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Activity-friendly neighborhoods and the moderating role of perceived safety

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Acknowledgments

This thesis marks the end of two brilliant years of public health studies in Ås. I am so happy I followed my dream and finally found my true passion! But even more importantly, I found some cool, like-minded people along the way who have become my dearest friends.

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Abstract

Background: Physical inactivity is a major global public health issue, and the potential influence of the built environment on activity levels has received significant attention in the last decade. Walking-friendly neighborhoods with access to recreational facilities seem to promote physical activity. The Norwegian government has stated that they want to strengthen the development of activity-friendly living areas. However, there is a lack of research into the potential health-promoting influence of different built environment characteristics on physical activity levels among adults in Norway. Thus, this study aimed to investigate the relationships between neighborhood green spaces, walkability, and physical activity. We also examined whether such relationships were moderated by perceived neighborhood safety.

Methods: This cross-sectional study combined data obtained from the Norwegian County Public Health Survey (NCPH) in Rogaland (N = 5670) and built environment variables computed using geographical information systems (GIS). Neighborhood green space was measured as a vegetation score, whereas the walkability score was computed as an index based on population density, intersection density, and recreational space within the postal code areas where the participants resided. Physical activity levels were assessed by transforming responses from two questions in the survey to create a measure of the weekly minutes of physical activity for each participant. Linear regression was performed with the walkability and vegetation scores as exposures and minutes of physical activity per week as the outcome. Separate models were fitted for each exposure variable. The analyses were adjusted for age, sex, educational level, and perceived financial status. A moderation analysis was also provided to study perceived safety when out walking.

Results: Neighborhood green space was associated with higher physical activity levels in the unadjusted analysis. The associations were weaker when adjusting for age, sex, educational level, and perceived financial status but remained significant, with a mean value of 24 more minutes of physical activity per week per unit increase in the NDVI score. The walkability score showed a slight negative trend in the physical activity levels, although not significant. No moderating effects of perceived safety were observed in the models. However, perceived safety was positively related to physical activity.

Conclusion: Our study emphasizes the importance of providing green spaces as a key factor in promoting physical activity. Preserving green spaces under pressure, such as walking paths, parks, and wild nature can be an investment in public health. This is important knowledge for

policymakers, planners, and public health professionals. Future studies should investigate how perceptions of safety are associated with physical activity, and there is especially a need for more prospective studies considering these associations in the Nordic context.

Sammendrag

Bakgrunn: Fysisk inaktivitet er en stor utfordring for folkehelsa, og påvirkningen som det fysiske miljøet har på fysisk aktivitet har fått mer oppmerksomhet de siste årene. Grønne og gåvennlige nabolag ser ut til å kunne øke folks aktivitetsnivåer. Den norske regjeringen har i den forbindelse uttalt at de ønsker å styrke utviklingen av aktivitetsfremmende nærområder. Det er derimot lite forskning på mulige sammenhenger mellom fysiske omgivelser og fysisk aktivitet hos voksne i Norge. Målet med studien var derfor å studere sammenhengen mellom gåvennlige, grønne nabolag og fysisk aktivitet. Vi ønsket også å undersøke om disse eventuelle sammenhengene ble moderert av at nabolagene opplevdes trygge.

Metode: Denne tverrsnittstudien kombinerte data fra Fylkeshelseundersøkelsen i Rogaland (N = 5670) og geografisk data ved bruk av geografiske informasjonssystemer (GIS). Andel grøntområder ble målt med en vegetasjonsscore, mens gåvennlighet ble beregnet som en indeks basert på befolkningstetthet, tetthet av veikryss og rekreasjonsområder innenfor postnummerområdene der deltakerne bor. Fysisk aktivitet ble beregnet ut fra to variabler i Fylkeshelseundersøkelsen til en ukentlig minutt-score for hver deltaker. Lineær regresjon ble gjort med gåvennlighet og vegetasjonsscoren som eksponering og minutter med fysisk aktivitet per uke som utfall. Separate modeller ble gjort for hver utfallsvariabel. Analysene ble justert for alder, kjønn, utdanningsnivå og opplevd økonomisk status. Det ble også gjort en moderasjonsanalyse for å studere opplevd trygghet som en mulig moderator.

Resultater: Tilgang til grøntområder var assosiert med økte nivåer av fysisk aktivitet i den ujusterte analysen. Etter justering for alder, kjønn, utdanningsnivå og opplevd økonomisk status var assosiasjonen noe svakere, men fortsatt signifikant, med gjennomsnittlig 24 minutter mer fysisk aktivitet per uke for hver økte NDVI-enhet. Gåvennlighet viste en liten negativ assosiasjon med nivå av fysisk aktivitet, men denne sammenhengen var ikke signifikant. Opplevd trygghet viste ingen moderator-effekt på de to modellene. Den var derimot positivt assosiert med fysisk aktivitet.

Konklusjon: Studien understreker viktigheten av å sikre tilgang til grøntområder for å fremme fysisk aktivitet i befolkningen. Dette er viktig kunnskap innen folkehelsearbeid. Å

bevare grøntområder under press bør vektlegges i deres arbeid. Fremtidige studier bør undersøke sammenhenger mellom opplevd trygghet og fysisk aktivitet, og det er et særlig behov for prospektive studier i en nordisk kontekst.

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List of figures and tables

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Abbreviations

MVPA	Moderate to vigorous physical activity
NCD	Non-communicable diseases
NSD	Norwegian center for research data
NCPH	Norwegian County Public Health (Survey)
NIPH	Norwegian Institute of Public Health
SEP	Socio-economic position
SSB	Statistics Norway
WHO	World Health Organization

1. Introduction

The condition of our everyday environments plays an important role for health and quality of life (World Health Organization, 2018b). The recent World Health Organization (WHO) report "Healthier and happier cities for all" chose to highlight the need for a transformative approach for inclusive, safe, sustainable, and resilient societies (World Health Organization, 2018a). One of the aims presented was to design urban places that improve health and well-being. This has also been emphasized in the Norwegian Law of Public Health (Folkehelseloven, 2011), the National Action Plan for Physical Activity (Ministry of Health and Care Services, 2020), and the recent Public Health Report (Ministry of Health and Care Services, 2019).

Being physically active every day provides substantial health benefits and reduces the risk of non-communicable diseases (NCDs) (Katzmarzyk et al., 2022; Lee et al., 2012) and premature death (Lear et al., 2017). Despite this knowledge, physical inactivity is globally attributable to 7.2% and 7.6% of all-cause and cardiovascular disease deaths, respectively, making it a global pandemic (Katzmarzyk et al., 2022; Pratt et al., 2020). Finding solutions to turn this trend is therefore a highly prioritized task in the field of public health.

A growing body of research has identified characteristics of the built environment in neighborhoods that seem to promote active living among adults (Bird et al., 2018; Dixon et al., 2021). The design of our environments can encourage and facilitate walking, outdoor life, and other kinds of physical activity. However, there is a lack of research considering possible health-promoting built environment characteristics on physical activity levels among adults in Norway. Thus, this study addresses two factors in the built environment: access to green spaces and walking-friendly areas.

The aim of our research is two-fold. First, we aim to investigate the relationships between neighborhood green space, walkability, and physical activity levels. Second, we explore if such relationships are moderated by perceived neighborhood safety. The study consists of a thesis and an attached article. The thesis gives an overview of physical activity and its health benefits, with a presentation of physical activity levels globally and nationally. Determinants affecting physical activity levels are described in an ecological framework, emphasizing the environmental effects of green spaces and walking-friendly areas. The method and result section briefly presents the methodology and results of our study, referring to the article. The emphasis is on a thorough methodological discussion and discussing the results from a more theoretical perspective than in the article. The results are interpreted in the Norwegian context, and implications for further public health work are drawn.

Second, the article will be presented. The article is called "Examining activity-friendly neighborhoods in the Norwegian context: built environment characteristics in relation to physical activity and the moderating role of perceived safety." The article is planned to be published in a scientific journal.

2. Background

2.1 Physical activity and related health benefits

Being physically active is considered an important part of a healthy life. This study will use the physical activity definition by the WHO, which is "any bodily movement produced by skeletal muscle that requires energy expenditure" (World Health Organization, 2010). Physical activity can be performed in several ways, such as walking, cycling, or doing sports. The WHO recommends performing 150-300 minutes of moderate activity weekly or 75-150 weekly minutes of vigorous physical activity (Bull et al., 2020). Regular physical activity is a well-established protective factor against the leading non-communicable diseases (NCDs) such as stroke, heart disease, type 2 diabetes, and different cancers (Katzmarzyk et al., 2022; Lee et al., 2012; Roth et al., 2020). Physical activity is also associated with a general reduction in mortality (Ekelund et al., 2019; Lear et al., 2017).

Even though physical activity has major positive effects on health, it is estimated that 27.5% of the world's population are living inactive lifestyles according to the WHO recommendations (Guthold et al., 2018). A sedentary lifestyle is not optimal for the human body because the skeletal, muscle, metabolic, and cardiovascular systems function optimally when stimulated regularly by physical activity (Booth et al., 2008). Physical activity improves health through several mechanisms, including mitochondrial biogenesis, fatty acid oxidation, dilation of blood vessels, and reducing inflammation (Pinckard et al., 2019). These physical mechanisms are effective in preventing cardiovascular disease and type 2 diabetes. Nevertheless, a dose-response relationship between the extent and duration of exercise and reducing cardiovascular disease risk and mortality is still unclear (Nystoriak & Bhatnagar, 2018).

Physical activity is also found to be important in preventing mental disorders, such as depression, anxiety, and post-traumatic stress disorders (Hu et al., 2020; Mikkelsen et al., 2017; Schuch et al., 2019; Schuch et al., 2018). Present research shows that physical activity can create numerous physiological changes that can improve mood, self-esteem and lower anxiety levels and stress (Mikkelsen et al., 2017). Observations among a sample of Canadian adults suggest a dose-response relationship between physical activity and mental health (Bernard et al., 2018). This indicates that less physical activity than the WHO recommended levels are associated with mental health benefits. This was also supported by a systematic review showing that lower doses of physical activity (e.g., walking <150 min/week) are associated with a reduced likelihood of depression (Mammen & Faulkner, 2013).

