity aerobic PA, at least 75–150 minutes of vigorous intensity aerobic PA, or an equivalent combination of these throughout the week, with muscle-strengthening activities involving all major muscle groups done on two or more days a week (World Health Organization, 2020). For children and adolescents, the recommendations were higher, involving at least an average of 60 minutes per day of mostly aerobic moderate to vigorous physical activity (MVPA) and vigorous/very vigorousphysical activity (VPA/VVPA), as well as muscle- and bone-strengthening activities at least three days a week (World Health Organization, 2020).

As physical inactivity is linked to many non-communicable diseases, adults, adolescents and children are at increased risk of health problems (van Sluijs et al., 2019). Many adults, including middle-aged adults, do not meet the recommendations for physical activity. In addition, 80% of adolescents worldwide are physically inactive (Hallal, 2012; van Sluijs, 2021). The burden of physical inactivity among individuals 18 years old and older is most alarming in high-income countries such as Finland, and the prevalence has increased in these countries over time (Guthold et al., 2018). In comparison, the greatest number of physically inactive people can be found in middle-income countries, while the low-income countries have the lowest number (Katzmarzyk et al., 2022).

Increasing evidence has shown that the residential environment has an important role in daily routines, including physical activity behaviour. In particular, residential greenness has been suggested to be positively linked to physical activity (Karusisi, 2012; Klompmaker, 2018; Smith, 2019). Physical activity in green environments has also been shown to be more encouraging and restorative, and it can require less exertion compared to physical activity indoors (Akers, 2012; Araujo et al., 2019; Focht, 2009; Gladwell, 2013; Hug, 2009). Green environments provide many other physiological and psychological benefits (Beyer et al., 2014; James et al., 2015; van Dillen et al., 2012), and greenness combined with physical activity can be beneficial for our health (Han, 2017; Pretty et al., 2007; van den Berg et al., 2015).

In addition to examining residential greenness, a few studies exist on the associations between the natural landscape and physical activity. As the term 'landscape' is complex and very broad, previous studies have mainly focused on certain landscape types rather than the diverse landscape itself (Abraham et al., 2010). Aesthetic and diverse residential landscapes are vital for human health, encouraging us to spend time outdoors rather than indoors (Miralles-Guasch et al., 2019). Previous studies have mainly focused on green and blue environments, while the whole spectrum of landscape features – such as topography and landforms – has not been considered in the literature.

Strong nature relatedness (NR) or nature connectedness is positively linked to regular visits to natural areas (Martin et al., 2020; Zelenski & Nisbet, 2014). Urbanization and modern lifestyles have deepened the disconnect between people and nature and may have weakened our relationship with nature entirely (Bratman et al., 2012; Parker & Simpson, 2020; Soga et al., 2016). Nature relatedness and its association with physical activity has not been widely studied, but strong nature relatedness has been positively linked to physical activity and many health and well-being benefits (Lawton et al., 2017; Maas, 2006; Zelenski & Nisbet, 2012; Zelenski, 2014) People with strong nature relatedness tend to visit natural areas more often and regularly (Calogiuri & Chroni, 2014; Flowers et al., 2016), which can lead to higher amounts of physical activity. Visits to nature can have implications for exposure to nature's health benefits, and deeper nature relatedness can bolster positive feelings (Lawton et al., 2017). For example, visits to natural environments have been shown to be positively associated with mental health (White et al., 2021).

This study addresses the knowledge gap present in the current scientific literature and provides a better understanding of the associations between residential natural environment, nature relatedness, and physical activity. The study contributed to the existing literature understanding of the association of natural environments, nature relatedness and physical activity based on the large population settings living in different kinds of northern residential environments.

The first part of this study investigates the association between residential greenness and accelerometer-measured physical activity among Finnish middle-aged men and explores whether threshold values for ideal amounts of greenness exist (I). The second part examines the role of residential landscape diversity and accelerometer-measured physical activity in the same population (II), which has not been widely studied before. Finally, the third part focuses for the first time on the role of nature relatedness in physical activity and health among Finnish adolescent men (III).

2 Review of the Literature

2.1 Physical activity

Physical activity is considered to be any body movement above metabolic resting rate that results in energy expenditure (EE) (Myers et al., 2015; World Health Organization, 2019). The term differs from the term ‘exercise’, which aims to improve physical performance in a more goal-oriented way. Physical activity can technically be any kind of activity that causes movement, such household chores, transportation from one place to another, work-related activities, and actual sports (Caspersen, 1985). Physical activity can be divided into aerobic physical activity (endurance or ‘cardio’) and anaerobic physical activity depending on the aerobic energy-generating process (World Health Organization, 2010). Aerobic exercise is any kind of exercise type (e.g., running) that is linked to heavy oxygen demand in the cells. Anaerobic exercise (e.g., weightlifting) is dependent on glucose instead of oxygen, using energy quickly and efficiently (American College of Sports Medicine, 2013; Patel et al., 2017).

2.1.1 Physical activity in youth and midlife

Physical inactivity is common both in adolescents and adults. Worldwide, 27.5% do not meet the physical activity recommendations for health (Guthold et al., 2018; Katzmarzyk et al., 2021). In high-income Western countries, the overall percentage of insufficient physical activity is remarkably high, 36.8%. In Finland, the prevalence is lowest (16.6%), but it is expected to increase in the future (Guthold et al., 2018). Although leisure time physical activity (LTPA) in Finland has increased in the past 20 years (Borodulin & Wennman, 2019), adults are sedentary most of their day, approximately nine hours (Husu et al., 2021). For comparison, in Canada, adults are sedentary 9–10 hours of the day (Travis et al., 2020). Among adults, sedentary behaviour is typically work-related, but both adults and adolescents have been found to have similar leisure-time activities such as screen-based-behaviour (Aapola-Kari, 2022; Basterra et al., 2014).

Worldwide, 80% of adolescents do not meet the current recommendations for physical activity (Hallal et al., 2012). The younger generation spends an increasing amount of their free time engaged in indoor activities such as using the internet, social media, and games (Matthews et al., 2008; Tammelin et al., 2007; Thomée et al., 2015). A physically inactive lifestyle in childhood is associated with inactivity in adulthood (Kallio et al., 2020). Thus, childhood is a highly important period for learning habitual patterns of physical activity (Telama et al., 2014) and even preventing non-communicable diseases in adulthood and older age (Sawyer et al., 2012).

According to previous studies, low physical activity and high sedentary behavior have been linked to substantial economic burden, including both direct (health care utilization) and indirect (non-health sector) costs. At the global level, the direct and indirect costs of low physical activity were estimated to range from INT $67.5 billion to INT $145.2 billion (Ding et al., 2017). In Finland, the total costs of low PA and high sedentary behavior (SED) have been estimated to range from €1.5 billion to €3.2 billion in 2017 (Kolu et al., 2022).

2.1.2 Physical activity and health

According to previous evidence, physical activity has several physiological and psychological health outcomes. It has been linked to better cardiovascular health (Lacombe et al., 2019), insulin sensitivity, lowering cardiovascular risk factors such as haemostatic and inflammation (LaCroix et al., 2021; LaMonte et al., 2019; Lee et al., 2012), lower risk of musculoskeletal disorders (injuries or disorders of the muscles, joints, nerves, tendons, cartilage, and spinal discs) (Aktürk et al., 2019; Wu et al., 2017), and lower risk of pulmonary disease (Pelkonen et al., 2003) and colon and breast cancer (McTiernan et al., 2019). Physical activity has also been associated with better mental health (Teychenne et al., 2020), possibly because PA may ease symptoms of stress, anxiety, and depression or at least have a protective role (Biddle et al., 2019; Faulkner et al., 2022; Rodriguez-Ayllon et al., 2019; Tamminen et al., 2020; Teychenne et al., 2020).

Considering the health outcomes of PA, the field of sports sciences has been interested in not only the intensity of PA but also the importance of its dose and continuum (Chastin et al., 2019; Ekelund et al., 2019; Farrahi et al., 2021). Many of the previous studies on the association between PA and health have mostly focused on MVPA. However, according to recent studies, even a smallest decrease in sedentary lifestyle behaviours toward light physical activity is better than none (Chastin et al., 2019; Fuezeki et al., 2017). This knowledge supports the advantage of even small efforts to become less sedentary, also indicating the importance of light physical activity and total physical activity. Light physical activity has recently been found to be positively associated with health as well. It has been shown to be beneficial for cardiovascular health (Amagasa, 2018; Chastin et al., 2019; Howard et al., 2015; Matthews et al., 2016; Riou et al., 2014), all-cause mortality, diabetes markers (Bird et al., 2017; Healy et al., 2007), mental health (Hamer et al., 2014), and higher cognitive functioning (Johnson et al., 2016). In addition, total physical activity, which includes all physical activity performed at any intensity level, has been found to reduce the risk of cardiovascular diseases, mortality (Aune et al., 2021; Lear et al., 2017), and premature death (Ekelund et al., 2019). In high-income countries, leisure-time PA (LTPA) has been suggested to have the main role, whereas household chores and transportation are the main physical activities in low- and middle-income countries (MacNiven et al., 2012). As LTPA can be integrated into daily activities in many ways and does not require actual time planning or commitment to exercise (Buman et al., 2017), increasing LTPA could be an especially feasible way to improve the most sedentary people's physical activity at the population level (Pulsford et al., 2017).

2.2 Determinants of physical activity in youth and midlife

To improve physical activity, it is important to identify the major determinants of PA and understand which of them are modifiable (Brug et al., 2017).

2.2.1 Ecological model of the determinants of physical activity

Because physical activity is affected by diverse factors, models and behavioral theories are needed to understand causally which behavior changes and modifiable factors in an individual's everyday environment affect PA (Bauman et al., 2002).

An ecological model (Fig. 1) of the determinants of PA consists of both an individual's social and physical environments and their relationships. Ecological models are frameworks that target increasing population PA through evidence-based public health planning of PA. Individual and interpersonal determinants of PA (such as biological and psychological factors) are widely studied, yet the associations between the environment, global variables, and policy on PA are less known. It has been suggested that all these factors are related and that their combination is expected to influence PA (Bauman et al., 2012).

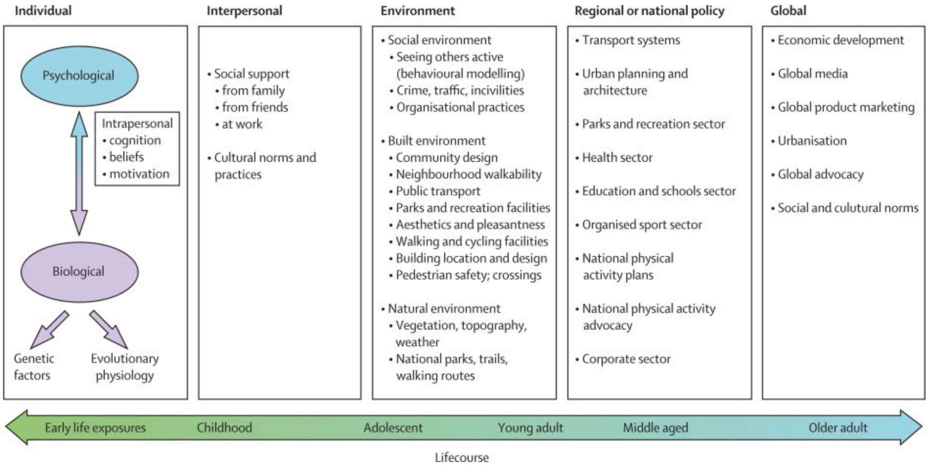

Fig. 1. Ecological model of the determinants of physical activity (Bauman et al., 2012) Copyright 2012 by Elsevier Ltd. Reprinted with permission.

2.2.2 Genetics

A recent study suggests that physical activity is a major factor in our evolutionary history due its preventive role in many diseases (Kim et al., 2022); therefore, it is important in many ways to improve population health and especially prevent sedentary behaviour. As the main findings of previous studies suggest, biological factors such as genetics regulate physical activity at the individual level (Aaltonen et al., 2013; Stubbe & de Geus, 2009), but maximum performance is strongly heritable (Bouchard et al., 1999). Physical activity can also suppress the genetic risk of adiposity (Schnurr et al., 2021). The effect of genetics has been studied to be strongest in adolescence, slowly decreasing toward young adulthood. Epigenetics can be described as changes in gene functioning that cannot be explained by changes in DNA sequence (Russo et al., 1996). Previous studies suggest that epigenetic response, being a dynamic process, can be influenced by aging, physical activity, nutrition, and the environment. DNA methylation is one of the most studied epigenetic processes, allowing gene expression and the so-called 'activation process of genes. Physical activity, in turn, can alter epigenetic effects, having significant health benefits and preventing chronic diseases (Klose & Bird, 2006).

2.2.3 Health, health behaviour, and psychological factors

Health, as a term, is multidimensional. According to the World Health Organization (WHO), health is 'a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity' (WHO, 2006). An individual's health affects physical activity, and health barriers and physical activity limitations may vary by age and gender. Generally, mental health – especially stress and low mood (Firth et al., 2016), chronic diseases, and different symptoms are factors linked to low physical activity (Brazeau et al., 2008; Brawley et al., 2003; Clark, 1999; Zalewski et al., 2011) and obesity (McIntosh et al., 2016).

Health behaviour consists of individual daily actions, thoughts, and attitudes that control the choices that we make for our health. Health behaviour can be both beneficial and harmful. For example, a healthy diet is good for our health, and physical inactivity is harmful for our overall health. Smoking, excessive alcohol consumption, media overuse, obesity, and an unhealthy diet are risk behaviours linked to physical inactivity and poor health both in adults and adolescents (Kenney & Gortmaker, 2017; Sawyer et al., 2012; van Sluijs et al., 2021). Risky health behaviours can also be the result of other factors, for example, socioeconomic status (SES). Generally, people with low SES are less physically active and have more risky health behaviour than those with high SES (Stalsberg et al., 2018; Trost et al., 2002). Health behaviour determinants of physical activity can be different for people with disabilities and chronic illness. Generally, living with a chronic illness is stressful, affecting the quality of life. Health status has been suggested to be one of the main determinants of PA in adults (Bauman et al., 2012). Many chronic diseases, such as cancer, CVD, stroke, diabetes, bowel diseases, HIV, renal diseases, and diseases of the central nervous system, can potentially worsen the patient's overall health. Diseases can limit their capacity to live a normal, good life, decrease their psychological well-being, and limit functional status and productivity (Devins et al., 1984; Megari, 2013). People with type 2 diabetes, for example, are often obese and may suffer from comorbidities, which can decrease their physical activity (Jing et al., 2018; Mortensen et al., 2022).