In addition to premature mortality and mental disorders, physical inactivity is also responsible for a substantial economic burden. It is conservatively estimated that physical inactivity cost the international healthcare systems 53.8 billion (INT$) worldwide in 2013 (Ding et al., 2016). Physical inactivity is also responsible for 13.4 million DALYs worldwide (disability-adjusted life years) (Ding et al., 2016). This further justifies prioritizing physical activity promotion worldwide as part of a global strategy to reduce NCDs.

With the increased emphasis on physical inactivity being a public health issue, the WHO launched the Global Action Plan on Physical Activity 2018-2030 (GAPPA) in 2018. The action plan sets a global target to reduce physical inactivity by 15% by 2030 (World Health Organization, 2018b). It engages multiple sectors, strategies, and partners to reach its goals, and many countries have included similar measures within their public health plans (Pratt et al., 2020). However, major challenges with implementation remain (Sallis, Bull, et al., 2016).

2.2 Physical activity in Norway

Inactivity is also a major challenge in Norway, with a mean value of only 32 percent of the adult population reaching the minimum physical activity recommendations (Hansen et al., 2015; The Ministry of Health and Care Services, 2019). The national recommendations for physical activity were updated in May 2022. They are mainly based on the WHO guidelines (Bull et al., 2020), but with minor adjustments to the Norwegian context. The new recommendations highlight that every minute of activity counts. Low-intensity and short-lasting activities are also important, especially to compensate for sedentary living and spending many hours sitting every day (Norwegian Directorate of Health, 2019). Norwegian surveys show that outdoor walking is the most common type of physical activity in Norway (Hansen et al., 2015). Statistics Norway found that 68,1 % perform physical activity because they want fresh air and nature experiences. This was second only to the highest-rated motivation, which is keeping good health, with 84,5% (Statistics Norway, 2021b).

Following GAPPA (World Health Organization, 2018b), the Norwegian government has developed a corresponding national action plan that aims to reduce the inactivity levels of Norwegian citizens by 30% by 2030. The overall objective of the Norwegian action plan is to create a more activity-friendly society where everyone, independent of age, gender, function level, and social background, is given the opportunity to live a more active life (Ministry of Health and Care Services, 2020). This places great demands for collaboration on many different government institutions.

2.3 Determinants of physical activity – an ecological perspective

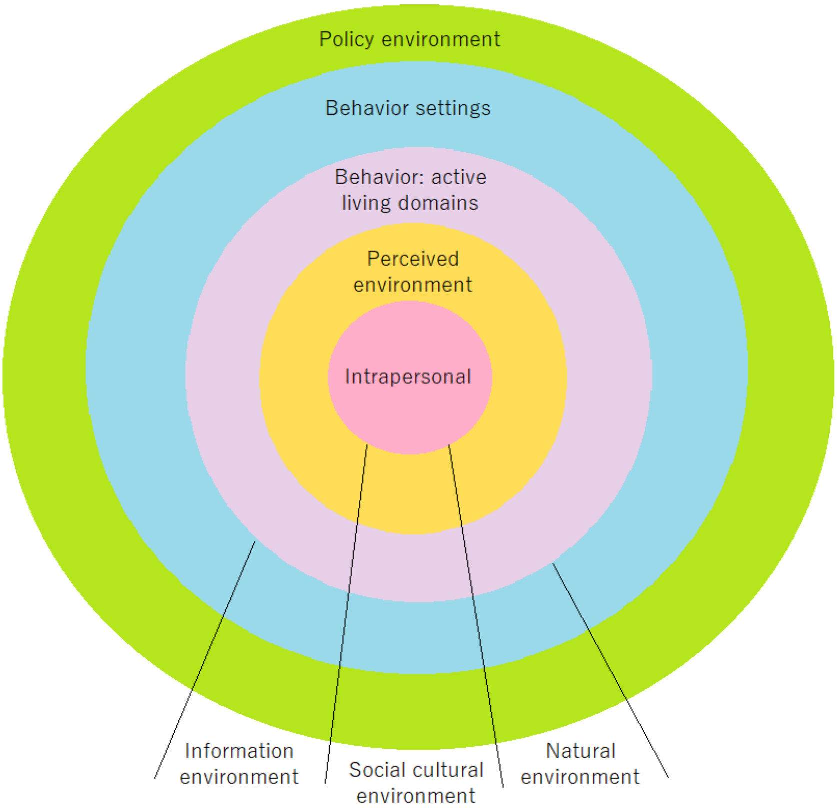
Explaining why some people are physically active and some are not, is complex, and theoretical models can help explain some of these mechanisms and factors. How the determinants of physical activity are understood in this thesis will now be presented using the ecological model of active living proposed by Sallis et al. (2006). This model forms the basis of the perspectives and contexts of our study.

For a long time, the use of behavior models has led to an almost exclusive focus targeted at interventions aimed at individuals or small groups (Sallis et al., 2006). Educational and behavior-change interventions have been found too narrow of an approach with limitations regarding effect sizes, reach, and maintenance of change (Sallis et al., 2006). As a result, there has been a growing interest in ecological models as a framework for promoting physical activity (Sallis et al., 2006). Such models do not only include a narrow range of psychosocial variables like motivation or knowledge, but also focus on a person's interactions with their physical and socio-cultural surroundings (DiClemente et al., 2019). Ecological models are considered especially well-suited for studying physical activity because the activity is performed in specific environments. It is then possible to examine what characteristics of places work as barriers or facilitators of physical activity. Ecological models can direct attention to environmental and policy factors that may cause the epidemic of sedentary lifestyles (Lavizzo-Mourey & McGinnis, 2003).

In their multilevel model, Sallis et al. (2006) use the term "active living" as a broad concept that incorporates recreational activities, exercise, household and occupational activities, and active transportation (Sallis et al., 2005). The four domains of active living are presented with multiple levels of influence on each domain. A modified version of the model is presented in figure 1.

Broad categories of interpersonal factors are placed in the center of the model. This includes demographic-, biological-, and psychosocial factors, as well as family situations, which can all influence activity levels. For instance, children and the elderly can have different needs, interests, and physical abilities for being active (Bauman et al., 2012). Perception of the environment, which is the second layer of the model, is distinguished from the more objective aspects of the environment. These perceptions can relate to attractiveness, accessibility, or if a person finds their neighborhood safe or not. To illustrate, a park perceived as aesthetically pleasing can make it more attractive for people to use it for activities (Giles-Corti et al., 2005). Perceptions of safety as an aspect will be examined in our analysis and described in more detail later (see chapter 2.7).

Figure 1: Adjusted ecological model, based on Sallis et al. (2006).



The next level of the model is the individuals' interaction with their environment, including diverse types of activity. In this layer, four domains of active living are presented – active recreation, occupational activities, active transport, and household activities. The model emphasizes that different kinds of physical activity occur in different settings and are therefore influenced by different environmental characteristics, which are placed in the fourth layer denoted as behavior settings. The neighborhood and its built environment are the location of physical activity that this thesis addresses and will be further described later (chapter 2.4). The outer layer is the policy environment where development regulations, park policies, public recreation investments, and traffic management are relevant.

An essential principle of the ecological model is that interactions can occur across levels. For instance, built environment characteristics interact with perceptions of those environments, the natural environment, the social/cultural environment, and the information environment. The natural environment describes factors regarding the weather and climate, while information environment refers to the health information provided by the government or the media. The sociocultural environment is presented as cutting across all layers of the model. This relates to a person's social environment, including culture, income, and socioeconomic position (SEP), referring to how an individual's activity is shaped by the cultural meanings of activities as well as by social interactions. In conclusion, ecological models highlight the importance of multi-layer interventions for effective promotion of physical activity. In a neighborhood, this could include targeting negative social norms about exercise, lack of parks, free parking, and weak physical education policies at once.

2.4 The neighborhood as an arena for physical activity

In recent years, the neighborhood has received greater attention as a contextual factor where people are involved in everyday activities (World Health Organization, 2017). A neighborhood is usually made up of housing areas, parks, open spaces, roads, streets, playgrounds, nature, and cultural landscapes, in addition to institutions such as kindergartens, schools, and nursing homes. The neighborhood also includes a psychosocial space of community, perceived safety, and trust (Jenks & Dempsey, 2007; Norwegian Directorate of Health, 2014). Neighborhoods are shared by people of all ages, genders, socioeconomic positions, and backgrounds, and can therefore be a universal arena for health promotion. It is also a place close to our homes, making it a part of our daily living. The neighborhood can, for instance, be part of people's way to work or a place to meet friends after school. The size of a neighborhood depends on the individual's movement radius, making it different when studying children, adolescents, adults, the elderly, or people with disabilities (Norwegian Directorate of Health, 2014).

Therefore, the emphasis on health-promoting neighborhoods has been implemented in policy work, like in the Norwegian Public Health Report from 2019 (Ministry of Health and Care Services, 2019), which stated that the Norwegian government wants to strengthen the development of activity-friendly neighborhoods. The physical aspects of the living environment are the focus of this study and will now be further described.

2.4.1 Activity-friendly built environments

The term "built environment" encompasses human-made elements that create a setting for human activity (Papas et al., 2007). This can include transportation, green spaces, training facilities, and urban development. A growing body of research has identified characteristics of the built environment that seem to promote active living among adults (Dixon et al., 2021; Smith et al., 2017). Neighborhoods with a high walkability score, recreational facilities, public transport density, and green areas seem to be possible facilitators for physical activity. For instance, Sallis et al. (2016) did a study in 14 cities in ten countries on five continents. They found a difference in physical activity levels between the most and least activity-friendly neighborhoods ranging from 68 to 89 minutes per week (Sallis, Cerin, et al., 2016). The built environment seems to motivate and facilitate the possibility of walking, outdoor life, and other kinds of physical activity. Two built environmental factors – green space and walkability – will now be discussed.

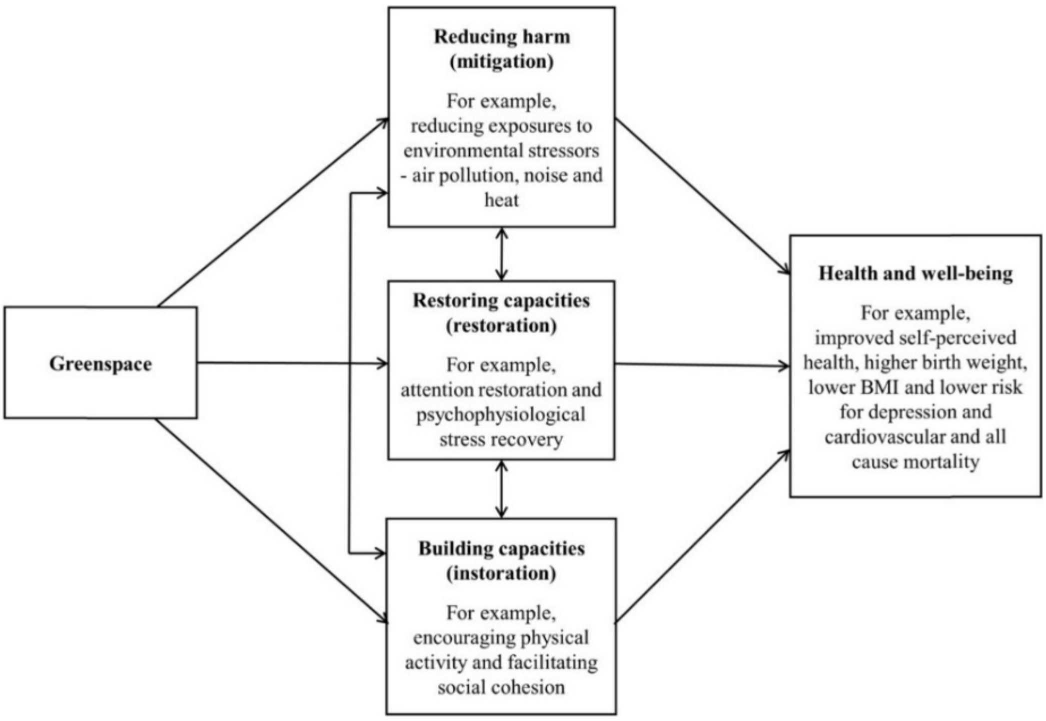
2.5 Green space and its influence on health and activity

Green spaces can be defined in numerous ways. Usually, it includes green natural environments but also more urban forms such as parks, street trees, and greenery (Taylor & Hochuli, 2017). In our study, a vegetation index (NDVI) was used to measure neighborhood greenness. NDVI uses infrared radiation to measure the amount of healthy green vegetation in satellite pictures of the earth (see further description in chapter 3.3.1).

Contact with natural environments, and especially green spaces, seems to positively affect self-perceived and objectively measured health and quality of life (Dadvand et al., 2016; Hartig et al., 2014). The research in this field is thorough and convincing (Gascon et al., 2016; Rojas-Rueda et al., 2019; Twohig-Bennett & Jones, 2018). A recent study found that a large number of premature deaths in European cities could be prevented by increasing the amount of neighborhood greenness (Barboza et al., 2021), showing the significant impact green space can have on health globally. Green space is also found to have more beneficial effects on people with lower SEP – making it a promising tool to advance health equity (Rigolon et al., 2021).

Various biopsychosocial pathways have been proposed to explain the relationship between green space and health. Markevych et al. (2017) present three main domains explaining the connection between green space and health (see figure 2). These include reducing harm, restoring capacities, and building capacities. Green spaces and their vegetation improve health by reducing exposure to environmental stressors like air pollution, which is harmful to the human respiratory and cardiovascular systems (Manisalidis et al., 2020). The second domain of the model, restoring capacities, refers to natural surroundings being positive for restoration and reducing stress, although recent findings are inconclusive (Kondo et al., 2018). The latter domain describes how green space can facilitate physical activity and social cohesion by being a suitable arena for these behaviors (James et al., 2015). This is the focus of our study.

Figure 2: Markevych's three domains.



Previous research has found a quite strong association between access to green space and the degree of physical activity (James et al., 2015; Lachowycz & Jones, 2013; Smith et al., 2017). It has been stated that green spaces are likely to provide safe, attractive, and accessible settings for people to be physically active (Astell-Burt et al., 2014). This has also been seen in the Nordic context among adults (Jansen et al., 2017) and children (Nordbø et al., 2019), although findings are not consistent (Stefansdottir et al., 2019).

Green space in different forms has also been researched. Sallis, Cerin, et al. (2016) found the number of parks in people's neighborhoods positively related to moderate to vigorous physical activity (MVPA) in 14 cities worldwide. Provision of quality parks has also been found positively related to active transport and physical activity (Smith et al., 2017), although the association is inconsistent (Bancroft et al., 2015). The size of green space could also matter. Previous research show that larger green spaces with maintained walking paths are more attractive for adults to be active than small pocket parks (Giles-Corti et al., 2005). Jansen et al. (2017) also found that larger-sized natural environments were associated with higher levels of MVPA. Other green space qualities like aesthetics, training equipment, and trail access can also be mentioned as possible factors which can facilitate active living (Fitzhugh et al., 2010; Kaczynski et al., 2008).

In conclusion, physical activity may serve as a mechanism between green space and health by providing increasing opportunities for outdoor exercise and play. However, findings are inconsistent when mediation analyses have been used to investigate if physical activity lies on the causal pathway between green space and health (Markevych et al., 2017; Nieuwenhuijsen et al., 2017). What appears certain is that the sole presence of green space does not necessarily imply that people use it (Markevych et al., 2017).

2.6 Walkability and physical activity

Walkability as an idea was first introduced by critical thinkers like Jacobs, Lewis Mumford, and Jan Gehl. They started criticizing the approach of car-centric design rather than human-centered design (Claris & Scopelliti, 2016). The term walkability can be described as "the extent to which characteristics of the built environment and land use may or may not be conducive to residents in the area walking for either leisure, exercise or recreation, to access services, or to travel to work" (Leslie et al., 2007). A General Theory of Walkability has also been created. The theory states that to be favored, a walk has to satisfy four main conditions: it should be useful, comfortable, safe, and interesting (Speck, 2013). Useful refers to the accessibility of aspects of daily life needs in an easy and organized matter. Safe means to feel safe from cars and other intimidating factors. Comfortable is that the environment serves as an "outdoor living room," and interesting is that it gives a pleasing walking experience with friendly faces and signs of humanity around. In line with the ecological model, the idea behind considering walkability as a built environment characteristic in this study is that walkable areas create possibilities for physical activity (Sallis et al., 2006).

In the literature, walkability is often measured as an index made up of a combination of variables, usually street connectivity, population density, and land use mix (Frank et al., 2010). How this walkability score and related single variables have been defined and computed in this present study will be described in the method section (see chapter 3.3.2).

Land use mix, or entropy score, indicates the degree of diversity of land types in the measured area (Frank et al., 2010). Speck (2013) says that "for people to choose to walk, the walk must serve some purpose." The theory proposes that various land types can make the walk more interesting and is supported by several studies (Christiansen et al., 2016; Kärmeniemi et al., 2018; Smith et al., 2017). The following variable is population density, which is associated with the availability of walkable destinations. Studies have found that densely populated areas are associated with higher levels of physical activity and outdoor activity than in less populated areas (Bird et al., 2018; Glazier et al., 2014; Sallis et al., 2020). This was also found in a Norwegian context, where Nordbø et al. (2019) investigated the physical activity and the built environment among children and adolescents in Norway. They found more densely populated areas to be associated with participating in organized and social activities (Nordbø et al., 2019). The last variable used for the walkability index is intersection density – an indicator of street connectivity that can provide direct pathways for vehicles and pedestrians (Sallis, Cerin, et al., 2016). This measure has also been positively associated with minutes of physical activity (Christiansen et al., 2016; Frank et al., 2010; Sallis et al., 2020).

A recent scoping review has summarized existing research on associations between the built environment and physical activity (Dixon et al., 2021). Across all the included studies in this review, the most consistent association observed (supported by 83,3% of the studies) was a positive association between physical activity and the index score of walkability. These findings are supported by previous reviews, especially about physical activity in the form of active transportation (McCormack & Shiell, 2011; Sallis et al., 2020; Smith et al., 2017). A safe, walkable environment seems to promote walking and different kinds of physical activity. Creating a favorable context for walking or other types of physical activity may be beneficial for public health.

Another example is a study from 2016 (Sallis, Cerin, et al.), which showed that adults from ten different countries who lived in walkable districts were doing up to 90 minutes more physical activity than those who lived in the least walkable areas. A US national study also found an increased "walk score" associated with higher levels of MVPA (Twardzik et al., 2019). These findings were independent of gender, color, and age. However, most of the previous walkability studies have been done in American and southern European cities – which can affect the transferability of the results. The possible association is less studied in a Norwegian context. This is why this project is aimed at adults' physical activity levels and the built environment.

2.7 Perceived neighborhood safety

Fear is "an unpleasant emotional state triggered by the perception of a threatening stimulus" (Ruiter et al., 2001). This state creates physical arousal and motivates cognitive, affective, and behavioral responses. The behavior process aims to alleviate the threat and reduce or eliminate fear (Frijda, 1986). Feeling safe is a prerequisite for well-being, quality of life, and good health (Green et al., 2002; Ruijsbroek et al., 2015) Statistics Norway found that 6% of Norwegians are afraid of violence and crime in their neighborhoods, and women more so than men (Vrålstad, 2017).

The urban activist Jane Jacobs (1961) emphasized that keeping the city safe is a fundamental task of the streets and its sidewalks. The pedestrians are all active participants in making the city safe. Jacobs (1961) pointed out that streets need to be full of life and people, calling it "the eyes on the streets." This corresponds with Sallis et al. (2006), who present perception of the environment in the second layer of their ecological model – suggesting that unsafe environments can prevent people from doing activities in their neighborhoods.