As a formative phase of life for growing, overall development, and behaviour, adolescence lays a basis for health behaviours and health in later life and for the next generation (Azzopardi, 2019; Patton et al., 2018). The disease burden of adolescents has clearly decreased in the past 25 years (van Sluijs et al., 2021), but it has been estimated that 18% of the world's adolescents are obese or overweight (Azzopardi et al., 2019). Health behaviour factors, especially high use of social media and lack of sleep, have been linked to low levels of physical activity in adolescents (Shimoga et al., 2019). In addition, a peer social network is important for choosing healthy lifestyle behaviours in adolescents (Montgomery et al., 2020). Physical inactivity has been suggested to be one of the key drivers of risky health behaviours in adolescents, and studies highlight the importance of a physically active childhood in various forms – active transport between home and school, independent mobility (e.g., play and hobbies), and activities that do not require adult supervision (Condello et al., 2017; van Sluijs et al., 2021).

The psychological determinants of PA have been widely studied, yet the results have been inconclusive (Cortis et al., 2017). There is some evidence on the positive association with self-efficacy among adults (Fjeldsoe et al., 2020; Olsen, 2013). Also, in adolescents (14–18 years old), self-efficacy has been found to be positively associated with overall PA, including goal setting/planning and perceived behavioural control (Craggs et al., 2011; Van Der Horst et al., 2007). Stress has been found to be negatively associated with PA regardless of age (Cortis et al., 2017).

Personality traits, which describe how an individual feels, thinks, and behaves, have a role in physical activity as well (McCrae & Costa, 2003). Traits such as extraversion, conscientiousness, and neuroticism are mostly positively associated with vigorous physical activity (Rhodes & Boudreau, 2017; Wilson & Dishman, 2015). Personal traits linked to physical activity have been suggested to be gender-specific (Karvonen et al., 2020), and people with certain personality traits seem to prefer specific activities. For example, neuroticism is linked to exercising alone, and extraversion and conscientiousness are linked to group exercise (Costa & McRae, 1992; Courneya & Hellsten, 1998; Hagan & Hausenblas, 2005).

Temperament is a foundation of personality that develops in a child's early years and is inherited, emotionally based, and developmentally stable (Caspi et al., 2003; Cloninger, 2004; Karppanen et al., 2023; Heath et al., 1994). Temperament affects the way a person reacts to the world – their environment – and how they interact with other people (Cloninger, 2004). Previous studies have suggested that a passive temperament is negatively associated with the amount of MVPA (Grandi et al., 2011; Karppanen et al., 2023).

2.2.4 Socio-cultural and socioeconomic factors

Socio-cultural determinants of PA have several levels, including the house/household (family composition, health status, and PA of other co-inhabitants, participation in organized sports, social norms, and social interaction), educational institutions (support from school and teachers, teacher's specific educational level, and individual PA), the neighbourhood (exercising in the neighbourhood, societal composition, social inclusion and acculturation, and neighbourhood satisfaction), and also the city/municipality/region/country (cultural and religious factors) (Jaeschke et al., 2017). These determinants vary among adults and adolescents. In adolescents, supportive behaviour or so-called social support from others, including encouragement from significant others (e.g., parents) and having a companion were positively associated with adolescent PA (Jaeschke et al., 2017; Seabra et al., 2008; Yao et al., 2015). Support and behavioural control were also positively associated, in the longer term, with a smaller decline in changes to PA (Craggs et al., 2011). In adults, according to Engberg et al. (2012), marital status (living together with parents) was negatively associated with PA among adults.

Culture can affect PA behaviour through thoughts, religion, acceptance, feelings, and how well people receive and adapt to health education (Caprio et al., 2008; Joseph et al., 2018). For example, in some cultures, physical activity as a free time activity can be seen as a selfish behaviour (Babakus et al., 2012) or as a non-acceptable behaviour for women (Peterson et al., 2011).

Collectivism as a promoter of social cohesion – for example, in ethnic groups (Cogbill et al., 2011; Kim et al., 2014; Mohamed et al., 2014) – has been found to be positively linked to PA in adults. However, language barriers have been seen as restriction for PA in ethnic groups when dealing with the majority population, though it can also engage people from the same culture (Kim et al., 2014). Religion can improve collectivism, but it can also positively affect PA through the attendance of religious services – for instance, clubs and specific practices organized by the church (Robinson & Wicks, 2012). Cultural factors, such as a lack of culturally suitable sport facilities, lack of motivation due to certain cultural backgrounds, and cultural perspectives toward body appearance and physical activity, can be important restrictions for PA among adults (Griffith et al., 2011; Im et al., 2013; Martinez et al., 2009)

Socio-economic disadvantage is associated with physical inactivity. However, it has been noted that the association between SES and physical activity is not straightforward, and some methodological issues concerning mediators should be considered (Bauman et al., 2012; Del Duca et al., 2016). Many typically used socioeconomic variables in epidemiology to measure inequality in a population. Measures are linked to education, occupation, income, and housing tenure, with the inclusion of age, gender, and possibilities in mobility, such as car ownership

(Gidlow et al., 2006). Inequality can also result from environmental factors such as accessibility to services (natural areas, health care, everyday life errands). For example, gentrification is one possible reason causing inequality between citizens in terms of the accessibility of natural green areas in cities (Chen et al., 2020; Nesbitt et al., 2019).

Among adolescents from families with higher SES, physical inactivity is less common than among those with lower family SES. The results of previous studies highlight the importance of economic factors, especially when it comes to activities that require financial investments such as memberships, equipment, and transportation (Stalsberg & Pedersen, 2010). Low SES residential areas with fewer opportunities or poorly maintained facilities for physical activity (e.g., parks, sport facilities) can lead to lower physical activity levels among adolescents (Alliott et al., 2022; Gordon-Larsen et al., 2006). Also, this type of area may also be less secure, so parents may not allow their children to spend time outdoors, or adolescents may avoid spending time outdoors (Maljak et al., 2014).

Socioeconomic status affects adult physical activity regarding the possibility to have LTPA (Stalsberg & Pedersen, 2018). A country's level of development is connected to how socioeconomics can affect the possibilities of engaging in physical activity. In high SES countries, physical activity is mainly recreational (Lear et al., 2017); in developing countries, it is mainly work-based (Warren et al., 2004). Recreational physical activity has been found to be more beneficial for health than occupational physical activity (Holtermann, 2012). Low SES individuals may lack the financial resources needed for sports memberships or transportation costs. In more developed countries, people have more possibilities to affect their health behaviour, but childhood has an important role in adapting health behaviour. In developed countries, sedentary behaviour is common, and it is linked to technology such as computers, remote work, and the use of technology in jobs that require manpower. Possibilities for LTPA are better in developed countries, though they may be disturbed by other, mostly psychological issues – for instance, stress-related symptoms (Landsbergis et al., 2003; Stalsberg & Pedersen, 2018). However, high SES and being physically active does not necessarily indicate better health. For example, the study of Beckvid-Henriksson et al. (2016) found that children with higher SES backgrounds and were physically active were still obese or overweight.

In Finland, nature is more present, and cities are greener than in many European cities, which also offers more opportunities for physical activity in natural environments. This is mainly due to public rights of way and low population density. This reduces the impact of SES on equal access to natural areas for the population. It is estimated that 96% of Finns spend time in nature, indicating that outdoor recreation is an important part of Finnish culture for people of all ages. (Neuvonen et al., 2022; Special Eurobarometer 2018)

2.2.5 Residential environment and physical activity

Residential environment refers to a place (i.e., building) and area (i.e., neighbourhood) that is used for regular living, sleeping, and daily activities such as dining, commuting, and leisure time activities (Fitzpatrik & LaGory, 2002). For this reason, people are strongly affected by the environment they live in (Giles-Corti et al., 2002; Giles-Corti et al., 2005). In epidemiological studies, residential environments are often divided into built and natural environments.

Environmental factors are linked to recreational, transportation, occupational, and household PA (Kärmeniemi et al., 2018; Sallis et al., 2006). Generally, PA is more likely to be performed at home or near the home (Hurvitz et al., 2014; Huston et al., 2003). In particular, yards are ideal for LTPA such as walking and gardening (Crespo et al., 1996). Physical environments provide circumstances for physical activity in several forms through the geographical diversity of areas and urban design (Forsyth et al., 2007). Also, the literature has recognized the limitations of residential environments for PA, such as hills and greater distances (Forsyth et al., 2009). The role of the residential environment for physical activity can differ regionally and across different SES groups (Smith et al., 2017). These differences may be due to land use, safety, urban structure, and cultural aspects – e.g., how people perceive and use their residential environment for mobility (Hallal et al., 2012; Lear et al., 2017). There is some evidence that in children, leisure time activities are somehow depended on the type of the residential environment. Children living in bigger cities and densely populated areas tend to spend more time in the built environments, for example by the streets and in the urban parks including nearby forests. In rural areas, in turn, natural spaces such as yards, gardens and fields. This may be closely linked to accessibility in the residential environment. (Aapola-Kari, 2022) In addition, as Finland is considered as a relatively safe country, children and adolescents are allowed to play and spend time outdoors.

Residential environment can support health and PA in several ways, providing restorative, aesthetic, cleaner, and less noisy environments for PA, especially when linked to nature Browning, et al., 2022; Dadvand et al., 2015; Kaplan & Kaplan, 1989). Accessibility is an important driver for daily life mobility and leisure-time activities. People who live close to natural areas tend to visit them more often for recreational purposes (Schipperijn et al., 2010). In addition, targeted and sufficient services for daily activities within walkable distances (e.g., shops, sport facilities) can improve daily movement and encourage physical activity. According to the literature, the type and number of places for PA near the home (e.g., walking trails and sport facilities) are key to promoting PA at the population level (Kahn et al., 2002). For example, access to places for physical activity has been found to be positively associated with physical activity in diverse adult populations depending on income, race, and education (Huston et al., 2003).

Adolescents and adults may have different demands for the residential environment to improve their PA. It has been suggested that certain residential environmental features can improve PA among adolescents whose self-efficacy and MVPA are low. Attention has especially been paid to the positive association between natural environments, street connectivity, population density, land-use patterns, and PA (Aznar et al., 2018; Ding et al., 2011). Some studies have found differences between urban and rural adolescent PA behaviour, highlighting the importance of future studies on regional differences in the determinants of PA. MVPA at school has been shown to be more common in rural adolescents, while active commuting is more common in urban and suburban adolescents (Rainham et al., 2012). For adults, aesthetics, accessibility, opportunities for PA, walkability, and environment quality have been found to be positively related to PA (Humpel et al., 2002; Van Holle et al., 2012).

2.3 Measurements of physical activity

Methods to measure physical activity can be divided into subjective and objective approaches. Subjective methods rely on an individual's own evaluation of PA performed – for example, PA questionnaires and diaries. Objective PA measures include wearable monitors like pedometers, heart rate monitors, and accelerometers (Hills et al., 2014). Doubly labelled water (DLW) and indirect calorimetry can be used for measuring the EE of PA; they are often utilized in research and for calibrating and validating other measuring modalities (da Rocha et al., 2006; Dishman, 2022; Schoeller & van Santen, 1982).

2.3.1 Self-reported physical activity

Subjective PA can be measured with questionnaires, interviews, diaries, and logs; of these, questionnaires are widely used in scientific studies due their cost-effectiveness and applicability. With questionnaires, it is possible to collect information on physical activity from large populations. Questionnaires can define a participant's recent physical activity (e.g., in the past two weeks) or lifetime scale physical activity. Participants are typically asked about the type of activity, its duration, and intensity (Sylvia et al., 2014). Many of the questionnaires have been validated, such as the International Physical Activity Questionnaire (IPAQ) and the Global Physical Activity Questionnaire (GPAQ) (Craig et al., 2003), and many of them have shown moderate reliability – with limitations (Ainsworth et al., 2015; Cleland et al., 2018; Dishman et al., 2022). Bias, such as overestimation of physical activity, is still a problematic feature of questionnaires and should take into consideration (Strath et al., 2013). Also, self-reported data do not typically allow researchers to explore the timing and precise intensities of movements (Lee et al., 2014).

2.3.2 Device-based measurement of physical activity

Generally, device-based methods are wearable (placed on the wrist, waist, thigh, or ankle) and use sensors to assess body motion (Yang & Hsu, 2010) and acceleration during habitual activities, which can be used to estimate EE, total PA volume (Strath et al., 2013; Welk, 2002), and activity patterns (Warren et al., 2010). The devices have become more reliable in the last decade, especially for detecting light physical activity (Lee et al., 2014; Shephard et al., 2016), since they do not have response or recall bias (Celis-Morales et al., 2012).

Accelerometers are commonly used to measure physical activity; they provide a more comprehensive picture of and more accurate feedback on PA behaviour compared to self-report (Bassett et al., 2014; Butte et al., 2012). Their advantages are their small size and light weight; they are wireless, non-invasive, and thus easy to use; and they do not interfere with body movements (Chen & Bassett, 2005; Trost & O'Neil, 2014). Accelerometers are electromechanical sensing devices that mechanically measure an acceleration (rate of change in time) produced by the movement of the body segment to which it is attached, whether caused by gravity or motion; then, they convert this data into an electrical signal (Kavanagh et al., 2008; Mathie et al., 2004). Acceleration is measured in one, two, or three axes, including the vertical, anterior-posterior, and lateral axes acceleration, and it is usually expressed based on gravitational acceleration units (g; 1 g = 9.81 m/s2) (Chen & Bassett, 2005). The operation principle for most accelerometers is based on Hooke's and Newton's laws (Kavanagh et al., 2008). Typically, the monitor is placed either on the waist or lower back with the help of an elastic belt or clip to ensure that the monitor is as close to the centre of the mass of the human body as possible. This enables the most accurate measurement of the whole-body movement (Plasqui et al., 2013; Skender et al., 2016). Wrist-worn accelerometers have higher compliance of wearing an activity monitor among study participants, and the use of wrist-worn accelerometers has increased (Troiano et al., 2014). Another advantage of wrist placement has been suggested to be the possibility of detecting low-intensity PA as well, such as arm movements caused by household work (Hildebrand et al., 2014). Other possible body sites for monitor placement are the thigh and ankle. The decision concerning the site of monitor placement is based on the behaviour to be studied and the monitor selected (Matthews et al., 2012). In research, accelerometers are usually worn either 24 hours a day or during all waking hours (Corder et al., 2008). Participant compliance with the monitoring protocol is an important factor, and it should be ensured in order to obtain accurate accelerometer data. Among young people, wear time has been shown to be affected, for example, by the appearance and usability of the device (Audrey et al., 2013). A seven-day measurement period has been found to be suitable for different age groups, including children, adolescents, and adults (Matthews et al., 2012; Skender et al., 2016; Trost et al., 2005). The most commonly used definition of a valid measurement day is 600 minutes per day (Matthews et al., 2012; Skender et al., 2016), and four days is typically used as the minimum number of valid days to be included in final data (Skender et al., 2016).

Device-based methods have weaknesses that should be noted. First, devices are expensive, may be uncomfortable to their user, and require expertise to manage and analyse the outcome data (Lines et al., 2020). Also, they may work well in a laboratory environment (Gorzelitz et al., 2018), but tracking activities such as cycling and swimming is limited (Koolhaas et al., 2018).

2.4 Natural environments and physical activity

The scientific evidence concerning natural residential environment and physical activity has been growing in the past decades, but their interactive role is not well known. It has been suggested that exposure to natural environments can modify the benefits of physical activity, especially strengthening the positive effects of physical activity. According to Shanahan et al. (2016), the benefits of nature exposure to physical activity can be sub-additive, additive, or synergistic (Fig. 2).

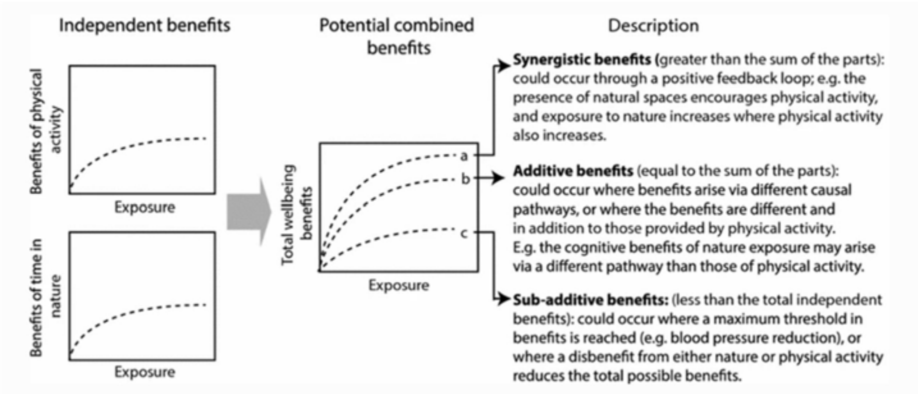

Fig. 2. Possible interactive benefits of nature exposure and physical activity (Shanahan et al., 2016) Copyright 2016 by Springer Nature. Reprinted with permission.

2.4.1 Green residential environment and physical activity

The term 'greenness' indicates natural vegetation, the presence of forests, and other healthy vegetation such as bushes and grass. In science, there are several terms for green environments, including green spaces and green areas, which can be naturally or artificially green, such as urban parks. In the literature, greenness has often been described as a single entity, which is linked only to the green colour itself and its quantity or location, or the terms 'nature' and 'greenness' have often been used as synonyms when studying natural environments and their association with the health. (Houlden et al., 2018). However, cultural and location features have not been widely taken under consideration, as people from different locations and cultural backgrounds may perceive their environment differently (Lachowytz & Jones, 2013; Houlden et al., 2018). In addition, greenness is depended on seasonal variation, especially in the northern hemisphere providing different environment for example for physical activity in winter. It is still unclear which kind of greenness is more beneficial for health and PA – artificial or natural green environments – and how scientific information should be used in practical land use design (Boulton et al., 2018).

For now, there are no unambiguous guidelines for optimal distance from home location or quantity of residential greenness, even though some studies have suggested a distance of 300 m from home (Ekkel & de Fries, 2017; Houlden et al., 2018; Klompmaker et al., 2017). Previous studies suggest that green environments are more likely to be used for physical activity if they are located near the home or otherwise easily accessible. In addition, the quality of the environment, the availability of trails, and the size of the green environment is important when it comes to its usability for physical activity (Kaczysnki et al., 2008; Sugiyama et al., 2010). Therefore, if an individual does not live in direct contact with greenness (e.g., have their own yard), residing near forests, green parks, or other green areas can be beneficial for physical activity (Kajosaari & Laatikainen, 2020; Pyky et al., 2019). The role of greenness in activating people becomes even more important among those individuals who are physically inactive, come from lower SES backgrounds, or live in remote or disadvantaged locations without sport facilities or organized activities such as sport clubs (Halonen et al., 2020; Li & Bell, 2018).

In the last decades, researchers from physical activity to epidemiology have been interested in the association of greenness and physical activity. There is both longitudinal and cross-sectional evidence on the positive linkage between greenness and different physical activity intensities and types, including maintenance and meeting physical activity recommendations (Chaix et al., 2014; James et al., 2015; Pasanen et al., 2022). Green environments may be beneficial for physiological and psychological health since they encourage people to participate in physical activity in different forms, regardless of age (James et al., 2017). A positive association between greenness and self-reported and accelerometer-based physical activity, particularly recreational or leisure-time physical activity, has been shown in population-based studies (Marquet et al., 2022; McMorris et al., 2015). In adolescents, residing in green areas has been positively associated with moderate to vigorous physical activity (Markevych et al., 2016). Klinker et al. (2015) found that boys spent more time in green areas than girls. In adults, green environments have been shown to be positively associated with the amount of self-reported and accelerometer-based PA, especially light physical activity (LPA) and moderate to vigorous physical activity (MVPA). Previous studies suggest that low-intensity outdoor exercise, such as walking, slow cycling, activities with animals (dog walking, leisure riding), and gardening typically occur in green environments (Marquet et al., 2022; Schipperijn et al., 2013; Villeneuve et al., 2018;). Denser greenness in neighbourhoods was positively associated with middle-aged and older

Canadian adults' self-reported PA, highlighting the possible importance of vegetation quality (Klicnik et al., 2022).

As green environments can support physical activity through, for example aesthetics, they provide positive experiences. This may encourage people to visit natural places frequently (Cox et al., 2017; Shanahan et al., 2016). From a theoretical aspect, visiting natural areas can cause hedonic well-being (HWB) and eudaimonic well-being (EWB) (Houlden et al., 2018; White et al., 2017). HWB is linked to pleasure, enjoyment, and happiness, while EWB describes the subjective feeling of belonging (McDowell, 2010) and the meaning of life. They both improve vitality, mood, and psychological well-being in general and support physical activity (Waterman et al., 2010).

Visits to nature tend to be longer lasting compared to indoor physical activity, especially when it comes to walking or cycling (Joseph & Maddock, 2016; Karusisi et al., 2012; Pretty et al., 2007; Sugiyama et al., 2013). PA in a green environment has been suggested to be more motivating and requiring less exertion compared to physical activity performed indoors, which could engender positive feelings toward being physically active (Akers et al., 2012; Focht et al., 2009; Gladwell et al., 2013). Green environments offer healthier physiological and psychological bases for PA compared to urban environments because they have less noise, cleaner air, and cooler temperatures (James et al., 2017; Markevych et al., 2017). Moreover, social cohesion is stronger in green spaces (Berkman & Kawachi, 2000; James et al., 2015).

2.4.2 Residential landscape diversity and physical activity

Throughout human history, people have tended to seek to live in landscapes that provide food, water, and shelter, without forgetting the cultural aspect. Gardens and parks have been included in urban design since the 15th century. The health benefits of beautiful and restorative natural landscapes have been recognized among people, but urbanization and the modernization of leisure time have disturbed people's connection with nature and decreased natural landscapes (Gerlach-Spriggs et al., 1998; Thompson, 2010). The WHO (1946) has recognized landscape as one 'key element of individual and social well-being'; therefore, landscape has also become an increasingly interesting topic in research and policy (Velarde & Tveit, 2007). In addition, it is possible that not only green environments, but other kinds of natural environments can support physical activity. For this reason, diverse landscapes and their association between human health should be studied.

The term ‘landscape’ is not unambiguous since it has been defined to be the result of culture and one’s individual perspective. The European Landscape Convention defines landscape as ‘an area as perceived by people, whose character is the result of action and interaction of natural and/or human factors’ (Council of Europe, 2000). In this study and based on previous definitions, the residential environment plays the role of an everyday landscape where interaction between nature and human life occurs. Our definition follows the European Landscape Convention’s (Council of Europe, 2000) definition, which suggests that landscape can be seen as ‘a zone or area as perceived by local people or visitors, abiotic and biotic features whose visual features and character are the result of the action of natural and/or cultural (that is, human) factors’. Landscape can be experienced in several pathways, including our memories, experiences, meanings, attachment to place, and belonging, which shape our perspective concerning it (Augenstein, 2002; Daniel, 2002; Davenport & Anderson, 2005; Fahrig, 2005; Oreszczyn & Lane, 2000; Parsons & Murphy, 2016). However, in this study, the focus was mostly on the natural landscape, though it also considered artificial natural elements such artificially created landforms.

In research, there is no unambiguous definition for the term ‘landscape diversity’. In physical sciences such as physical geography or ecology, it can be seen as the simplest form, referring to the variability of landscape features such as habitat types in certain spatial environments, with numerous natural forces (e.g., erosion) shaping it through time (Bojie & Liding, 1996; Murphy, 2016). In epidemiological studies, landscape diversity can be described as the diversity of visible natural areas or built areas separately or together. It can be seen as the combination or presence of several abiotic and biotic natural features such forests, fields, bodies of water, wetlands, and landforms. In urban environments, it can consist of parks or other local natural environments together with artificial landforms, urban creeks, and so on (Fahrig, 2005; Murphy, 2016).

People tend to prefer aesthetically pleasant landscapes that provide affordances (Berlyne, 1973; Heft, 2010; van den Berg, 2005). In the literature, the term ‘landscape affordances’ indicates the functionalities that different landscape settings can provide (Heft, 2010). The need for aesthetics is recognized as one of the cognitive needs for all humans, meaning that people need to experience satisfaction and pleasure in their lives. The visibility of landscape is most important when people collect information from the environment (Murphy, 2016), and a variability in natural elements can be one of the factors that make a landscape pleasing (Berman et al., 2014; Franco et al., 2017; Kardan et al., 2015).

Landscapes can also promote physical activity through aesthetics (Bull et al., 2010). They provide circumstances for varying types of physical activity. The association between landscape diversity and physical activity has not been studied widely, and studies have mainly focused on the linkage of greenness/blueness, built landscapes and physical activity, and restrictions of varying topography for physical activity (Alahuhta et al., 2022; Keskinen et al., 2018; Miralles-Guasch et al., 2019).

2.4.3 Built environment and physical activity

The built environment is the environment where people and communities live on a day-to-day basis. It consists, for example, of buildings, traffic, green spaces, and other public spaces (Renalds et al., 2010). As the built environment represents a 'man-made', artificial, and mostly urban environment, the natural features in it play an important role by supporting nature relatedness and providing nature's health benefits. Design inspired by natural patterns and elements can be brought to built environments in many forms (Berto et al., 2015; Kellert, 2018).

The connection between urban environments and physical activity has been a research interest in the past years (Ewing, Brownson, & Berrigan, 2006; Renalds et al., 2010). Positive associations have been found between walkability (Frank et al., 2010; Renalds et al., 2010), street connection, land use mix, housing density, retail floor area, and block length. In addition, some studies have shown that infrastructure for pedestrians and biking, such as cycle paths and sidewalks, are positively associated with physical activity (Giles-Corti & Donovan, 2002; Krizek & Johnson, 2006; Renalds et al., 2010). Urban neighbourhood features such lighting, safety, and aesthetics are also factors linked to physical activity (Bedimo-Rung et al., 2004; Brownson et al., 2001). Parks offer different opportunities for physical activity and recreation for people from different backgrounds and interests (Hayward & Weitzer, 1984). Parks with easy access can also help people meet recommended levels of physical activity (Giles-Corti et al., 2005; Kaczynzki et al., 2007; McCormack et al., 2010).

2.4.4 Nature relatedness

Previously, it has been suggested that nature relatedness is a basic psychological need (Baxter & Pelletier, 2019; Hurly & Walker, 2019). According to Wilson's biophilia hypothesis, human beings and other living systems are instinctively bonded, which indicates that nature relatedness is important for humans; part of this behaviour can possibly be explained by the genes (Baxter & Pelletier, 2019; Joye & De Block, 2011; Wilson, 1984;). Modern Western ways of living can widen the gap between people and nature (Bragg, 1996; Roszak, 1995). However, many factors can affect the strength of nature relatedness. It has been proposed that people suffer from the 'extinction of experience' (Gaston & Soga, 2020; Pyle, 1978). This is caused by the lack of access to nature, especially in bigger cities (Gaston & Soga, 2020). Also, the cultural heritage of nature relatedness has suffered, since knowledge concerning nature is not necessarily transferred from older generations to younger ones. This is a socioeconomic factor in which Western culture has a weakened connection with nature (Bragg, 1996; Roszak, 1995; Windhorst & Williams, 2015). Thus, the gap between nature and people can lead to weakened nature relatedness. Recently, the importance of nature relatedness has been recognized not only in research but also in government policy in terms of human and environmental well-being (Baste et al., 2021; DEFRA, 2018).

Nature relatedness generally includes the affective, cognitive, and experimental aspects of the human–nature relationship (Nisbet et al., 2009). In practice, it defines how motivated a person is to interact with nature in their own way and how strong the environmental values the person has. The terms 'nature relatedness' and 'nature connectedness' have been used interchangeably and consist of similar features (Nisbet & Zelesnky, 2014; Pritchard et al., 2020). Studies concerning nature relatedness suggest that the foundation of nature relatedness is in childhood and develops over the course of life. Direct, indirect, and vicarious interactions in early childhood are vital for a child's cognitive, affective, and evaluative development (Kellert, 2002; Thompson et al., 2008). Exposure to nature and sensory stimuli in natural environments during childhood can be vital for sensory processing in adulthood, which is positively linked to nature relatedness (Li et al., 2022). However, adolescence is the most challenging period for nature relatedness, since it is a period of transition from childhood to adulthood and needs to be supported (Kaplan & Kaplan, 2002). The younger generation has less interaction with nature than the older ones, whose members were exposed to nature to a greater extent and to technology and the hectic modern lifestyle to a lesser extent (Ballouard et al., 2011; Hofferth, 2009M; Pergams & Zaradic, 2006). A Finnish study of children and adolescents found that 90% of the younger population spend time outdoors and that their relationship with nature was stronger than in other European countries (Aapola-Kari, 2022). Another study showed (Kaplan and Kaplan, 2002) that adolescent men in particular spend less time outdoors and their relationship with nature may be weaker during the transition from adolescence to adulthood (Hakoköngäs & Puhakka, 2023; Kaplan & Kaplan 2002).