A study of deprived British neighborhoods supports Jacobs' theory. The study found that people who feel safe and trust their neighbors tend to walk more often (Mason et al., 2013). A longitudinal multi-country study also found a positive linear relationship between perceived safety from crime and recreational walking (Sugiyama et al., 2014). A Swedish study found that only people who find their neighborhood safe have a positive association between the built environment and physical activity levels (Weimann et al., 2017). Other studies support these findings (Evenson et al., 2012; Foster et al., 2016). However, findings in review papers are inconclusive (Foster & Giles-Corti, 2008; Mancus & Campbell, 2018; Van Holle et al., 2012). A recent review of reviews found only 26.3% of the included studies supported an association between safety in relation to the built environment (Dixon et al., 2021). For instance, Mason et al. (2013) found no association between infrastructure and security, safety from traffic, and walking measures. Providing safe activity-friendly neighborhoods can be important for physical activity, even though Jacobs' theory has not yet been proven true.

2.8 Aim and research questions

This thesis aims to obtain more knowledge on the relationship between built environment characteristics and physical activity in Norway.

The research questions are:

Is there an association between adults' self-reported physical activity and the amount of green space in people's living areas?

Is there an association between adults' self-reported physical activity and objectively measured walkability in people's living areas?

Are any such relations moderated by perceived safety? The model of moderation is presented in figure 3.

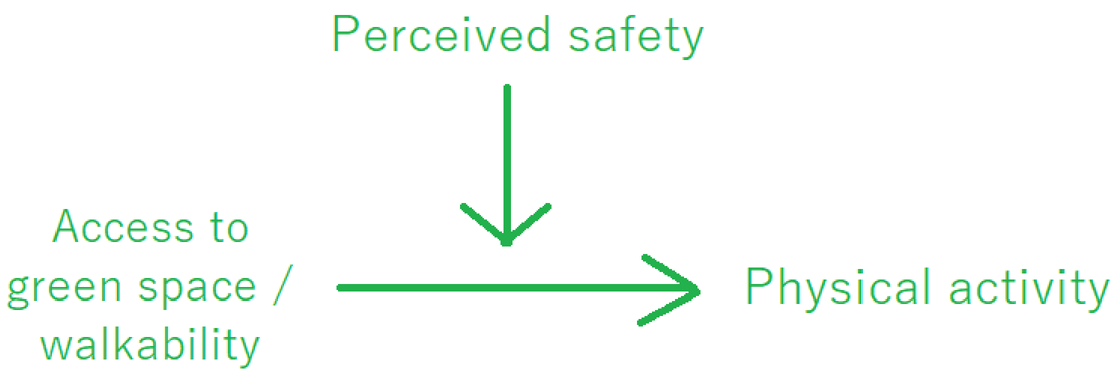


Figure 3: Moderation model.

3. Methods

The attached article describes the methodology of our study (Juul et al., in prep). This chapter will give a more detailed description of a few sections.

3.1 Context of the study

The present study was part of the NORDGREEN project "Smart Planning for Healthy and Green Nordic Cites", where Stavanger is one of the six participating municipalities (Nordregio, 2020). Stavanger municipality is part of Rogaland country, on the western coast of Norway (Thorsnæs & Amoriza, 2022). The city of Stavanger is the 3rd biggest in Norway, with 228.287 inhabitants in 2020 (Thorsnæs & Amoriza, 2022). Stavanger city consists of nine districts – including the two islands Finnøy and Rennesøy (Stavanger kommune, 2022).

Stavanger municipality has created a Green Plan, a general strategic document for managing the green spaces in their area (Stavanger kommune, 2020). The Green Plan will contribute to Stavanger's preservation and further development of green spaces. More cohesive green areas will increase the quality of public spaces which are to be used for recreation and physical activity (Stavanger kommune, 2020). The plan will contribute to developing a new municipality plan for Stavanger.

3.2 Study design and data material

3.2.1 Study design

This study used a cross-sectional design that combined health data from the Norwegian County Public Health (NCPH) survey in Rogaland (Skogen et al., 2020) and environmental variables calculated based on geographical data using GIS.

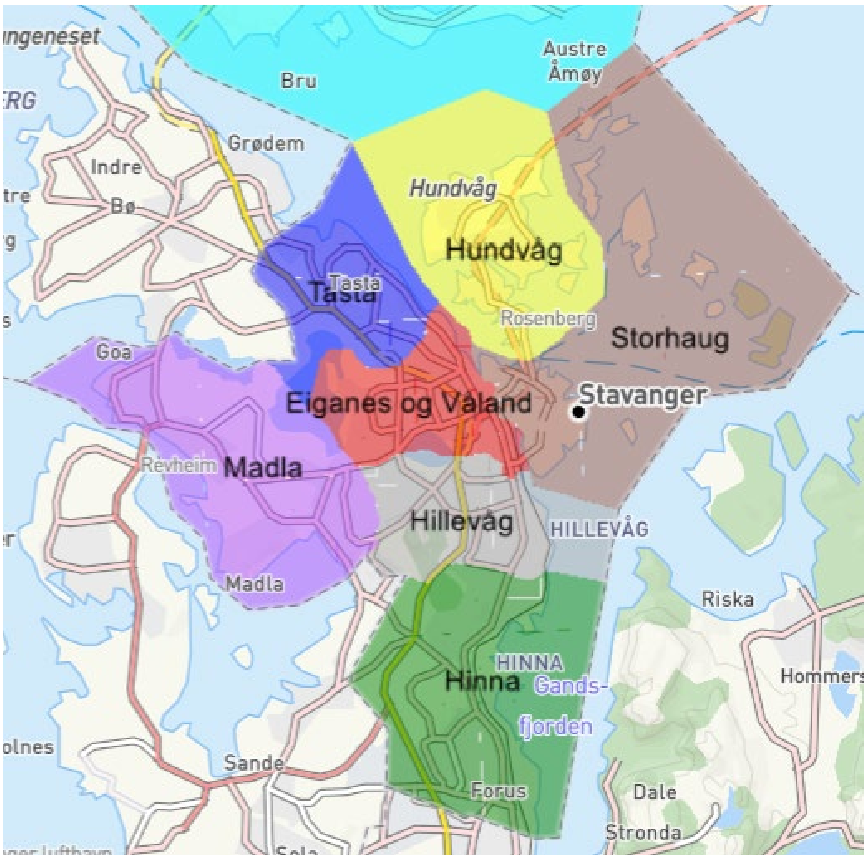


Figure 4: Districts of Stavanger municipality.

The Norwegian Institute of Public Health (NIPH) was responsible for the data collection. A total of 35.191 (45.2%) randomly selected adults responded during the fall of 2020 (Skogen et al., 2020). Our study sample consisted of 5670 adults living in urban districts of Stavanger. In this present study, the inhabitants of Rennesøy and Finnøy were excluded (see figure 4). This was done because of the walkability index, which is primarily used in cities and urban areas. The two islands are rural areas dominated by agricultural areas and were, for that reason, not well fitted to the analysis (Thorsnæs & Amoriza, 2022).

3.2.2 Variables obtained from the survey

Our outcome variable, physical activity, was assessed using two questions capturing frequency and duration. For details on the recoding, see the attached article (Juul et al., in prep.). The frequency and duration values were multiplied to a total value of minutes of physical activity per week – ranging from 0 to 420 minutes. This classification was based on the methodology of the Norwegian HUNT studies (Kurtze et al., 2007). The minute score was treated as a continuous variable in the analyses.

The moderation variable, perceived safety, was measured with a question phrased like this: "all in all, how safe do you feel when walking in your local area?". The scale went from 0 to 10 and was treated as a continuous variable in the analyses.

3.3 Geographical data and GIS analyses

Geographical information systems can help describe the world and study the physical qualities of built environments (Rød, 2017). GIS can be described as a combination of geographical data, map systems, methods, and human knowledge, making it possible to collect, adjust, analyze and present the geography surrounding us (Grinderud & Forsvarsbygg, 2009). GIS as a method can help us visualize our built environment and understand how the surroundings are affecting us.

To link our geographical data to the data set from the NCPH survey, we needed computations aggregated to the participants' postal codes. This was done by using a data set from GeoNorge presenting the postal codes' borders (GeoNorge, 2022). The postal codes were checked with updated numbers from the Norwegian postal service Bring to ensure that all postal codes were still part of Stavanger (Bring, 2021).

3.3.1 NDVI as a green space measure

Our green space measure was based on an NDVI score (normalized difference vegetation index). The principle of NDVI is that green vegetation reflects infrared radiation more than non-vegetated surfaces and can therefore be detected by satellite (Rhew et al., 2011). It provides an objective metric for levels of green spaces that can be easily applied in studies of the built environment and health. The index reaches from -1 to +1, and the computations were performed for postal code areas of the urban districts of Stavanger in QGIS (see figure 5). The data set was then checked for negative measures, which usually would represent water, ice, and bare earth. The data contained none of these measurements and was therefore treated as a continuous variable with values from 0 to 1.