In this study, the focus was on the direct interaction with nature that participants have in their ordinary lives. Direct interaction with nature refers to personal contact with nature that cannot be replaced by vicarious, metaphoric interaction (Pyle, 1993). Direct interaction is highly multisensory, which includes, for example, being surrounded by natural landscape – the view, the smell, the touch, and the sounds. These multisensory experiences usually lead to positive experiences and possibly strengthen nature relatedness (Kellert, 2002).

According to previous studies, nature relatedness is positively associated with happiness and subjective well-being (Capaldi et al., 2014; Pritchard et al., 2020; Zelenski & Nisbet, 2012). In addition, strong nature relatedness can improve physical activity through several pathways, which are highly linked to nature's well-being effects, the visual stimulation of aesthetic natural environments, and the instinctual and learned need to interact with nature (Capaldi et al., 2014; Dean et al., 2018; Lawton et al., 2017; Loureiro & Veloso, 2014). There is evidence that people whose connection with nature is strong tend to spend more time in natural areas and have more physical activity in those settings (Lawton et al., 2017; Flowers et al., 2016). Nature relatedness is positively connected to emotional well-being, so nature relatedness can possibly improve psychological functionality and psychological well-being, affecting positively physical activity as well (Howell et al., 2011). Physical activity outdoors predicts lower somatic anxiety compared to physical activity indoors (Lawton et al., 2017). Physical activity in natural environments also prevents stress in the longer term (Korpela et al., 2014). It seems that nature relatedness and seeking to spend time in natural areas can be beneficial for physical activity (Lawton et al., 2017). However, it remains unclear what amount of 'naturalness' for a natural scene is needed to maintain nature relatedness, since people have their personal preferences for natural environments (Baxter & Pelletier, 2019).

2.4.5 Residential environment, health, and well-being

Well-being has been defined as the combination of feeling good, functioning well, and experiencing positive emotions such as happiness. It is intricately linked to positive mental health – having control over one's life and being satisfied with life, as well as experiencing positive relationships (Huppert, 2009; Ruggeri et al., 2020). The WHO (2001) defines positive mental health as 'a state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community'.

The physiological and psychological well-being effects of nature constitute a relatively young but growing field of study, leading back to the 1960s, when the first studies were published (Berlyle, 1971; Proshansky, 1976). Their role in human health has been found to be important, especially due to their salutogenic role. Nature's health benefits are not dependent on cultural boundaries, and they benefit people across the life course, meaning that all people can benefit from nature. (Hurly & Walker, 2019) The main theory explaining these positive effects of nature is Wilson's biophilia hypothesis, which is based on evolutionary psychology. It suggests that humans have an instinctive need to interact with living nature and that, therefore, we seek to spend time in nature or with animals (Ulrich, 1993; Wilson, 2007). Following the biophilia hypothesis, Max-Neef presented his taxonomy of human needs, which identifies the nine main needs for humans to be fulfilled: subsistence, protection, affection, understanding, participation, leisure, creation, identity, and freedom; many of these needs can be realized by interaction with nature. In addition, Maslow recognized in his hierarchy of needs a 'need of aesthetics', which can be linked to nature and provide aesthetic and well-being effects (Maslow & Lewis, 1987; McLeod, 2007).

Exposure to nature has been shown to support both physiological and psychological health. (Hartig et al., 2014; James et al., 2015) Spending time in nature provides direct well-being effects due to cleaner air, less noise (Dzhambov et al., 2014; Mace et al., 2004), fewer odours (Franco et al., 2017), favourable sounds (Alvarsson et al., 2010), exposure to sunlight, and positive effects on body microbiota (Flandroy et al., 2018; Ruokolainen et al., 2017) and temperature regulation (van den Bosch & Sang, 2017), which support our physiological health. In addition, spending time in natural settings can decrease the stress hormone cortisol and stress-related symptoms. (Hung & Chang, 2021; Tyrväinen et al., 2014).

In addition to the physiological advantages of exposure to nature, several studies have found that there are many psychological well-being effects of nature. (Capaldi et al., 2015; James et al., 2015; Puhakka et al., 2021). Exposure to nature gives rise to positive emotions and thus improves mood and vitality. (Pasanen et al., 2014) In particular, the colours green and blue are pleasant and the most restorative for most people (Akers et al., 2012; Jeong & Park, 2021). Also, other natural environments, depending on individual preferences, are vital for well-being in many ways (Van den Berg et al., 2003). There are two remarkable theories that highlight the meaning of biological mechanisms of nature's well-being effects. Ulrich's stress reduction theory (SRT) suggests that all kinds of natural landscapes calm down the parasympathetic nervous system, which may have an immediate impact on the body's physiology: lower blood pressure, decreased cortisol, and improved mood. Therefore, spending time in natural environments has restorative value, helping with faster recovery and preventing chronic stress (Ulrich, 1991; Brown et al., 2013) According to attention restoration theory (ART), being in nature improves involuntary attention, instead of directed attention, which has restorative effects and prevents mental fatigue (Kaplan & Kaplan, 1989; Kaplan, 1995). In addition, being in nature together with other people affects our psychological well-being through social cohesion (Darcy et al., 2019).

Further theories on nature's psychological well-being effects are linked to neurophysiological responses to nature. The perceptual fluency account (PFA) assumes that natural settings capture attention better than built environments and intensify positive feelings. Natural environments are more suitable and fluent for our information collection process due to their fractal patterns, which are natural geometry (Almkerk et al., 2018; Joye, 2007). The other competitive theory is called reward restoration theory (RRT), according to which restoration occurs through pathways in the ventral areas of the brain (Valtchanov et al., 2013). Regular visits to nature over the course of life can make nature an important part of health behaviour – similar to physical activity or a healthy diet. For example, in a recent cross-sectional, population-based study questionnaire study, 87% of the Finnish participants stated that nature is a particularly important part of their daily life, highlighting its meaning for overall well-being (Sitra & Kantar TNS, 2021).

2.5 Measuring objective features of residential environment using a geographic information system (GIS)

A geographic information system (GIS) is a tool for gathering, analysing, and mapping data based on location. It is a bounded compilation of hardware, software, people, and organization. The utilization of GIS is highly field-based, and it can be exploited in numerous ways – not only for different scientific purposes but also for daily life (e.g., weather maps, general maps) and economic solutions (e.g., cost distance analyses). GIS-based methods are efficient and reliable because they provide objective information on the environment (Pandey & Pathak, 2014).

In epidemiological studies, GIS can be especially used to define environmental factors to which study participants are exposed, such as a residential area, city, or municipality (Clarke et al., 1996). The area size and selected environmental factors depend on the study topic. In epidemiology, they often are linked to land use, street network, services, demography, socio-economy and prevalence of natural elements. (McCrorie et al., 2014; Thornton et al., 2011) The collected GIS data are linked in many cases, and changes of environment can be studied with GIS in a longitudinal setting.

There are multiple ways in which GIS can be exploited to study the role of the environment for physical activity. For example, GIS has been used to identify the proximity of neighbourhood physical activity facilities such as trails (Merom et al., 2003) and recreational areas used for MVPA (McCrorie et al., 2014). Many studies have used it to calculate the study area's walkability (Audrey et al., 2015; Kikuchi et al., 2018; Sallis et al., 2020). GPS data have been used to locate the movements of study subjects and combine with accelerometer-based data (time and intensity) (Andersen et al., 2015). Neighbourhood characteristics such as parks and public transportation (Cerin et al., 2018), as well as socio-economic factors (Molina-Garsía, 2019) and urban-rural classifications of area (Panter et al., 2013) have been measured in several studies, and they have even become standard variables to be considered in PA studies.

2.5.1 Measuring residential greenness and landscape features with GIS

Residential greenness and landscape in epidemiological studies can be measured in multiple ways, including objective and subjective (perceived) methods. Perceived methods are based on an individual's own perspective on nature – for example, the amount of greenness, quality of nature, and accessibility to natural areas and parks (Sugiyama et al., 2010; Tilt et al., 2007). Studies are performed through questionnaires, interviews, and empiric walks. Subjective methods are important since individuals perceive nature differently.

Objective methods mostly measure distance to natural areas, their size, quality, and quantity in some area (Dadvand et al., 2016; Vienneau et al., 2017). In the past, empirical methods were used especially in biology and physical geography and are still irreplaceable in some cases. Due to progress in digital mapping and GIS tools, many methods rely on them. Commonly, features of natural environments are defined around a participant's residential location based on coordinates or addresses. In some cases, the neighbourhood and nearby environments are used in calculations. In addition, GPS methods are becoming more universally used to track a participant's daily movement, including leisure time activities and commuting (James et al., 2017).

Different indices are often used for defining greenness. Commonly used is the normalized difference vegetation index (NDVI). Vegetation indices are based on satellite images and exploit the reflection of light from the photosynthetic activity of the vegetation (Weier et al., 2011). The method's accuracy is dependent on the resolution of satellite images, which have mostly relied on Landsat images with a spatial resolution of 30m x 30m. Spatial resolution used in similar studies differs widely, from 5m up to 250m (Dadvand et al., 2015; Sarkar et al., 2017).

2.6 Measuring nature relatedness

Generally, in research, nature relatedness is measured through questionnaires or interviews in different forms. They are made to measure an individual's relationship with nature and are therefore not suitable for community use. In science, there are three commonly used questionnaires for measuring nature relatedness: 1) the Nature Relatedness Scale (Nisbet, 2009), 2) the Connectedness to Nature Scale (Mayer & Franz, 2004), and 3) Inclusion of Nature with Self (Schultz, 2002). These all have similar features, yet they measure nature relatedness from various aspects – well-being effects as well as the importance of nature and ecological behaviour.

The content of questionnaires used for measuring nature relatedness is dependent on the age of the target population and the purpose of the study. In this study, measuring nature relatedness was mainly based on the work of Nisbet et al. (2009), the theory of motivations for visiting natural areas (Lemieux et al., 2016), and the theory of social aspects of being outdoors (Staats & Hartig, 2004). The Nature Relatedness Scale is a self-report measure that can be used to assess the affective, experiential, and cognitive aspects of an individual's relationship with nature. According to it, nature relatedness can be seen as a trait that remains stable across the course of life, though it may change in form or become less or more apparent due to changes in life. It was originally created for environmental psychology and to suit the needs of studying conservation behaviour. The NR scale focuses on understanding the importance of overall nature, not only things that are aesthetic, such as beautiful landscapes (Nisbet et al., 2009).

3 Aims of the study

The first aim of the study was to study the association between green residential environment and physical activity and find threshold values for greenness in residential environment that could be used as indicator values to improve physical activity. The second aim was to study the connection between landscape diversity and physical activity. The third aim was to investigate the association between nature relatedness and physical activity and health among adolescents.

The more specific research questions were the following:

1. Is green residential environmental connected to physical activity in mid-life? (I)
2. Is there threshold for amount of greenness and physical activity? (I)
3. Is landscape diversity positively associated with physical activity in mid-life? (II)
4. What kind of landscapes support physical activity in mid-life? (II)
5. Is nature relatedness positively connected to physical activity and health among adolescent men? (III)

4 Subjects and methods

4.1 Study design

This study used an observational cross-sectional study design in which data were collected from certain time points: 2012 - 2014 (I, II) and 2013 (III)

4.1.1 Northern Finland Birth Cohort 1966 – NFBC1966 (I, II)

The Northern Finland Birth Cohorts, NFBC1966 is a longitudinal research program aiming to promote the health and well-being of the population. The NFBC1966 includes all those born in Northern Finland whose expected dates of birth fell in 1966 and who were invited to the study (n = 12,058 live births) (University of Oulu, 1966). The participants have been followed up with regularly since their birth. This cross-sectional study analyzed the data obtained from the most recent time point, at 46 years of age (n = 10,321). The data were collected (from 2012 to 2014) through health care records, questionnaires (n = 6,384), and clinical examinations (n = 5,852). Physical activity was measured by wrist-worn Polar Active accelerometers for 14 days (n = 5,481), and participants had to have four or more eligible days of measured physical activity. The final study population consisted of all those whose residential environmental features were objectively measured by a GIS (n = 5,433).

The study was approved by the ethics committee of the Northern Ostrobothnia Hospital District in Oulu, Finland (94/2011), and it was performed in accordance with the Declaration of Helsinki. The subjects and their parents (at the time of child's birth) provided written consent for the study. The personal identity information was encrypted and replaced with identification codes to provide full anonymity. Regarding the availability of data and material, data are available from the University of Oulu, NFBC, for research collaborators who meet the criteria for accessing confidential data.

4.1.2 MOPO study

The study was a part of a comprehensive population-based study (MOPO) that aimed to promote physical activity and health and to prevent social marginalization among young, conscription-aged Finnish men (Ahola et al., 2013). The study was conducted in the City of Oulu in Northern Finland in 2013, during call-ups for military service. Military service or civic duty is compulsory for all Finnish male citizens. The entire age cohort of 18-year-old men – except those whose physical or mental health or psychological capacities do not allow for independent living – participate in it. The call-ups provide a large, population-based representative sample of young men. All the young men who attended the call-ups for military service in 2013 (N = 1,352) were invited to the present study. Overall, 914 subjects (mean age 17.8; SD 0.5 years; 68% of the age cohort) completed the questionnaire concerning their nature relatedness, physical activity, physical activity with parents, psychological and physical health, socioeconomic factors, life satisfaction, nutrition, smoking, and alcohol intake.

The MOPO study was conducted in accordance with the Declaration of Helsinki of 1964, as revised in 2000, and the Ethical Committee of Northern Ostrobothnia Hospital District (ETMM123/2009) approved it. The subjects had the right to refuse to participate and to withdraw from the study. The manuscript does not contain any individual personal data. Regarding the availability of data and material, data are available from the University of Oulu, NFBC, for research collaborators who meet the criteria for accessing confidential data.