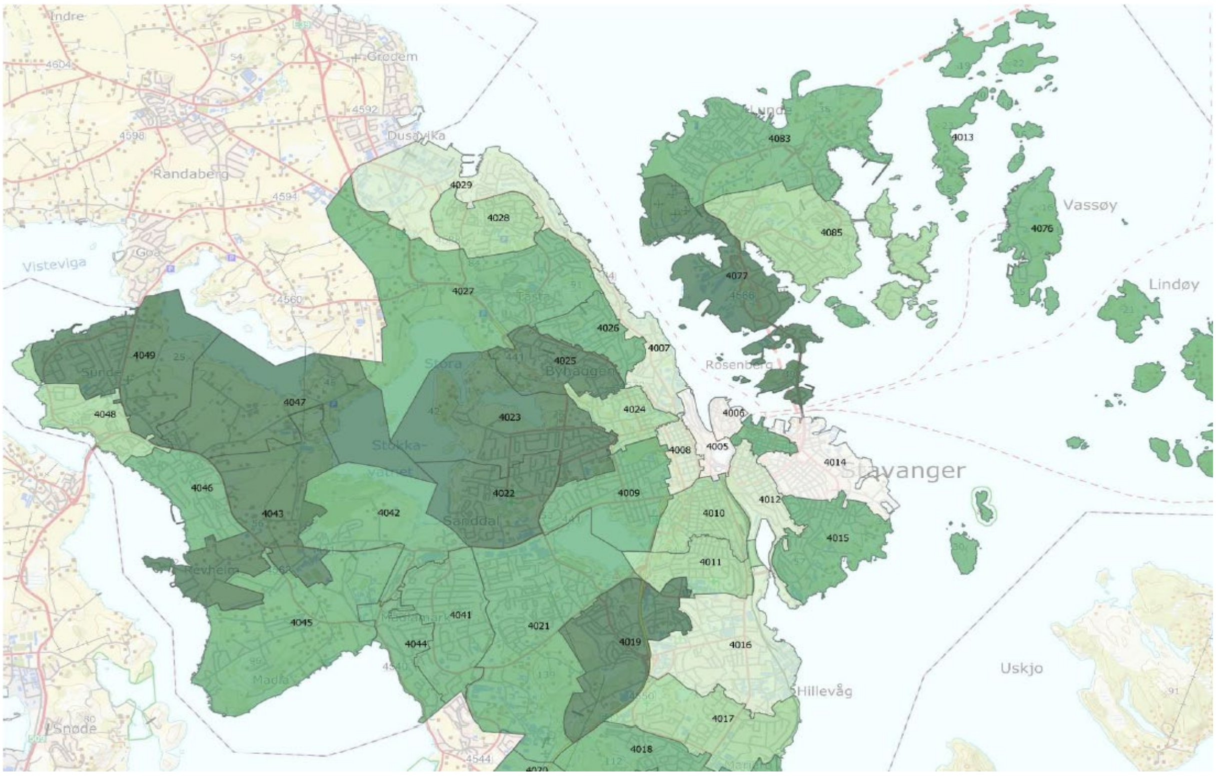


Figure 5: NDVI map.

3.3.2 Computing walkability

For the walkability measurement, the three variables *intersection density*, *residential density*, and *land-use mix* to create an index. The *land-use mix* variable was changed to *proportion of green space* to adjust to a Norwegian context. It was computed mean and standard deviation (SD) for all variables.

The proportion of green space was calculated based on a land-use map from GeoNorge (Geonorge, 2017). The measure of the total area of green spaces (km^2) within each postcode area included parks, forests, and cemeteries.

The population density was calculated using a raster map from GeoNorge, showing 250 m x 250 m of the population (Geonorge, w.y.). Population density was calculated using the intersect tool to connect the population map with the postal code map. Then, the population number was multiplied by the polygon's area. By collecting all the polygons in one table, the population number of each postal area was found. The population number per km^2 was finally calculated.

Intersection density is a measurement of the connectivity of the street network, represented by the ratio between the number of true intersections (three or more legs) to the land area of the block group in acres. A higher density of intersections corresponds with a more direct path between destinations (Frank et al., 2010). A road map was downloaded from the dataset N50 (Geonorge, 2017). After identifying all the roads, an intersect analysis was done to make a layer of points in all the intersections (see figure 6). Then the number of intersections in each postal code was counted. This was divided by 1000 km^2 for each postal code area.

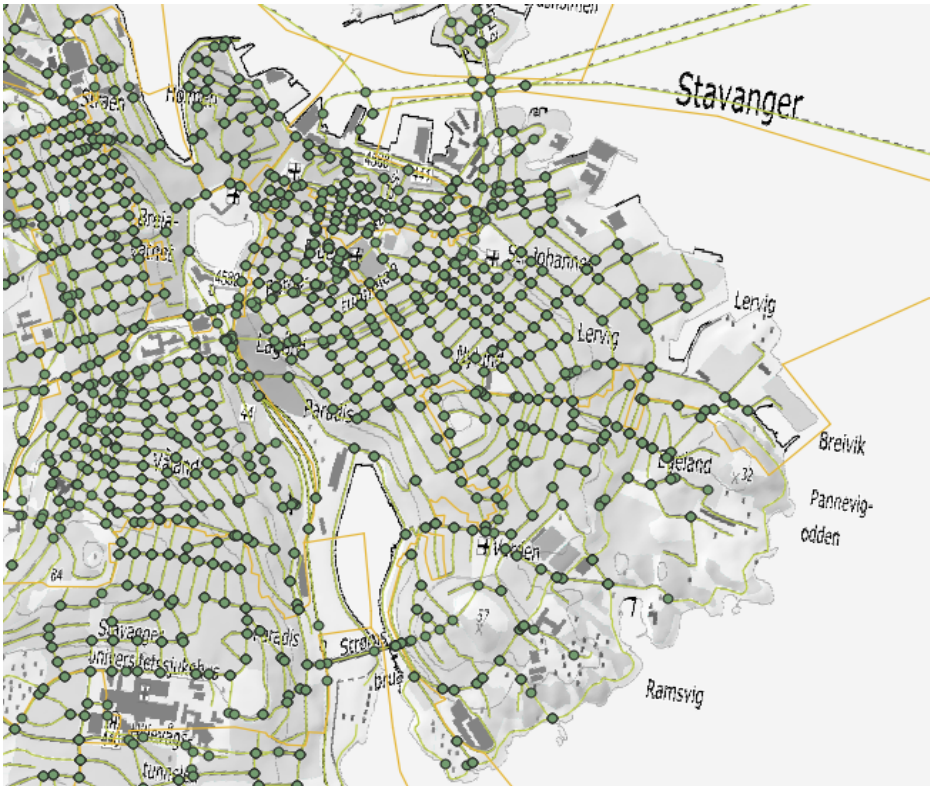


Figure 6: Intersections measured in QGIS.

We computed normalized z-values for population density, the proportion of green space, and the count of intersections using this formula:

$$Z_i = \frac{xi - \bar{y}}{SD}$$

Finally, we computed the walkability index by summarizing the Z-values as described in the following formula:

Walkability = z(intersection density) + z(residential density) + z(proportion of green space).

3.4 Statistical analyses

The statistical analyses were performed in SPSS (version 28). Linear regression is a statistical method commonly used to model a value of a dependent scale variable based on the linear relationship with one or several predictors (Pallant, 2016). In the present study, we aimed to model weekly minutes of physical activity dependent on the walkability index score and NDVI-scores. Linear regression was therefore considered appropriate. To account for potential confounders, the analyses were adjusted for age, sex, educational level, and perceived financial status. It was also done a moderation analysis studying the possible moderation effect of perceived safety. P-values <0.05 were considered statistically significant. See the attached article for further details (Juul et al., in prep.).

3.5 Ethical considerations

The study was conducted in line with the Declaration of Helsinki and their ethical principles for research (World Medical Association, 2013). Participating in the NCPH survey was voluntary, and the data could be withdrawn at any time by contacting the NPHI. Our data was anonymized and saved according to the guidelines of NMBU (Fossum-Raunehaug & Straumsvåg, 2021).

The study applied for approval to the Norwegian center for research data (NSD) in July – August of 2021, because the NCPH survey included personal information like gender, age, and educational level (see Appendix 2). The application was approved by the NSD before the study started.

4. Results

The results are presented in the article, and the tables are attached. This chapter will shortly summarize the findings.

Characteristics of the participants are presented in Table 1 and 2 (see attached article). There were more women than men, and the majority of the participants were aged between 30-69 years (72.7%). The participants had a mean value of 148 minutes of weekly physical activity. We observed high perceived neighborhood safety in this sample of adults from Stavanger. On a scale from 0 to 10, the mean perceived neighborhood was 8.84.

The mean walkability score was 0.28 on a scale from 0 to 1, whereas the vegetation score, NDVI, had a mean score of 0.65 on a scale from 0 to 1. Access to green space was associated with higher levels of physical activity in the unadjusted model, presented in table 3 (B =

40.39; 95% CI = 15.63-65.14). When adjusting for age, gender and SEP, the association became weaker but remained significant, with a mean value of 24,85 more minutes of physical activity per NDVI unit increase (B = 24.85; 95% CI = 0.29-49.41). The walkability score showed a slight negative trend in the physical activity levels, although not significant (B= -1.18; 95% CI = -3.15, 0.79). A moderating effect of perceived safety was not observed in the two models (see table 4). However, a one-point higher score of safety seemed to contribute directly to physical activity in the adjusted models.

5. Discussion

In this section, the results will be discussed in the light of the theory and empirical knowledge which was presented in the background section. The two built environment factors in relation to physical activity are each discussed, before perceived safety is addressed. In chapter 5.4 the methodology of our study will be considered.

5.1 Green space and physical activity

In our article (Juul et al., in prep), we found access to neighborhood green space to be a potential determinant for physical activity. The association was statistically significant, making it reasonable to believe that the relationship between the two variables is not caused by chance. The association was still found after the analysis was adjusted by the participant's age, gender, and socioeconomic status, even though it decreased. Our findings can enhance the prior understanding by demonstrating that greener neighborhoods are associated with the likelihood of being physically active (James et al., 2015; Jimenez et al., 2021; Lachowycz & Jones, 2013). However, the results have a large confidence interval (95% CI = 0.29-49.41) which makes our results less certain.

Studies show that outdoor walking is the most common type of physical activity in Norway (Hansen et al., 2015), in which green space can be a suitable arena. Norwegian people seem to be motivated by wanting to experience nature while being active (Calogiuri & Elliott, 2017; Statistics Norway, 2021b). Hence, our results highlight the importance of access to neighborhood greenspace as part of promoting outdoor physical activity in Norway. However, a limitation to our study, is that we did not consider where the physical activity is conducted (Markevych et al., 2017). According to Statistics Norway, 24,3% of Norwegians spend time doing strength training every week (2021a), which is usually performed indoors. This form of activity will not be affected by the outdoor environment and could explain some of the inconsistent evidence between access to green space and general physical activity levels.

The ecological model present physical activity as four active living domains (Sallis et al., 2006). The model suggests that different kinds of physical activity take place in different settings and will therefore be affected by different types of environments. Parks and green spaces are suggested to be more important for active recreation than to the other domains of active living. This is supported by a recent study finding that Norwegians increased their recreational use of urban green spaces during the covid-19 pandemic, in comparison to use of other land use zones (Venter et al., 2021). Our study measured physical activity levels in general, including all domains of the model – active recreation, household activities, active transport, and occupational activities. It is reasonable to say that green space is less important when doing household activities or strength training. Hence, our results could have been more confident if we only measured levels of active restoration. This can also indicate the importance of providing access to indoor training facilities in addition to activity-friendly environments outdoors.

Former research advocate that the sole presence of green space does not imply that people will use it. Qualities like size, lighting, and maintenance of green spaces could affect people's motivation to use the green spaces for activities (Bird et al., 2018; Jansen et al., 2017; Lachowycz & Jones, 2013). These qualities are also presented in Sallis' ecological model (Sallis et al., 2006). Other characteristics like trail systems which link homes to green spaces could also be relevant to all domains of active living. In a study which included youths, an urban greenway trail designed to connect pedestrian infrastructure to nearby retail and schools, showed significant changes between the experimental and control neighborhoods for total physical activity levels (Fitzhugh et al., 2010). However, trails and similar qualities were not accounted for in our study. Literature suggests that the quality of green space and health outcomes should be more thoroughly investigated in a Norwegian context (Nordbø et al., 2018).

From the perspective of the socioecological model (Sallis et al., 2006), the effect of green space is also affected by other individual and environmental factors. This could impact how individuals perceive their neighborhoods and green spaces (Lachowycz & Jones, 2013). Perceptions of green space are found in earlier studies to be a stronger predictor of usage than objective measures (Bloemsma et al., 2018). This has also been found in the Norwegian context (Fongar et al., 2019). Understanding how and why residents interact with their neighborhood green spaces is essential for planning green spaces, so that the green spaces can fulfill their role in facilitating physical activity and improving health.

5.2 Walkability and physical activity

In our article (Juul et al., in prep.), walkability was not found to be associated with higher levels of physical activity. This contrasts with a recent review of reviews which found a positive association in 83.3% of the reviews (Dixon et al., 2021). The theory of walkable areas creating possibilities for physical activity did not apply to our study (Sallis et al., 2006).

The walkability features – mixed land use, street connectivity, and residential density are used frequently in existing research. These variables are found to be positively associated with physical activity and active transportation (Frank et al., 2010). Therefore, these variables were expected to be positively associated with the physical activity measure. It could be that the index, even though it was adjusted for Norwegian environments, is not applicable.

The Sallis et al. (2006) model presents domains of active living in their second layer. The model presents four domains which would all be included in the definition of physical activity (World Health Organization, 2010). As mentioned earlier, the model indicates that specific environments are more associated with certain types of physical activity. Walkability is placed on the right side of the circle, connected to active transport and occupational activities, in addition to aspects like parking, transit access, and trail access from the workplace. Systematic reviews support this theory by finding stronger associations between walkable environments and active transport than other physical activities (McCormack & Shiell, 2011; Smith et al., 2017). It is, therefore, possible that active transportation as an outcome would give more specific and positive results to our study.

Considering Sallis' ecological model, other qualities of the built environment could explain physical activity levels to a more extensive degree than the walkability measure. For instance, traffic. Studies show that denser, and therefore also more walkable, neighborhoods generally have more facilities but also more traffic (Lee & Maheswaran, 2010). This could be an explanation as to why the walkability measurement did not seem to facilitate physical activity. Such other factors were not accounted for in this study.

Moreover, although walkability is measured as high in an area does not mean that it is also perceived that way by the residents. This is presented as the perception of the environment in the ecological model (Sallis et al., 2006). The walkability index simplifies reality, and other measures like traffic, quality of sidewalks, lighting, and noise could affect how walkable a neighborhood is perceived. These measures can promote a walk that is more useful, comfortable, safe, and interesting (Speck, 2013).

5.3 Perceived neighborhood safety

In the perspective of the socioecological model of Sallis et al. (2006), the effect of the built environment will be influenced by other individual and social factors, like the perception of safety. However, we did not find support that perceived safety moderates the association between access to green space and physical activity levels in this sample of Norwegian adults. Nor was this moderation effect found with walkability as the predictor (Juul et al., in prep). Our findings contrast with some previous studies (Evenson et al., 2012; Foster et al., 2016; McGinn et al., 2008; Weimann et al., 2017) while they are consistent with other studies, which have not found a moderating effect of perceived safety (Loh et al., 2019; Ruijsbroek et al., 2015). It is noteworthy that Ruijsbroek et al. (2015) found perceived safety to be more relevant to general health levels than to physical activity. This could imply that the negative health effect of feeling unsafe has a more significant impact on our general health.

Having said that, we did see a direct connection between perceived safety and physical activity levels. A one-point higher score of safety seemed to contribute to higher physical activity levels per week in our study sample. This association is supported by several studies (Evenson et al., 2012; Foster et al., 2016; Lee & Maheswaran, 2010). Foster et al. (2016) even found a three times higher level of physical activity with a similar safety scale. Considering that perceived safety is a prerequisite for good health (Ruijsbroek et al., 2015), creating safe neighborhoods can be conducive to promoting public health. Overall, these findings support the general theoretical underpinnings by Jane Jacobs (1961) who highlighted the importance of perceived safety by bringing more people and "eyes on the streets". Other potential moderating factors, like cultural factors, community activity, infrastructure, and traffic provide better conditions for an environment in which physical activity can take place (Lachowycz & Jones, 2013).

5.4 Methodological considerations

In epidemiological studies, we usually recruit a sample of individuals, measure their exposures and outcomes, and then, calculate a measure of association between the exposure and outcome (Webb et al., 2017). We want these results to be as true as possible, so that we can generalize our results to the entire population.

Internal validity is defined as the extent to which the results represent a truth in the population and are not caused by methodological errors (Webb et al., 2017). Some of these errors will now be discussed before the generalizability (external validity) of our study is discussed in the end.

5.4.1 Limitations of the study design

Our study used a cross-sectional design that combined data obtained from the NCPH survey in Rogaland (Skogen et al., 2020) and built environment variables computed using GIS. The use of objectively measured exposure variables eliminates the risk of single-source bias, which is a methodological strength. However, our study is limited by the constraints of a cross-sectional study design which excludes any inferences of causality. One can instead investigate differences and associations between variables, as well as an association between two variables in the population. For instance, a recent Swedish cohort study found people moving to greener areas decreased their physical activity levels, whereas people moving to less green areas increased their walking and cycling (Persson et al., 2019). The cohort study with repeated measurements did not support the current available cross-sectional studies showing strong relations between green spaces and physical activity. This highlights the need for more sophisticated study designs which can implicate causality.

5.4.2 Selection bias

The strength of the NCPH survey is a large sample that was randomly selected from the population register (Skogen et al., 2020). This increases the likelihood of a representative sample and is positive for external and internal validity (Webb et al., 2017). However, with a response rate of 45.2 %, one cannot rule out the risk of selection bias. The response rate could implicate a sort of volunteer bias, where the people wanting to participate in the survey are often more health-conscious than the people not participating (Webb et al., 2017). Our sample could, for this reason, have higher physical activity levels than the general population. This should be kept in mind even though, compared to other similar surveys, 45.2% is considered a high response rate (Skogen et al., 2020).

Another possible selection bias is related to the level of education variable. Our study has a higher proportion of highly educated participants compared to the Norwegian adult population (50,6% versus 35%) (Statistics Norway, 2022). Higher education is associated with increased physical activity levels than the general population (Gidlow et al., 2006; Hansen et al., 2015), implicating that the mean value of physical activity in our sample (148 weekly minutes) could be higher than in the general population. The value is relatively high and in line with the WHO-recommended guidelines (Bull et al., 2020). This contrasts with previous population surveys that found that most Norwegian adults do not meet these guidelines (Hansen et al., 2015). An explanation is that our value did not include an intensity measurement, which means that also light intensity activity is included. This will be discussed further in chapter 5.4.3.

In this study, we used an analytical sample. This means that all those participants with missing data are excluded. In our article (Juul et al., in prep.), the variable of perceived financial status had the most missing data. 286 participants (5.0 %) were excluded for this reason. There might be several reasons why people abstain from responding to a question assessing financial status. This raises a question of who was lost by excluding participants with missing data. We cannot rule out that this may have influenced our effect estimates.

5.4.3 Consideration of confounders

Confounding variables are factors associated with both the exposure and the outcome variable. Confounders can also affect the results when the association studied is affected by other factors (Webb et al., 2017). The chosen confounders were age, gender, educational level, and perceived financial status. This is based on a consistent foundation of literature (Bauman et al., 2012; Guthold et al., 2018; Lachowycz & Jones, 2013). Age, gender, and SEP differences seem to affect physical activity levels – where women, the elderly, and those with lower SEP are generally less active (Althoff et al., 2017; Guthold et al., 2018). This is also found in Norwegian surveys (Hansen et al., 2015). Characteristics of the built environment, such as walkability, seem to be associated with a smaller gender gap in activity differences. This indicates the importance of the built environment and how it can improve inequal activity levels (Althoff et al., 2017). It was also accounted for gender, age, and SEP difference in the perception of safety, which was described in the report from NIPH (Skogen et al., 2020).

Although we adjusted for these confounders, other variables not available in the NCPH could confound the results. Other environmental variables, such as traffic, noise, lighting, and maintenance, or an individual characteristic like motivation for physical activity, could also influence the association between the built environment exposure and the physical activity outcome.

5.4.4 Information bias

When assessing physical activity levels, the aim is usually to identify four dimensions: duration, frequency, intensity, and type of activity performed (Ainsworth et al., 2015). A problem with public health surveys in Norway is that all four have seldom been included in the same survey (Kurtze et al., 2003). This methodological weakness makes it more difficult to compare results and draw conclusions on the development of physical activity levels with time. Further, when making a “score” of physical activity, an alternative was to dichotomize all participants into “physically active” or “physically inactive” (Kurtze et al., 2003) according to the WHO recommendations (Bull et al., 2020). Instead, we chose to keep a continuous outcome because literature shows that physical activity of also less than 150 weekly minutes of physical activity can have a positive health impact (Bernard et al., 2018).