4.2 Methods

4.2.1 Health questionnaires

The cohort participants (studies I and II) completed a postal questionnaire concerning their demographic features, perceived health, life satisfaction, health behaviours (smoking, alcohol consumption), and socioeconomic background (SES) (marital status, education, strenuousness of work). (Nordström et al., 2021)

In the MOPO study (III), participants filled a comprehensive questionnaire concerning their SES, including parents (education, profession), nature relatedness, self-rated health, life satisfaction, health behaviour (smoking, alcohol consumption), and demography.

4.2.2 Nature relatedness

In Study III, Health and well-being from Finnish national parks - A study on benefits perceived by visitors (Kaikkonen et al., 2014), originally developed for the Finnish National Parks Health and Well-being Survey, was used as a basis for assessing the relationship with nature. Items on nature relatedness were based on the original Nature Relatedness Scale (Nisbet et al., 2009) and supplemented with items from two other questionnaires (Lemieux et al., 2016; Staats & Hartig, 2004).The questionnaires and items s were selected to meet the purpose of this study (Table A1), which aimed to assess the importance of nature for young people, the regularity of nature visits and how they perceive the well-being effects of nature.

A part of the questionnaire (statements 1, 2, 3, and 4) was based on the Nature Relatedness Scale (Nisbet et al., 2009), which was chosen due to its statements related to the experiences that an individual has in natural environments and the importance of nature to the individual. The original version of the Nature Relatedness Scale consists of 21 items, and it is designed to measure nature relatedness through self-identity, experience, and environmental behaviour. The other version of the scale comprises self-identity and experience (six items) (Nisbet et al., 2009; Nisbet & Zelenski, 2013). Other parts of the questionnaire used in this study were based on the theory of motivations for visiting natural areas and the theory of social aspects of being outdoors (Lemieux et al., 2016; Staats & Hartig, 2004). The final nature relatedness questionnaire used in study III was based on the scoring of these statements. Each statement had three response alternatives (1 = 'always or mainly', 2 = 'sometimes', and 3 = 'seldom or never'), except for statement number 3 ('The thought of being deep in the woods, away from civilization, is frightening'), which had reversed scoring. The range of the index was 0–36 (with a higher score indicating stronger contact with nature). The continuous variable was used in the multivariable linear regression. For the univariate analyses, the index was categorized into four quartiles: 1 = Weak (score $\leqslant$ 14), 2 = Moderate (score of 15 – 18), 3 = Good (score of 19 – 26), and 4 = Strong (score $\geqslant$ 27). Finally, it was dichotomized by combining categories 1 and 2 (0 = 'Lower half of the group') and 3 and 4 (1 = 'Upper half of the group'). The higher the sum of the points, the higher the nature relatedness.

Table 1. Scoring of nature relatedness (Staats & Hartig, 2004; Nisbet et al., 2009; Nisbet & Zelenski, 2013; Lemieux et al., 2016). The participants were asked how well the following statements applied to feelings towards nature.

Statement	Always or mainly	Sometimes	Seldom or never
I spend time in natural areas (e.g., recreational grounds, nearby forests, parks, national parks, and other nature reserves and bodies of water).	2	1	0
I enjoy being outdoors, even in unpleasant weather.	2	1	0
The thought of being deep in the woods, away from civilization, is frightening.	0	1	2
Experiencing nature is an important part of my well-being.	2	1	0
My thoughts become clearer.	2	1	0
Tomorrow looks brighter.	2	1	0
I get new energy and eagerness to engage in my daily tasks.	2	1	0
I relax and recuperate.	2	1	0
I get more self-confidence.	2	1	0
I get new, inspiring thoughts.	2	1	0
I enjoy meeting new people during my visits to nature.	2	1	0
I enjoy the company of the people closest to me.	2	1	0
It is easy to discuss your personal issues in nature.	2	1	0
I enjoy being alone.	2	1	0
I enjoy silence.	2	1	0
I can test my personal limits.	2	1	0
I feel that exercising outdoors improves my physical condition.	2	1	0
I feel my physical wellness improving.	2	1	0

4.2.3 Clinical measurements

The weight and height of the participants were measured, and their body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2) (I, II, III)

4.2.4 Physical activity

Self-reported physical activity

For the participants of the MOPO study (III), self-reported physical activity was measured through the question, ‘How much do you exercise during your leisure time?’ The responses originally constituted a four-point scale: 1 = ‘I read, watch television, and do tasks that do not require physical activity or sweating’; 2 = ‘I walk, bicycle, or engage in some other kind physical activity for at least 4 hours per week’; 3 = ‘I exercise vigorously or do equivalent activities for at least 2 hours per week, on average’; 4 = ‘I exercise competitively several days a week’. The variable was transformed into a two-point scale (1 = ‘Low leisure time physical activity’; 2–4 = ‘Higher leisure time physical activity’). The participants were also asked whether they exercised with their parents (1) during childhood (≤6 years); (2) at primary school age (7 – 12 years); (3) at secondary school age (13 – 15 years); (4) currently. The response options were ‘yes’ and ‘no’.

Accelerometer-measured physical activity

In the NFBC1966 studies (I, II), physical activity was measured with an accelerometry-based wrist-worn waterproof activity monitor, the Polar Active (Polar Electro Oy, Kempele, Finland). The monitor was blinded, giving no feedback to the user. The Polar Active provides metabolic equivalent (MET) values every 30 s (Hautala et al., 2012) and has been shown to correlate (r = 0.86) with the double-labelled water technique, assessing energy expenditure during exercise training (Kinnunen et al., 2012). It uses the height, weight, gender, and age of the user as predefined inputs. The monitors were given to the participants during clinical examinations, with the participants being instructed to mail them back after the measurement period. The participants (I) were asked to wear the Polar Active monitors 24 h per day for at least 14 days, including while sleeping, on the wrist of the nondominant hand. The daily averages of time spent in different activity levels (very light: 1 – 1.99 MET; light: 2 – 3.49 MET; moderate: 3.5 – 4.99 MET; vigorous: 5 – 7.99 MET; very vigorous: ≥8 MET) were calculated for all the participants (Jauho et al., 2015). Wear time during waking hours (min/day) was calculated as the sum of all five activity levels. The ‘very light’ activity was excluded from the study since it estimates the time spent sedentary. The first day, when the activity monitor was given to the participant, was excluded from the analysis. Finally, participants with four or more eligible days (wear time of at least 600 min/day) were included in the study (Husu et. al., 2014, Niemelä et al., 2019).

The PA of the participants was expressed as the total daily average MET minutes spent in light physical activity (LPA), moderate physical activity (MPA), vigorous/very vigorous physical activity (VPA/VVPA), and moderate to vigorous physical activity (MVPA) (I). Also, PA intensity level was used separately as a dependent variable to analyse the associations between residential greenness and different intensities of PA (I). The volume of each PA intensity level in MET minutes was calculated by multiplying each MET value with its duration (30 s).

In study II, instead of using MET minutes, the daily averages of time spent in activity levels (light, moderate, vigorous, and very vigorous) were calculated for all the participants. All the intensity levels were summed up to describe the total physical activity (TPA) of the participants. In addition, for univariate analyses, the participants were classified into tertiles based on accelerometer data: least physically active (low tertile – less than 934 minutes of TPA per week) and physically active (middle and upper tertiles – 934 min or more of TPA per week).

4.2.5 Quantitative measurements of residential environment features

A geographic information system (GIS) was used to assess the quantitative features of an individual's residential environmental features, such as greenness, landscape diversity, land use, and sport facilities (I, II, III).

In studies I and II, spatial information on the participant's immediate residential environment was based on the exact geographical coordinates of the participant's home during 2014. A circular buffer with a 1 km (I, II) or 500 m (III) radius was fixed around each participant's residence to represent the everyday living environment. The buffer size was based on similar scientific studies (Martin et al., 2020; Nordbø et al., 2019). In the lack of a precise definition of the extend of residential environment, different buffer sizes were tested, assuming a daily walking distance of about 1 km. (Martin et al., 2020; Nordbø et al., 2019)

Only periods of residence that had lasted at least three months were included in the studies (Younan et al., 2016). The participants were geographically located all around Finland, but a fifth of them lived in Northern Finland, and 5% of them lived in Helsinki, the metropolitan area of Finland. ArcGIS Pro 2.1 (Redlands, CA, USA) was used in creating the GIS data (ESRI, 2001).

In study III, the spatial information was linked to the exact locations of the participants' residences, based on geographical coordinates. The ESRI GIS-tool, ArcMap 10.2 (Redlands, CA, USA), was used to calculate the GIS data for the study.

Greenness

Residential greenness was measured (I) with the normalized difference vegetation index, which has been widely used in both epidemiological and environmental studies (Cusack et al., 2017; James et al., 2015; Rhew et al., 2011). In this study, NDVI was used to assess the surrounding greenness (calculated in means) within a 1 km buffer of each participant's residential environment. In the case of several periods of residence (≥3 months) during 2014, the annual average of the NDVI was used. The NDVI method is based on satellite imaging (resolution 30 × 30 m) and provides quantitative information on the land cover's greenness (Weier & Herring, 2000). Healthy green vegetation (chlorophyll) reflects infrared and green light, and it can also absorb red and blue light. The NDVI uses the following formula:

$$NDVI = (NIR - R) / (NIR + R),$$

in which the NDVI is calculated from the red (R) and near infrared (NIR) values. Values of the NDVI range from −1 to +1. Values close to −1 indicate water bodies, rock, and snow. Values close to 0 (such as 0.2–0.3), in turn, indicate densely built surfaces or other surfaces with sparse vegetation. Highly positive values (>0.6) indicate areas with very dense and healthy green vegetation, such as forests and paddocks (Weier & Herring, 2000). The NDVI was measured from Landsat 8 (L8) satellite images administrated by the United States Geological Survey (United States Geological Survey, 2017). Images with less than 10% cloud cover were selected, and the months of June to July (2013–2016) were used in the calculation because they represent the greenest months in Finland's seasonal variation.

Urban–rural classification

The 2010 urban–rural spatial classification of Finland is a GIS-based area classification provided by the Finnish Environment Institute (I, II, III). The data were calculated with overlaying 250 × 250 m grid cells, and the classification is based on several statistical features, such as population, standard industrial classification of the workforce (Statistics Finland, 2016), CORINE Land Cover, commuting, potential accessibility, and area density of buildings. The classification consists of two main regional classes – urban areas and rural areas – that are further divided into seven regional classes: (1) inner urban area, (2) outer urban area, (3) peri-urban area, (4) rural area close to urban areas, (5) local centre in rural areas, (6) rural heartland area, and (7) sparsely populated area. In this study, classes 1–3 were combined (1 = 'urban areas'), and classes 4–7 were grouped together (2 = 'semirural and rural areas') (Helminen et al., 2014).

CORINE land cover

For study II, multiple environmental variables based on GIS were created and compared to measure landscape diversity in cohort members' residential environment. First, forest and fields were identified in the CORINE Land Cover data (2012). The resolution of the raster was 20 x 20 meters. The data were used to define different types of natural elements (land use types in square meters) that form natural landscapes. The calculation of the variable contained 48 land use classes (CORINE, 2012) from which the most relevant ones for this study were selected: 1) pastures; 2) land principally occupied by agriculture, with significant areas of natural vegetation; 3) broad-leaved forest; 4) coniferous forest; 5) mixed forest; and 6) natural grassland. For study III, CORINE land cover data were modified to measure the number of natural elements in each participant's residential environment – for instance, forests; transitional woodlands/shrub; wetlands and peat bogs; bodies of water, such as rivers, lakes, and seas, salt marshes, and inland marshes; bare rocks; beaches; dunes and sand planes; non-irrigated arable land; and natural grassland. In addition, the number of natural elements within a 5 km radius of each participant's residence was identified (III). The supposition was that the greater the number of natural elements in a residential environment, the more diverse it was. Distance to the closest park (in meters) was defined from CORINE by identifying the shortest distance between two objects (as the crow flies). In this case, it was the distance between the coordinates of each participant's residence and the closest park or forest.

Hydrology and topography

Hydrological features were derived from the Finnish Environment Institute (2015) (II). The variable was formed by adding together all the hydrological features, including lakes, rivers, sea areas, and wetlands. The final variable was named 'Waterbodies and Wetlands'. In addition, the distance to the closest body of water (in meters) and the distance to the closest wetland were calculated.

Topographical and geomorphological variables describe the variation in altitude and landforms, respectively, of a participant's residential environment; they thus also represent how attractive or challenging the environment is for PA (II). Globally acquired geomorphological GIS data were based on the work of EarthEnv project, which aims to provide data for monitoring and modelling biodiversity, the climate, and ecosystems. The product is based on the digital elevation model products of global GMTED2010 (resolution 250m) and near-global 90 m SRTM4.1dev. These recent high-quality data have a high resolution (1 km spatial grains) and provide a novel methodology, especially for epidemiological studies (Farr & Kobrick, 2000; Hong et al., 2006). Two variables from the EarthEnv data were selected to this study: 1) count of geomorphological landforms and 2) mean of terrain ruggedness index (TRI). TRI is the mean of absolute differences in elevation between a focal cell and its eight surrounding cells. It quantifies the total elevation change across 3 × 3 cells. Flat areas have a value of zero, while mountain areas with steep ridges have positive values, which can be greater than 2,000 m in the Himalaya region (Riley et al., 1999). In other words, TRI describes how a residential environment varies topographically (hillocks vs. flat areas).

Landscape diversity

The landscape diversity index (II) describes the presence of 1) forests (no/yes), 2) fields (no/yes), 3) wetlands (no/yes), 4) bodies of water (yes/no), and 5) landforms (yes/no) in a residential environment. First, continuous variable 'landforms' were dichotomized using tertiles (no = lowest tertile, yes = middle and highest tertile). Finally, a landscape diversity index was calculated by adding up all the different residential environment landscape types (from different land cover types to landforms) and used as a continuous variable (range: 0–5).

Sport facilities

The number of sport facilities (I, III) within each participant's residential environment (1 km circular buffer) was calculated based on the data contributed by the University of Jyväskylä (Lipas Sports Facility GIS Database, 2014). These data include information on public sport facilities in Finland, mainly the municipal ones, as well as a number of sites run by private companies or associations (McMorries et al., 2015).