Our measure of physical activity relies on self-reported measures, which are prone to recall bias and social-desirability bias. Comparisons of direct versus self-report measures of physical activity suggest that the measurement method can significantly impact physical activity results (Prince et al., 2008). Self-reported measurements are of generally low correlation with direct measures, higher and lower than the actual measured levels. This can pose a problem of reliance on self-report and makes it difficult to adjust the numbers. Self-report questionnaires are also found to be less robust in measuring light or moderate activity and other external factors. On the other hand, it is cost-effective and easy to administer (Sylvia et al., 2014). A methodological strength is that the questions used have been validated against VO2max measures (Kurtze et al., 2007) and the International Physical Activity Questionnaire (Craig et al., 2003).

In our article (Juul et al., in prep.), perceived safety was assessed with the question, “all in all, how safe do you feel when walking in your local area?”. The scale went from 0 to 10 and was treated as a continuous variable. The use of different measures of perceived safety in earlier studies has made limitations on the consistency of results (Foster & Giles-Corti, 2008), and it may not be sufficiently valid. The mean score in our sample of 8.84 suggests a lack of variability and a potential ceiling effect. Therefore, it could be necessary to develop improved measures to evaluate this measure adequately. We based our value on one single question that could reduce the benefit compared to other studies using more complex measures. It is also directly aimed at perceived safety when out walking, which can rule out how other kinds of physical activity, like a bike ride or a run, would be perceived in comparison. It is, although, a methodological strength that the question asks about safety in a specific setting related to physical activity and not just a general measure of perceived safety (Foster & Giles-Corti, 2008). Finally, the association between perceived safety on physical activity was highly significant ($p<0.001$) indicating that this association could be trusted.

Using different green space metrics has different advantages and drawbacks. NDVI is a valid metric of green spaces and was therefore chosen for our study (James et al., 2015; Rhew et al., 2011). The strength of NDVI, in comparison to predefined land cover maps, is that it includes all vegetation. This would also cover gardens, street trees, and green pathways – which all can be suitable arenas for activities. NDVI is also proven to be highly correlated with environmental psychologists' evaluation of green spaces, which reduces the risk of systematic errors (Rhew et al., 2011).

An alternative to NDVI is downloading land-use datasets, which may provide more information about specific types of green spaces. This could give more indications of their quality or usability (James et al., 2015). Multiple studies show that the quality of green space is essential factors affecting the use and health benefits (Brownson et al., 2009; Lachowycz & Jones, 2013; Smith et al., 2017). The type, size and distance to green space can influence the use and activity performed in a green area, which could be measured with the use of land-use datasets (Jansen et al., 2017). It is suggested in the literature that the quality of green space and health outcomes should be more thoroughly investigated in a Norwegian context (Nordbø et al., 2020), but this was not the focus of our study. Nevertheless, a drawback of using land-use maps is that they can mischaracterize areas that are not really "green" - for example, parks without vegetation. They can also miss out on small gardens, green corridors, or walking paths, which can be suitable arenas for physical activity. For this reason, the NDVI measure was a better choice for our study. Another advantage of choosing NDVI is that vegetation measures cover the whole planet and are collected with uniform methods (Rhew et al., 2011). This gives consistency and a possibility to compare results worldwide.

Regarding the walkability index, it has been discussed if more variables would be applicable. Examples are pavements, traffic exposure, and the quality of the road crosses, all being possible barriers and facilitators of physical activity. The problem is that these qualities are not regularly available in geographical datasets. For this reason, three validated and available measures were used (Frank et al., 2010), although one, land-use mix, was adjusted to the Norwegian context. Land-use mix usually indicates the degree of diversity of land use types, like residential, entertainment, retail, institutions and offices (Frank et al., 2005). Our study used a measure of the total area of parks, forests, and cemeteries instead. In retrospect, land-use mix could have been a better measurement, because it includes features like offices and supermarkets, which are important destinations for active transportation also in Norwegian people's daily lives. In addition, our measure was not a validated part of the walkability index, making our results less comparable to other studies.

A conventional approach when examining the health effects of area-based attributes is to use buffers around home addresses or, like in our study, postal code areas. A problem can occur as effect measures of spatial attributes are influenced by how neighborhoods are geographically delineated. This is known as the "the uncertain geographic context problem" (Kwan, 2012). One could imagine a resident living close to the border of their postal code area, who only moves around in the postal code area next to it. In this way, our analysis would have analyzed the wrong neighborhood. This information bias makes it important to pay attention to a potential confounding effect on research results. It could explain why research findings on the built environment and health outcomes are often inconsistent.

Another possible weakness is the difference in time between the oldest map, lastly updated in 2017 (Geonorge, 2017), and our survey being condoned in 2020 (Skogen et al., 2020). During these years, the built environment could have changed, and in this way make our geographical measures less accurate. However, changes in infrastructure, population density and development of green spaces are fairly slow processes, which limits this margin of error.

5.4.5 External validity

The external validity criterion indicates how well study results can be generalized to the population. For our study, this applies to whether or not access to green space is associated with physical activity levels of Norwegian adults in general. When wanting to generalize to the population, it is essential to consider how representative the study sample is. Stavanger is the third biggest city in Norway (Thorsnæs & Amoriza, 2022), which could make it possible to generalize our findings to similar Norwegian cities. Other cities in Scandinavia could also be comparable because of social, cultural and climate similarities. However, several limitations to the internal validity of our study have been discussed previously in this chapter. For instance, we found our sample to have higher educational levels than the general Norwegian population, not making our sample fully representative. This can limit the transferability of our results and one must be careful when it comes to generalizing.

6. Implications for public health work

Neighborhoods are important arenas with possibilities for health promotion. It is stated in the Norwegian law of Public Health (Folkehelseloven, 2011) and The Planning and Building Act

(2008) that place development should consider people's health and well-being. Urbanization has taken hold in Norway, like in the rest of the world. According to Statistics Norway, more than 8 of 10 Norwegians lived in central areas last year (2021c). Urbanization creates pressure on land usage and places great demand on city planning, which will only increase in the future. Therefore, preserving areas under pressure, such as parks, nature, green spaces, and walking paths, is urgent.

In our article (Juul et al., in prep.), we have addressed the importance of how green spaces are associated with physical activity levels. Stavanger municipality has already created an action plan; a strategic document for better preserving and developing green spaces (Stavanger kommune, 2020). Incorporating green spaces into the formal planning system is a good way to ensure their existence. These green spaces must be seen as an essential investment in the residents' health and physical activity levels (Stavanger kommune, 2020).

Creating activity-friendly environments can be expensive, but given the economic burden of physical inactivity (Ding et al., 2016), built environment interventions that facilitate active lives can be useful also from a cost-benefit perspective. A systematic review has reported a substantial benefit-cost ratio for walking and biking infrastructure interventions (Brown et al., 2016). This must be emphasized if the national goals (Ministry of Health and Care Services, 2020) should be reached in time.

7. Conclusion

Physical inactivity is a major global issue of public health, and the effect of the built environment on activity has received increasing focus the last few years. Our study found an association between access to green space and increased physical activity levels in Stavanger, Norway. The same association with walkability was not found in our study sample. Perceived safety when out walking did not show a moderating effect but rather a direct association with increased physical activity levels. Our study emphasizes the importance of providing safe neighborhoods and green spaces as key factors in promoting physical activity. This is especially important for policymakers, planners, and public health professionals to integrate into their work. Therefore, preserving areas under pressure, like parks, nature, green spaces, and walking paths, should be emphasized.

The findings of this study contribute to the field of research on health-promoting environments. Future studies should aim to investigate further how perceptions of safety are associated with physical activity. There is still a need for more research before conclusions are made.

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Appendix 1: article.

Examining activity-friendly neighborhoods in the Norwegian context: built environment characteristics in relation to physical activity and the moderating role of perceived safety

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Abstract

Background: Physical inactivity is a major global public health issue, and the influence of the built environment on activity levels in the population has received significant attention in the last decade. This study investigated relationships between neighborhood green space, walkability, and physical activity, and whether any such relationships were moderated by perceived neighborhood safety.

Methods: This cross-sectional study combined data from the Norwegian County Public Health Survey (NCPH) in Rogaland (N = 5670) and geographical data describing the built environment. Neighborhood green space was measured using the normalized difference vegetation index (NDVI), whereas walkability was computed as an index of population density, intersectional density, and recreational space within the participants' postal code areas. Physical activity was self-reported and assessed the total minutes of activity performed per week.

Results: Neighborhood green space was associated with higher physical activity levels in both unadjusted and adjusted analyses. The walkability score was not significantly related to physical activity. No moderating effects of perceived safety were observed.

Conclusion: Although our findings should be interpreted with caution due to the study's cross-sectional nature, the results point toward the importance of providing green spaces for promoting physical activity in the adult population. This is essential knowledge for policymakers, planners, and public health professionals. Future studies should aim to further investigate how other social determinants can moderate this connection.

Keywords: physical activity; built environment; perceived safety; green space; walkability.

Introduction

Being physically active daily provides substantial health benefits. It reduces the risk of non-communicable diseases (NCDs), such as cardiovascular diseases, diabetes, and cancer as well as depression and anxiety (Katzmarzyk et al., 2022; Lee et al., 2012). Despite this knowledge, physical inactivity is still the fourth leading cause of death worldwide, making it a global pandemic (Kohl et al., 2012; Pratt et al., 2020; Sallis et al., 2016). It has been estimated that 27.5% of the global population lives inactive lives (Guthold et al., 2018). The levels are even more critical in Norway, with 68% estimated to not meet the recommended levels of physical activity (Hansen et al., 2015). Therefore, finding solutions to turn this trend is a highly prioritized task among public health researchers, practitioners, and policymakers.

With the increased emphasis on physical inactivity being a major public health issue, the World Health Organization (WHO) launched the Global Action Plan on Physical Activity 2018-2030 (GAPPA) in 2018. This action plan sets a global target to reduce physical inactivity by 15% by 2030 (World Health Organization, 2018). The action plan is well elucidated and evidence-based. Importantly, it engages multiple sectors, strategies, and partners to reach its goals, and many countries have included similar measures within their public health plans (Pratt et al., 2020). Following GAPPA, the Norwegian government has developed a corresponding national action plan that aims to reduce the inactivity levels of Norwegian citizens by 30% by 2030. The overall objective of the Norwegian action plan is to create a more activity-friendly society where everyone, independent of age, gender, function level, and social background, is given the opportunity to live a more active life (Ministry of Health and Care Services, 2020).