4.2.6 Statistical analysis

The hypothesis of the data analysis was that residential greenness (I) and residential landscape diversity (II) would be statistically and positively associated with all intensity levels of physical activity in middle-aged men and women. In addition, it was hypothesized that there are threshold values for residential greenness associating with levels of physical activity (I). In study III, the hypothesis was that there would be a statistically significant positive association between nature relatedness and physical activity among adolescent men. The other hypothesis was that physical activity with parents and the features of residential environment would be associated with young men's nature relatedness.

First, the variables were tested for normality (I, II, III). The statistical significance of the difference between the study groups was first analysed using cross-tabulation and the chi-square test for the categorical variables, and Pearson's correlation or Spearman's test for the continuous variables. Variables used in the final models were selected based on preliminary analyses. (I, II, III) The data were analysed using PASW Statistics software (IBM Corp., 2013) and R software (R Core Team, 2020).

For the Northern Finland Birth Cohort 1966 study (I, II), multiple linear regression analyses were used to study the association between residential greenness and physical activity (I) and the association between landscape diversity and physical activity (II). For the MOPO study (III), multiple linear regression analyses were used to explore the factors associated with nature relatedness in the total population and among those with weaker and stronger nature relationships. As a secondary method, logistic regression analysis was performed to explore the connection between nature relatedness and physical activity.

Assumptions for the multiple linear regression were controlled in all studies. The explanatory variables were tested for multicollinearity, and the highest two-tailed correlation allowed was 0.6. The variance inflation factor (VIF) value was supposed to remain below 10 and the tolerance measure above 20. Influential observation was handled using Cook's distance, meaning that observations significantly above 1 were influential and had to be excluded. Missing data were excluded through the pairwise deletion of cases. The 'stepwise' method (III) and 'enter' (I, II) were used in the analysis.

A generalized additive model (GAM) was used to study the association between residential greenness and PA at each intensity level and reveal possible curvature between the variables (I). The linearity of the effects is not required

(Hastie & Tibsharini, 1968), as the method permits both linear and nonlinear response shapes, as well as a combination of them within the same model (Austin, 2002). The GAM can be used to reveal curvilinearity and potential threshold values for the variable of interest (Benedetti et al., 2009). Natural cubic splines with four degrees of freedom were fitted using the ns function. The normality of the residuals was ensured, and the restricted maximum likelihood (REML) was used in the GAM.

5 Results

5.1 The association of green residential environment and accelerometer-measured physical activity among middle-aged men and women

This study aimed to investigate the role of residential greenness in middle-aged men's and women's physical activity. At the time of 46-year follow-up, there were 5,433 (3,043 male and 2,388 female) total participants who provided data for the study. The characteristics of the study population are presented in Table 2.

Table 2. Characteristics of the study population of the NFBC1966 (n = 5433).

Characteristics	All (n = 5,433)	Men (n = 3,043)	Women (*n* = 2,388)
NDVI (SD)[a]	0.4268 (0.1486)	0.4315 (0.1481)	0.4231 (0.1489)
Weight, kg (SD)	77.6 (16.1)	87.1 (14.8)	71.8 (14.7)
BMI, kg/m2 (SD)	26.8 (4.8)	27.3 (4.2)	26.4 (5.2)
Highly educated, N (%)	1,443 (26.5)	538 (17.6)	905 (37.8)
Physical strenuousness of work (SD)[b]	4 (3)	4 (3)	3 (2)
Children < 18 years old in the family (yes), N (%)	3,500 (64.4)	1,504 (49.4)	1,996 (83.5)
Daily alcohol intake, g (SD)	10.4 (16.9)	15.6 (21.8)	71.8 (14.7)
Smoking (yes), N (%)	1,168 (21.4)	569 (18.6)	599 (25.0)
Total annual household income, € (SD)	72202 (298532)	80141 (439388)	65823 (74487)
Excellent/good perceived health (yes), N (%)	3,510 (64.6)	1485 (48.8)	2025 (84.7)
Living in semi-rural and rural areas , N (%)	1,891 (34.8)	867 (28.4)	1024 (42.8)
Number of sport facilities, 1km buffer (SD)	10 (14)	9 (13)	11 (14)

[a] NDVI = values vary from -1 to +1,

[b] Physically strenuous work = values vary from 1 to 9

Values are means (SD) if not otherwise stated. Values do not match due to missing values.

Table 3 presents the amount of accelerometry-measured physical activity at different intensity levels according to socioeconomic factors, lifestyle, and residential environment. Women had more LPA than men, though men had more MPA, VPA/VVPA, and MVPA. Participants with low levels of education were more likely to have more LPA and MPA than highly educated participants. Participants with high levels of education had higher amounts of VPA. Participants without children under 18 years old had more LPA, and participants with children under 18 years old had more MPA. Non-smokers had more MPA, VPA, and MPVA than current smokers. Participants who reported having better perceived health also had more LPA, MPA, VPA/VVPA, and MVPA. Participants living in more rural areas had more LPA, MPA, and MVPA.

Table 3. Daily average MET minutes (metabolic equivalent (SD)) of accelerometer-measured PA according to socioeconomic, lifestyle habits, and residential environment.

Characteristics	LPA	MPA	VPA/VVPA	MVPA
All (n = 5,433)	719 (193)	144 (88)	226 (160)	370 (209)
Men	697 (191)	188 (98)	234 (174)	422 (233)
Women	736 (193)**	109 (58)**	219 (147)*	328 (176)**
High education	662 (169)**	134 (71)**	236 (152)*	371 (188)
Low education	743 (198)	149 (93)	223 (163)	372 (217)
Minors at home (yes)	677 (196)**	146 (87)**	227 (154)	374 (203)
Minors at home (no)	733 (187)	136 (80)	225 (162)	362 (206)
Smoker	725 (188)	138 (87)**	330 (195)**	191 (143)**
Non-smoker	725 (188)	150 (88)	378 (198)	227 (149)
Perceived health (excellent/good)	724 (190)*	147 (86)**	390 (203)**	243 (158)**
Perceived health (moderate/poor)	707 (200)	138 (90)	331 (214)	193 (159)
Living in semi-rural or rural areas	764 (196)**	152 (101)**	378 (237)	225 (175)*
Living in urban areas	695 (188)	139 (78)	225 (151)	365 (191)

** $p < 0.001$, * $p < 0.05$. *p*-values indicate statistical difference between groups.

The association of greenness with various levels of PA in terms of crude and adjusted regression coefficients are summarized in Table 4. In light physical activity (LPA), a one-unit increase in the NDVI was associated with an increase of 174 MET minutes (95% CI 140—209). Adjusting for personal and environmental factors (BMI kg/m^2, physical strenuousness of work, children < 18 years old in the family, high education, daily alcohol intake (g), excellent/good perceived health and number of sport facilities) decreased this effect to 70 MET minutes (95% CI 26— 114). The crude and adjusted effects on LPA were more pronounced in men – 224 MET min (95% CI 173—275) and 140 MET min (95% CI 75—204), respectively – than in women. In women, only the crude coefficient indicated the effect of greenness on LPA – 142 MET min (95% CI 96—188) – which reduced to insignificance after adjustments.

Table 4. Association between residential greenness (NDVI) and accelerometry-measured LPA, MPA, VPA/VVPA, and MVPA (daily average minutes of MET minutes) among middle-aged adults according to multivariable linear regression.

Variables	All, N = 5,433		Men, n = 2,388		Women, n = 3,040	
	Unadjusted B (95% CI)	Adjusted B *(95% CI)*	Unadjusted B *(95% CI)*	Adjusted B (95% CI)	UnadjustedB *(95% CI)*	Adjusted B (95% CI)
Light physical activity (LPA)						
NDVI (residential greenness)*	174 (140–209) ***	70 (26–114) ***	224 (173–275) ***	140 (75–204) ***	142 (96–188) ***	17 (-42–76)
Moderate physical activity (MPA)						
NDVI (residential greenness)*	27 (11–43) **	5 (-14–24)	75 (48–101) ***	23 (-12–60)	-22 (-36– -8) **	-12 (-32–7)
Vigorous/very vigorous physical activity (VPA/VVPA)						
NDVI (residential greenness)*	-20 (-48–8)	-16 *(-56–23)*	13 (-33–61)	15 (-49–80)	-49 (-84– -14) **	-36 (-86–13)
Moderate–vigorous physical activity (MVPA)						
NDVI (residential greenness)*	7 (-29–44)	-11 (-61–39)	89 (25–152) **	39 (-46–125)	-71 (-113–-29) **	-48 (-108–10)

Note. ** p < 0.001, * p < 0.05. p-values indicate statistical significance in the models.

In this study, the aim was also to investigate possible threshold values for residential greenness that could be positively associated with physical activity among middle-aged participants. According to the results, association between residential and light physical activity were rather linear and no threshold values could be seen. (Fig. 3.).

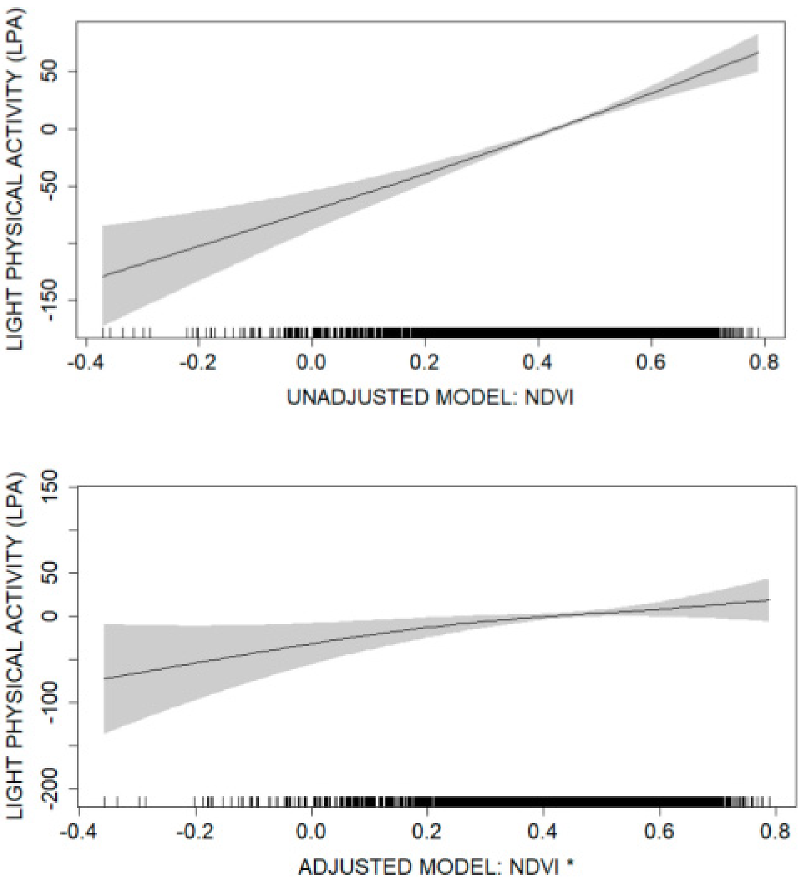

Fig. 3. The association between residential greenness and the amount of light-intensity activity in the crude model and in the adjusted model. * The model was adjusted with: BMI kg/m^2, physical strenuousness of work, children < 18 years old in the family, high education, daily alcohol intake (g), excellent/good perceived health and number of sport facilities.

Overall, residential greenness was positively and statistically associated with light physical activity in both genders, but after adjusting the models for personal and environmental factors the association remained positive only among men. When studying threshold values for greenness and physical activity, it appeared, that the association is rather linear.

5.2 The association between landscape diversity and physical activity in middle-aged men and women

The purpose of this study was to investigate the association between residential landscape diversity and total physical activity among middle-aged men and women. The characteristics of the study population are presented in Table 5. Physically active participants had less daily smoking, rated their health better, had a lower BMI, and had higher education than physically inactive participants. The residential environment of physically active participants had more natural areas.

Table 5. Characteristics of the Northern Finland Birth Cohort 1966 study population (*n* = 5,433) according to the total physical activity.

Characteristics	All (*n* = 5,433)	Low volume of TPA[a] (*n* = 1,789)	Moderate to high volume of TPA[b] (*n* = 3,644)
Men, *n* (%)	2390 (44)	734 (41)	1656 (45)
Women, *n* (%)	3043 (56)	1055 (59)	1988 (55)
Height, cm (*SD*)	170 (9)	169 (8)	171 (8) *
Weight, kg (*SD*)	77 (16)	79 (17)	76 (15) *
BMI (*SD*)	26 (4)	28 (5)	26 (4) *
Daily smoking, yes, *n* (%)	1168 (21)	429 (23) *	739 (20)
Alcohol intake (g/day) (*SD*)	10.4 (16)	11 (19)	10 (15)
Education, high, *n* (%)	1443 (26)	561 (31) *	882 (24)
Minors at home, *n* (%)	3500 (64)	1068 (59)	2432 (66) *
Perceived health, excellent/good, *n* (%)	3510 (64)	1042 (58)	2468 (67) *
Total physical activity, mean/week (SD)	1089 (326)	757 (131)	1252 (264) *
MVPA, mean min/week (SD)	370 (208)	214 (90)	446 (208) *
Work strenuousness (SD)	4 (3)	3 (2)	4 (3) *
Residential landscape features			
Forests (%)[d]	31 (16)	31 (16)	32 (17) *
Fields (%)[e]	8.0 (13)	1 (12)	9 (14) *
Distance to waterbody (m) (SD)	568 (461)	570 (459)	567 (462)
Distance to wetland (m) (SD)	2992 (3009)	3259 (3128)	2861 (2940) *
Number of geomorphological landforms[f] (SD)	28.0 (10)	27 (10)	28 (10)
Landscape ruggedness index[g] (SD)	3 (2)	3 (1)	3 (1)
Landscape diversity[h] (SD)	1.7 (1)	1.6 (1)	1.8 (1) *
Living in a rural environment (yes) (%)	1891 (34)	535 (29)	1356 (37) *

[a] Least physically active: < 934 minutes of any physical activity (low, moderate to vigorous, vigorous, very vigorous) per week [b] moderate to high physical activity: > 934 minutes of TPA per week

Characteristics	All (n = 5,433)	Low volume of TPA[a] (n = 1,789)	Moderate to high volume of TPA[b] (n = 3,644)

[c] Work strenuousness: High values indicate greater physical strenuousness (scale 0–9) [d] Forests (%): Percentage of a residential area (1 km buffer) [e] Fields (%): Percentage of a residential area (1 km buffer) [f] Number of landforms (EarthEnv) (1 km buffer) [g] Landscape ruggedness index: High values indicate great ruggedness (1 km buffer) [h] Landscape diversity: High values indicate high diversity (1 km buffer) * Statistically significant ($p < 0.05$) differences between physically active and physically inactive persons (*t* test)

Unadjusted and adjusted associations between landscape diversity variables and weekly total volume of physical activity are described in Table 6. After adjusting the models for education, gender, and BMI, a greater percentage of forests (β 50, 95% CI 35—64) and fields (β 56, 95% CI 39—74), greater number of wetlands (β 3, 95% CI 2—4) and a greater landscape diversity index (β 8, 95% CI 6—10) in the residential environment were positively associated with TPA.

In unadjusted models, a greater percentage of forests (β 56, 95% CI 42—70) and fields (β 59, 95% CI 42—77), greater number of wetlands (β 3, 95% CI 1—4) and a greater landscape diversity index (β 8, 95% CI 6—10) in the residential environment were positively associated with total physical activity among middle-aged men and women.

Table 6. Unadjusted and adjusted associations between natural elements, landscape diversity, and TPA (MET minutes) based on multiple linear regression.

Variable	Adjusted models		Unadjusted models)	
	Beta (CI 95%)	*p* value	*Beta (CI 95%)*	*p* value
Total PA, All (n = 5,433)				
Forests (%)[a]	50 (35–64)	<0.001	56 (42–70)	<0.001
Fields (%)[b]	56 (39–74)	<0.001	59 (42–77)	<0.001
Number of wetlands[c]	3 (2–4)	<0.001	3 (1–4)	<0.001
Landscape diversity[d]	8 (6–10)	<0.001	8 (6–10)	<0.001

[a] Forests (%): Percentage of a residential area (1 km buffer) [b] Fields (%): Percentage of a residential area (1 km buffer) [c] Wetlands: Number of wetlands (1 km buffer) [d] Landscape diversity: High values indicate high diversity (1 km buffer)* Models adjusted for education, gender, and BMI

5.3 The role of nature relatedness in young men's physical activity (III)

The aim of this study was to investigate the role of nature relatedness in physical activity and health among Finnish adolescent men. In 2013, 914 young men in total participated in compulsory conscription and completed the questionnaire. Of the participants, 430 (47.0 %) were classified as having strong nature relatedness (score $\geqslant$ 19) and 484 as having weak nature relatedness (score < 19). The characteristics of the study population are presented in Table 7.

The adolescent men with strong nature relatedness were more physically active, rated their health better, smoked less, had lower alcohol intake, and spent more time in nature than those who had weak nature relatedness.

Table 7. Characteristics of the MOPO study population (n = 914) by nature relatedness (NR)*.

Characteristics	All (n = 914)	Strong NR (n = 430)	Weak NR (n = 484)	p *
Age, years	17.8 (0.5)	17.7 (0.5)	17.8 (0.6)	0.678
Weight, kg	72.9 (6.4)	72.3 (13.5)	73.5 (14.7)	0.275
Height, cm	177.8 (14.1)	177.6 (6.2)	178.0 (6.2)	0.472
BMI, kg/m2	23.0 (4.2)	22.8 (3,9)	23.1 (4.5)	0.322
Good self-rated health, N (%)	660 (74.5)	343 (79.7)	317 (65.4)	<0.001
Life satisfaction (range: 4–20)[a]	9.97 (2.0)	9.79 (2.0)	10.13 (2.1)	0.015
Current alcohol intake (yes), N (%)	572 (63.2)	236 (54.8)	336 (69.4)	<0.001
Current smoking (yes), N (%)	246 (27.2)	95 (22.0)	151 (31.1)	0.002
Moderate physical activity ≥4 per week (yes), N (%)	722 (80.6)	369 (85.8)	353 (72.9)	<0.001
Physical activity with parents during childhood (yes)	672 (77.8)	340 (79.0)	332 (68.5)	<0.001
Physical activity with parents at secondary school age (yes), N (%)	241 (27.9)	148 (34.4)	93 (19.2)	<0.001
Current physical activity with parents (yes), N (%)	148 (17.3)	93 (21.6)	55 (11.3)	<0.001
Mother's higher SES, N (%)	406 (53.0)	193 (44.8)	213 (44.0)	0.942
Father's higher SES, N (%)	367 (49.9)	194 (45.1)	173 (35.7)	0.032
Amount of natural space in residential environment (500 m buffer), km^2	0.36 (0.15)	0.37 (0.15)	0.35 (0.14)	0,044
Distance to closest park, m	3744 (4241)	3764 (4834)	3166 (3616)	0.033
Distance to closest forest, m	455 (501)	453 (508)	457 (495)	0.887
Spends time in green areas (yes), N(%)	532 (59.0)	361 (40)	171 (19)	<0.001

Characteristics	All (*n* = 914)	Strong NR (*n* = 430)	Weak NR (*n* = 484)	*p* *
Diversity of residential environment, number of natural elements	42 (10)	42 (10)	42 (10)	0.950
Nature relatedness[b]	19.07 (8.9)	26.64 (4.4)	12.35 (5.9)	<0.000

* *p*-values (stronger nature relatedness vs. weaker nature relatedness group) independent samples crosstabs/chi-squared test or independent samples *t*-test.

[a] Life satisfaction: Higher score indicates lower life satisfaction. Numbers do not match due to missing values.[b] NR score: Ranging 0–36, higher score indicating better NR (lower half of the group ≤ 18 and higher half of the group ≥ 19). Values are means (SD) if not otherwise stated.

According to the multivariate linear regression involving the total population (Table 8), the following variables were positively associated with nature relatedness: physical activity (β = 2.13, 95% CI 0.31—3.94), primary school–age physical activity with parents (β = 2.06, 95% CI 0.57—3.56), current physical activity with parents (β = 2.88, 95% CI 1.12—4.65), good self-rated health (β = 2.84, 95% CI 1.15—4.53), and father's higher SES (β = 1.38, 95% CI 0.05—2.07).

Table 8. Factors associated with nature relatedness among young men (n = 914) according to multivariable linear regression.

Variable*	β	95 % CI	*p*
Physical activity ≥ 4 h per week	2.13	0.31, 3.94	0.021
Physical activity with parents at primary school age	2.06	0.57, 3.56	0.007
Current physical activity with parents	2.88	1.12, 4.65	0.001
Good self-rated health	2.84	1.15, 4.53	0.001
Father's higher SES	1.38	0.05, 2.70	0.041

* yes/no if not continuous

When participants with weaker natural relatedness were studied separately (Table 9), the following variables were found to be positively associated with nature relatedness: spending time in nature (β = 3.37, 95% CI 2.20—4.53), primary school-age physical activity with parents (β = 1.68, 95% CI 0.48—2.89), and father's higher SES (β = 1.19, 95% CI 0.10—2.31)

Table 9. Factors associated with nature relatedness among young men with weaker nature relatedness (NR score ≤ 18).

Variable*	β	95 % CI	*p*
Weaker nature relatedness			
Spending time in nature	3.37	2.20, 4.53	<0.001
Physical activity with parents at primary school age	1.68	0.48, 2.89	0.006
Father's higher SES	1.19	0.00, 2.31	0.038

* yes/no if not continuous

In the secondary analysis of this study, physical activity was used as a dependent variable (Table 9). According to the results of the logistic regression, self-rated health (OR (Odds ratio) = 0.17, $p \leqslant 0.001$, 95% CI 0.120—0.252) and nature relatedness (OR = 1.04, $p \leqslant 0.001$, 95% CI 1.021—1.064) were positively associated with physical activity among young men.

6 Discussion

The purpose of the present study was to investigate natural residential environments focusing on residential greenness, residential landscape diversity, and their association with physical activity. In addition, it investigated the relationship between nature relatedness and physical activity in adolescent men.
The results indicated that both residential greenness and landscape diversity in the residential environment can play a role in supporting physical activity among middle-aged adults (I, II). Among adolescent men (III), nature relatedness and current and childhood physical activity were found to be positively associated.

6.1 The role of the natural residential environment in physical activity (I, II)

The results of the study (I) are in line with many previous studies related to the association between greenness and light physical activity among middle-aged adults (James et al., 2017). The results showed a linear relationship between residential greenness and light and moderate physical activity, giving support to the assumption that every increase in residential greenness can support physical activity among middle-aged adults.

Other studies using accelerometers and GPS data to measure physical activity in both adults and adolescents have indicated that physical activity is more likely to occur in green environments than non-green environments (Dewulf et al., 2016). Similar buffer sizes (approximately 300–1,000 m) have been used to define residential areas, and NDVI has been widely used in many studies concerning residential greenness and physical activity, yet there is great variability in the resolutions of the satellite data (James et al., 2017; Marquet et al., 2022; McMorries et al., 2014). Some of the study results are also contradictory to previous studies (Melo et al., 2020; Ord et al., 2013), but the majority of the studies show that green environments provide settings that are especially suitable for light and moderate intensity physical activity such as walking, cycling, activities with animals (e.g., dog walking), and gardening (Markevych et al., 2016; Westgarth et al., 2014). Physical activity in natural environments, especially walking, can be more motivating – it can be regular and longer lasting, and it does not require equipment or facilities (Shanahan et al., 2016; Sugiyama et al., 2013). Light physical activity can be more easily adapted into daily routines and help people avoid time spent sedentary. Light physical activity in nature can also serve the needs of different groups of people with varied backgrounds – for example, those who have chronic diseases or other limitations for brisker physical activity. In addition, some studies have found positive associations between greenness and moderate to vigorous physical activity (Dewulf et al., 2016; Marquet et al., 2022). Moreover, for regular exercise, the environment is a less important source of well-being than physical activity itself (Kerr et al., 2006).

The results of the present study (I) indicated that the positive association between residential greenness and light physical activity was stronger among men than women, which cannot be comprehensively explained by relying on the previous studies, where greenness is positively associated more with women's physical activity (Triquero-Mas et al., 2015). According to the Working Paper of the Finnish Forest Research Institute (Sievänen & Neuvonen, 2020) women spend more time outdoors within residential areas such as their own yards, parks, and natural environments, which seems contradictory to the results of the previous study. It is possible that in natural environments, hobbies and activities such as fishing and hunting, which are more popular among men, increase men's physical activity. Men also tend to participate in yard work (e.g., shoveling snow, mowing the lawn) more than women, though this is not straightforward. In a study on middle-aged participants based on a self-reported questionnaire of physical activity, women were less likely have physical activity outdoors, though the type of the environment was not defined (van Uffelen et al., 2017).

In addition to residential greenness, a positive association was found between residential landscape diversity (forests, fields, wetlands, bodies of water, and landforms) and total physical activity among middle-aged men and women (II). This supports the assumption, that also other kinds of natural environments can encourage physical activity, not only green environments. Diverse landscapes increase the possibility for different types of PA (e.g., walking, viewing nature, cycling, skiing), which can support the needs of people from different backgrounds and with different interests (Bauman et al., 2012; Elliot et al., 2015; Hooper et al., 2017; Troped et al., 2013). As the aesthetics of nature vary based on individual perceptions, different kinds of natural features in a residential environment can encourage people to spend time outdoors more equally, as they provide possibilities not only for physical activity but also for restoration (Miralles-Guasch et al., 2019; Pikora et al., 2006). Recently, epidemiological studies have shown increasing interest in total physical activity because the WHO (2020) recommendation for physical activity has highlighted light physical activity (staying active as much and often as possible) and decreasing sedentary time. As landscape diversity was positively related to total physical activity, it may imply that diverse residential landscapes can encourage people to spend time outdoors and be more active. Only a few studies examine landscape diversity and physical activity, and they have mainly focused on the elements of built environment (Li et al., 2023). Studies have found positive associations between blue spaces (i.e., coastal areas and other bodies of water), rural areas, and physical activity (Gascon et al., 2017; Jansen et al., 2017). Shanahan et al. (2016) suggested that nature itself is a reason to spend time outdoors, and physical activity can appear as a 'secondary benefit' (Irvine et al., 2013). For example, many nature-oriented activities, such as photography and fishing, require at least light intensity physical activity (Giles-Corti et al., 2005). All these studies support the findings of this previous study about varying landscapes and total physical activity.

There are several theories explaining the relationship of natural environments and physical activity. First, people have an instinctive need to interact with the living nature (Wilson, 1984). Second, natural environments can provide well-being effects, as they are restorative environments through aesthetics, have better air quality and less noise, and thus provide ideal settings for physical activity (Fong et al., 2017; James et al., 2015; Shanahan et al., 2016; Wilson, 1984). In addition, it is important to bear in mind that nature exposure can possibly enhance the benefits of physical activity by providing sub-additive, additive, and synergistic benefits (Shanahan et al., 2016); this highlights the importance of natural areas in residential environments, where exposure mainly takes place on a daily basis. As an example, sub-additive benefits can occur especially in cases where some physiological effect occurs until it reaches its limits in a human body. For instance, the reduction of blood pressure is linked to physical activity, and this effect can even be strengthened with exposure to natural environments. This is naturally linked to the intensity of physical activity, the duration of exercise, and time spent in nature. According to Shanahan's theory (Shanahan et al., 2016), additive benefits may not be linked to physical activity itself but instead to nature. For example, a person can experience a better mood or another additional positive effect when exercising in natural areas compared to exercising indoors. Synergistic benefits occur only when physically active in nature and vice versa, suggesting the positive association between natural environments and physical activity (Astell-Burt et al., 2013).

As scientific evidence on the health benefits of green space has grown rapidly in recent decades, urban green space should be taken into account when planning residential and other urban areas. New tools should also be provided for such planning. (Oijstaeijen et al., 2020) The economic perspective is a key priority in urban planning and implementation, and the longer-term benefits of natural habitats should be taken into account, as they can provide substantial public health savings. (Elmqvist et al., 2015) However, these can be difficult to quantify in real terms. In addition to health benefits, natural areas also provide other positive impacts through, for example, reduced pollution and smoother water regulation (Escopedo et al., 2011; Pataki et al., 2011).

As scientific evidence on the health benefits of green space has grown rapidly in recent decades, urban green space should be taken into account when planning residential and other urban areas. New tools should also be provided for such planning. (Oijstaeijen et al., 2020) The economic perspective is one of the major priorities in the urban planning and implementation and longer-term benefits of natural residential environments should be considered as they may provide considerable public health savings. (Elmqvist et al., 2015) However, these can be difficult to quantify in real terms. In addition to health benefits, natural areas also provide other positive impacts through, for example, reduced pollution and smoother water regulation (Escobedo et al., 2011; Pataki et al., 2011). Densely built areas and large cities do not necessarily offer citizens access to natural areas on a daily basis. (Oijstaeijen et al., 2020) In addition, the quality of natural areas may be poor in urban areas and rural local centres. In Finland, larger cities face the same problem as other European cities - the trend to build increasingly dense residential areas with few natural elements or very large areas that exclude natural areas. One possible solution could be to ensure more varied and larger natural areas within walking distance of each residential area, providing suitable activities for different needs. This study has identified an urgent need for new urban planning considerations and possible future urban planning guidelines and regulations to integrate natural environments into land-use planning and the residential environment.

6.2 Nature relatedness as potential promoter of physical activity in adolescents

Recently, only a few studies have investigated the role of nature relatedness on adolescent physical activity, as the studies have mainly focused on children and adults (Flowers et al., 2016; Lin et al., 2014; Molina-Cando et al., 2021). Internationally, some studies have explored nature relatedness in adolescents but specifically within the scope of well-being (Nisbet et al., 2011; Townsend et al., 2015). In this study, a positive association was found between nature relatedness and current and childhood physical activity. Also, spending time in nature was positively connected to nature relatedness, which follows the findings of previous studies on adolescents (Lawton et al., 2017; Nisbet et al., 2011). This study not only supports previous research, but also points to the need for further research on nature relatedness and physical activity and the role of nature in the health behaviour of young people.

Strong nature relatedness in adolescents is important for motivating people to spend time in nature (Nisbet et al., 2009; Uhlmann et al., 2022) and thus also to participate in physical activity. A basis for this is in the theories focusing on the human–nature relationship and the key drivers of it. As Wilson (1984) suggested, people have an instinctive need to interact with the living world in various forms. As a conclusion of the theoretical background, Hurly and Walker (2019) found that nature relatedness is a basic human need that does not depend on culture, SES, and age (Kövi et al., 2021). Nature relatedness can also increase eudemonic and hedonic well-being, which are linked to motivation for physical activity (Jenkins et al., 2022). Strong connectedness with nature can help adolescents obtain more of nature's health benefits (Nisbet et al., 2011; Tang et al., 2015; Townsend et al., 2015). In this study, better self-rated health was positively associated with stronger nature relatedness. When it comes to overall physical activity in nature, studies suggest that exercising outdoors requires less exertion compared to exercising indoors and that it provides experiences of positive well-being benefits that can be linked to spending time in favourable natural environments and stronger nature relatedness (Loureiro & Veloso, 2014; Martyn & Brymer, 2016). Pasanen et al. (2014) show that physical activity in natural environments provided an added value to the benefits of physical activity, such as better sleep and emotional well-being, in a Finnish population-based study of different ages. According to the Children and Youth Leisure Survey 2022, the majority of young people (aged 7-29) like to spend time outdoors, especially in nearby natural areas. Self-directed activities in nature seem to be more popular among young people than guided activities, especially among young men. However, time spent in nature seems to decrease in early adulthood before increasing again with age. (Aapola-Kari, 2022; Neuvonen et al., 2022)

Childhood can play a key role in forming strong nature relatedness (Orr, 1993; Ward-Thompson et al., 2008). This study found that participants' physical activity with their parents in elementary school was positively associated with nature relatedness. In addition, this study showed that those young men who engaged in physical activity with their parents in early childhood were more likely to maintain these activities with their parents in adolescence and had strong nature relatedness. The type of activity with parents was not assessed in this study, but it is possible that especially in Northern Finland, where nature is generally accessible, parents and children spend time outdoors being physically active. Summer cottages are common in Finland, and most of them are located in natural areas such as lakes and forests. Spending time with family in such places can be meaningful in strengthening children's and young people's relationship with nature, especially for urban residents (Aapola-Kari, 2022).

This encourages further studies to have a deeper insight into how nature relatedness and physical activity are linked and develop during the life course. Supporting children and young people's relationship with nature can potentially strengthen their commitment to nature later in life. Family knowledge and motivation play an important role in providing nature experiences for young people. (Rantala & Puhakka, 2019) Therefore, early childhood education (e.g., nurseries, schools), public health (e.g., child health clinics) and various non-profit organisations should be involved in supporting families to strengthen their relationship with nature. In practice, this would require more information about nature and suitable and safe natural environments, such as local forests, urban parks and other nature-related facilities, such as farms with animals, to be made available to people living in different types of residential environments. (Rantala & Puhakka 2020.) Children and young people living in urban and rural areas may have different interests and opportunities for nature experiences. (Aapola-Kari, 2022) In northern areas, seasonal maintenance should be provided, especially in winter, to enable nature visits throughout the year.

6.3 Strengths and limitations

The previous study was based on a large population-based setting of middle-aged adults and adolescents. The participants of the 1966 cohort studies (I, II) were geographically located all around Finland, and the participants of the MOPO study (III) were located in Northern Finland, giving comprehensive information about adolescent men living in that specific area. As the participants live in different types of residential environments throughout Finland (I, II), it was possible to investigate how PA was related to different kinds of landscapes.

Physical activity – including leisure-time physical activity, work-related physical activity, and physical activity related to daily household chores – was assessed using an accelerometer-based measurement (I, II). However, participating in a follow-up study of physical activity can cause unusual behaviour, such as temporarily increased physical activity, which participants would not normally do. In addition, the wrist-worn activity monitor used to assess physical activity accelerometry could not accurately detect bicycling. Physical activity was assessed with a validated questionnaire when studying adolescent's physical activity. (III) Reliance on self-reported measures of behavioural factors such as physical activity is limited, since answering questionnaires can lead to an overestimation of the amount of physical activity and its intensity. The questionnaire used to measure nature relatedness was based on parts of previously used questionnaires. (Hartig, 2004; Kaikkonen et al., 2014; Lemieux et al., 2016; Nisbet & Zelenski, 2013; Staats & Nisbet et al., 2009) Although in can be seen as a reliable method for measuring adolescent's nature relatedness from the view of nature's wellbeing effect on overall health, it may not be suitable for measuring more ecological nature relatedness. However, the purpose of this study was focused on the association of nature relatedness and physical activity. Individual personality traits, which may have affected adolescent's nature relatedness, were not assessed in this study. The participants were not asked how they perceived their residential environment. (III)

Questionnaire methods are, however, widely used and useful for grouping people into categories on the basis of their physical activity. The questionnaires used in all three studies concerning health, health behaviours, and SES (I, II, III) were comprehensive and with high compliance. The role of several socioeconomic confounders was considered in this study since they may reveal area-level and individual differences in the association between natural environments and physical activity (James et al., 2015).

GIS as a method provides an efficient tool for measuring the residential environment, which can be easily exploited in urban planning. Residential greenness and the natural landscape were objectively measured (I, II, III). The calculation of the NDVI is inevitably sensitive to topographic and atmospheric factors, although this was addressed via careful data selection and processing. Bodies of water were not eliminated from the GIS data, which may have led to lower NDVI values in buffers with higher quantities of bodies of water. Since buffers were used in this study to estimate the features of participants' residential areas, their perception of greenness was not assessed, and their real-life movements were not more specifically defined. However, their usability is moderately reliable given the focus on objective greenness and PA from a phenomenological in our study and following the recommendations for natural area accessibility by the World Health Organization (2022). (European Environment Agency, 2022) Self-selection bias concerning moving to green residential environments as a part of subjective behaviour may exist (Chaix et al., 2012).

Due to the cross-sectional study setting, it was not possible to draw conclusions on a causal relationship between natural environments, nature relatedness, and physical activity. Even though the methodology used in this study has been widely used in epidemiological studies of various population and areas, the results of this study may not be generalized to different populations, age groups, or regions outside Northern Europe due to the cultural and climate factors and other differences between regions.

6.4 Future studies

Longitudinal, large population–based studies on people of different ages are urgently needed to gain knowledge about the causal relationship between residential natural environments and physical activity – especially how moving from built areas to natural areas affects physical activity. In addition, it would be important to better understand what kind of reliable GIS methods could be utilized in land use design.

When objectively measuring greenness, research has examined the size of natural environments and their role in PA, along with their typology, indicating that smaller natural areas (e.g., urban parks) are more likely used for social interaction and relaxation than for PA (Peschardt et al., 2012). Larger areas, meanwhile, are more likely used for different types of PA. There are still few studies focusing on the association of the size of natural areas and PA (Elliot et al., 2015). Perceived greenness and landscape were not assessed in this study, which futures studies should consider alongside objectively measured greenness. However, NDVI has been studied to correlate with perceived greenness (Hart et al., 2022). As landscape is a more complex ensemble, future studies should focus on developing reliable methods that could be efficiently used for measuring individuals' perception of the natural landscape, which could be used in urban planning. Associations between residential natural environments, nature relatedness, and physical activity can differ geographically, so different cultures and climates should be considered in future studies.

Further studies should focus on the methods for measuring and understanding nature relatedness, since nature relatedness can take several forms across different cultures and regions. Longitudinal studies can help understand how living in natural areas from childhood to adulthood affects nature relatedness and physical activity over the course of one’s life. Still, it is unclear how nature relatedness is born and developed and how it can be maintained throughout life. More information is needed to understand the role of nature relatedness in the use of natural areas, especially in how the type of residential environment supports nature relatedness among people of different ages from various backgrounds. Also, the role of the family in the process should be considered to better support families and their capability and willingness to develop children’s nature relatedness. In addition, health care professionals and early childhood educators should be educated on the human–nature relationship and be committed to fostering children’s nature relationship.

7 Conclusions

In this study, residential greenness and landscape diversity were positively associated with physical activity in middle-aged adults (I, II). Nature relatedness was also positively associated with adolescent men's physical activity (III).

Every citizen should have easy access to natural areas preferably within 300 m from home. (World Health Organization, 2016) Knowledge gained thus far implicates the need to prioritize greenness in land use planning. This especially stands out in densely built cities, which often lack green areas that are reasonably sized and easily accessible. Green parks in residential areas can provide one possibility for designing greenness in cities, and they have been found to be popular among adolescents and adults in urban environments (Roemmich et al., 2018; Grigoletto et al., 2021). In practice, easy access to natural areas means the possibility of accessing favourable natural environments in daily life, which can have positive implications for health and decrease inequality among citizens (Mitchell & Popham, 2006; Sharifi et al., 2020; European Environment Agency, 2022). In Finland, natural areas are more accessible than in many other countries and outdoor activities is an important part of the Finnish culture. Thus, raising the citizen's awareness of the benefits of nature may provide an efficient way for encouraging physical activity in the population.

The results of studies I and II can be used in further studies concerning different natural environments and physical activity and in planning residential environments that support physical activity. In addition, the knowledge can be used in interventions for promoting middle-aged citizens' physical activity. The knowledge gained in study III can be used for health interventions among young men, especially nature-related interventions aiming to promote adolescent men's physical activity. Supporting adolescent men's nature relatedness offers a great opportunity not only to improve physical activity but also to prevent marginalization among the target group. To improve their connection with nature, they should have the opportunity to access favourable natural areas on a daily basis. Knowledge is also required about the environments that are favourable for adolescents and encourage them to spend time in such environments.

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I Puhakka, S., Lankila, T., Pyky R., Kärmeniemi, M., Niemelä, M., Kangas, K., Rusanen, J., Kangas, M., Näyhä, S., & Korpelainen, R. (2019). Satellite imaging-based residential greenness and accelerometry measured physical activity at midlife – Population-based Northern Finland Birth Cohort 1966 study. *International Journal of Environmental Research and Public Health, 17*(24), 9202.

II Puhakka, S., Kangas, K., Lankila, T., Niemelä, M., Kärmeniemi, M., Tukiainen, H., Alahuhta, J., Hjort, J., & Korpelainen, R. (2022). Association between Residential Natural Landscape Diversity and Accelerometer-measured Physical Activity in adults: Population-based Northern Finland Birth Cohort 1966 Study (*Manuscript*)

III Puhakka, S., Pyky, R., Lankila, T., Kangas, M., Rusanen, J., Ikäheimo, T. M., Koivumaa-Honkanen, H., & Korpelainen, R. (2018). Physical activity, residential environment and nature relatedness in young men – A population-based MOPO study. *International Journal of Environmental Research and Public Health*, *15*(10), 2322.

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

1751. Geneid, Mohamed (2023) The relationship between retinal vessel diameter with retinal nerve fibre layer thickness and optic nerve head parameters : the Northern Finland Birth Cohort Eye study

1752. Hellberg, Iida (2023) 3D quantification of human knee articular cartilage and meniscus microstructures in osteoarthritis

1753. Kaikkonen, Kaisu (2023) Intensified lifestyle intervention with exercise as a treatment of severe obesity and prevention of cardiometabolic risks

1754. Rytky, Santeri (2023) Machine learning applications for multi-scale computed tomography of skeletal tissues

1755. Kerkelä, Martta (2023) Changes in the incidence of mental disorders in Finnish cohorts and the effects of being a participant of the Northern Finland Birth Cohorts

1756. Kauppi, Saana (2023) Comorbidity in atopic dermatitis

1757. Paukkonen, Leila (2023) Patient participation, adherence, and activation for self-management among adult patients with multimorbidity in primary healthcare settings

1758. Närhi, Anne Linnea (2023) Malocclusions and their associations with oral health-related quality of life in the Northern Finland Birth Cohort 1966

1759. Elseragy, Amr (2023) Predictive features and potential treatment targets for oral tongue cancer

1760. Keinänen, Anna-Leena (2024) Koulutusinterventioiden vaikuttavuus suun terveydenhuollon ammattilaisten opiskelijaohjausosaamiseen kliinisessä harjoittelussa

1761. Tikkanen, Ville (2024) Adolescent social functioning and later psychiatric morbidity in genetic high- and low-risk adoptees. The Finnish Adoptive Family Study of Schizophrenia

1762. Mäkikyrö, Elina (2024) Asthma subtypes formed by epidemiological and clinical methods

1763. Tervahauta, Elisa (2024) Occlusal characteristics, temporomandibular disorders, and oral health-related quality of life in the Northern Finland Birth Cohort 1966

1764. Mosorin, Maria-Elina (2024) Metabolic effects of hormonal contraception in women with and without polycystic ovary syndrome

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ACTA UNIVERSITATIS OULUENSIS

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ISBN 978-952-62-3965-1 (Paperback)
ISBN 978-952-62-3966-8 (PDF)
ISSN 0355-3221 (Print)
ISSN 1796-2234 (Online)