The explanation of why some people are physically active and others are not, is highly complex. Our behavior is determined by various factors, including the environments where we live our daily lives (Bauman et al., 2012; Sallis et al., 2006). In Bauman's review (2012) five levels of determinants are presented: individual (biological and psychological factors); interpersonal (cultural norms and social support); environment (built, natural and social); regional/national policy (transport systems, urban planning, national activity plans); and global policy (media, economic development). Ecological models have been developed to describe how determinants on all levels interact with each other to influence physical activity levels in the population (Sallis et al., 2008). Neighborhood environments have emerged as particularly relevant settings for promoting health and activity. Therefore, our study focuses on two built environment factors found in our neighborhoods: green space and walkability.

A growing body of research has identified different characteristics of the built environment that seem to promote active living among adults (Bird et al., 2018; Dixon et al., 2021). Accordingly, it has been argued that the design of our neighborhood environment may create opportunities for walking, outdoor life, and other forms of physical activity (Twohig-Bennett & Jones, 2018). An important quality of neighborhoods that has been widely studied is access to green space. Green space can be an arena for facilitating movement, play, and different types of physical activity (James et al., 2015; Markevych et al., 2017). An Australian study found that people living in greener neighborhoods were significantly more likely to walk and participate in physical activity at least once a week compared to those living in less green environments (Astell-Burt, Feng, et al., 2014). The same association has been found in Sweden (Weimann et al., 2017). However, other studies have not identified any relationship between access to green space and physical activity levels (Ord et al., 2013), and some have even found negative associations (Maas et al., 2008). Moreover, we have limited knowledge of the role of green space for physical activity in the Norwegian context (Nordbø et al., 2020).

Considering different types and qualities of green spaces, Sallis et al. (2016) found the number of parks in people's neighborhoods linearly and positively related to moderate to vigorous physical activity (MVPA) in 14 cities worldwide. Provision of quality parks has also been found to be positively related to active transport and physical activity (Smith et al., 2017). A Dutch study reported that larger natural environments were associated with higher levels of physical activity (Jansen et al., 2017). However, results of associations between parks and physical activity are inconsistent across studies (Bancroft et al., 2015), leaving the evidence inconclusive (Markevych et al., 2017).

Another factor that can promote physical activity is walkability, usually measured as an index combining the variables street connectivity, land use mix, and population density (Frank et al., 2010). Studies find increased physical activity levels in areas which are densely populated (Sallis et al., 2020), with various land types (Christiansen et al., 2016; Kärmeniemi et al., 2018) and a higher number of road intersections (Sallis et al., 2016). A recent review of reviews found a consistent association (supported by 83,3% of the studies) between physical activity and the index score of walkability (Dixon et al., 2021). These findings are supported by previous studies, especially those related to physical activity in the form of active transportation (Grasser et al., 2013; Sallis et al., 2020; Smith et al., 2017).

However, the relationships between the built environment characteristics and physical activity are complex. Different moderating and mediating factors contribute to explaining the observed relationships between the built environment and physical activity have been suggested in the literature (Lachowycz & Jones, 2013). One such factor is the residents' perceptions of their neighborhood's safety. This has been shown to influence physical activity levels, especially in groups known to exhibit greater anxiety about crime (Foster & Giles-Corti, 2008). Women and the elderly tend to feel more vulnerable and have greater concerns for personal safety (Hale, 1996). The same applies to ethnic minorities and groups of lower socioeconomic position (SEP) as they often tend to live in more deprived areas (Hale, 1996; Smith et al., 2017).

A possible moderation effect of perceived safety between the built environment and physical activity has not been thoroughly investigated in a Nordic context, to our knowledge, apart from in one Swedish study (Weimann et al., 2017). The study found that only the individuals who perceived their neighborhood as safe had a positive association between a green neighborhood and physical activity levels. These results suggest that perception of safety is a prerequisite for the activity promoting effects of green space. This may also apply to other built environment characteristics. Our study aimed to investigate the relationships between neighborhood green space, walkability, and physical activity in a Norwegian context. We also wanted to examine whether such relationships were moderated by perceived safety. Considering the potential that neighborhood green spaces and walkability may have for promoting physical activity, it is important to gain a deeper understanding of these relationships.

Methods

Study design and data sources

The present study was part of the NORDGREEN project *Smart Planning for Healthy and Green Nordic Cites*, where Stavanger is one of the six participating municipalities (Nordregio, 2020). We designed a cross-sectional study that linked data obtained from the Norwegian County Public Health (NCPH) survey in Rogaland (Skogen et al., 2020) to built environment variables computed within the participants' postal code areas using GIS.

The Norwegian Institute of Public Health (NIPH) was responsible for the survey and related data collection. A random sample of 90.215 adults (≥18 years old) living in Rogaland County was drawn from the population register. People reserved from participating, deceased, and those with unverified contact information were excluded. 77.889 residents were invited by SMS and e-mail to participate in the survey. A total of 35.191 (45.2%) adults responded to the survey from September 14 to October 5 in 2020 (Skogen et al., 2020). From this sample of respondents, we were interested in data from participants living in Stavanger municipality in Rogaland County.

Study sample

Our study sample consisted of 7057 adult individuals living in Stavanger municipality. For the present study, only inhabitants from the seven urban districts of Stavanger were included. The two islands, Rennesøy and Finnøy, were excluded because they mainly consist of rural and agricultural areas with few inhabitants. This left us with a total sample size of 5670 adults.

Variables obtained from the survey

Outcome measure

Physical activity levels were measured based on two questions capturing frequency and duration. *Frequency* was elicited through the following question: "how often do you work out or exercise in your free time?" The responses were "never", "less than once a week", "once a week", "2-3 times a week", "4-5 times a week" or "approximately every day". *Duration* was assessed with the question: "for how long do you usually exercise?" The responses were: "less than 15 minutes", "15-29 minutes", "30-60 minutes", or "more than 1 hour".

These two categorical values were then coded to numerical mean values, inspired by the Nord-Trøndelag Health studies (Kurtze et al., 2003). The six frequency responses were coded to the following values: 0 – 0.5 – 1 – 2.5 – 4.5 – 7. The four duration responses were recoded to these values: 8 – 22 – 45 – 60. The participants' new frequency and duration values were multiplied to obtain a total value of minutes of physical activity per week, ranging from 0 to 420 minutes.

Moderator

A question on perceived safety was used for the moderating analysis. It was phrased, "all in all, how safe do you feel when walking in your local area?". The scale went from 0 to 10 and was treated as a continuous variable.

Covariates

From the NCPH survey, we also obtained the variables age, sex, educational level, and perceived financial status to account for potential confounders based on existing knowledge and theoretical background (Bauman et al., 2012; Lachowycz & Jones, 2013; Sallis et al., 2008). Age was treated as a continuous variable, whereas sex remained dichotomized. The question of perceived financial status had seven possible responses. "Very hard", "hard" and "quite hard" were merged into a "difficult financial status" category. "Quite easy" and "easy" were labeled "easy financial status", whereas "very easy" remained a separate category.

Exposure variables

Geographical informational systems software (QGIS 3.16.6) was used to calculate the environmental variables within each of the postal code areas of the participants from Stavanger municipality. Geographical data was downloaded from GeoNorge (Geonorge, w.y.) and the Copernicus website (Copernicus Global Land Service, w.y.).

The normalized difference vegetation index (NDVI)

Vegetation data were downloaded from the Copernicus websites (Copernicus Global Land Service, w.y.) to compute a measure of green vegetation using NDVI. NDVI is a validated indicator for measuring green vegetation in pixels or grids (Rhew et al., 2011). The satellite data we obtained had a 250x250 meter grid resolution and was produced from the Sentinet-3 satellite. We downloaded six datasets from April 2020 to July 2020 and used the maximum value to select the data representing the greenest period based on previous research (Barboza et al., 2021). The NDVI index was examined for negative values, which usually would represent water, ice, and bare earth. As the data contained no negative values, our index values ranged from 0 to 1, where higher values indicated more green vegetation.

Walkability

Commonly, the walkability index is calculated based on a summary score of intersection density, residential density, and land-use mix (Frank et al., 2010). To adjust for the Norwegian context, the measure of the land-use mix was replaced by the proportion of green space. A detailed description of the components of the walkability score and how the score was calculated is provided below.

The proportion of green space was computed using national land cover and land-use maps. We identified and included the following types of green spaces: parks, forests, and cemeteries. The total area (in km^2) of these green space types was computed and summarized for each postal code area.

The population density was assessed using a Statistical Grid Dataset (250x250 meter) with population data from 2019 from Statistics Norway. An intersect analysis was performed with the postal code areas to connect the two data sets. The population density was operationalized as the number of residents (in km^2) within the participants' postal codes.

Intersection density is a measurement of the connectivity of the street network, represented by the ratio between the number of true intersections (three or more legs) to the land area of the block group in acres. A higher density of intersections corresponds with a more direct path between destinations (Frank et al., 2010). By using intersection analysis, all street intersections were identified within each postal code area. The count of intersections was then divided by the total area (in km^2) of each postal code to obtain the final density measurement.

The three values were then normalized using a z-score. Finally, we computed the walkability index by summarizing the z-scores for each postal code area:

Walkability = z(intersection density) + z(residential density) + z(proportion of green space).

Statistical Analysis

Descriptive statistics were used to describe the sample according to selected variables. Results from these analyses are presented as frequencies and proportions, as well as mean values with standard deviations. Linear regression models were then used to examine the relations between walkability, green space, and adults' physical activity levels. Before running these models, a complete case data set including participants with complete data on all variables of interest was created. This resulted in an analytical sample of 5307 participants for the regression models. Two linear regression models, one for each environmental characteristic against the physical activity outcome, were fitted. Both unadjusted and adjusted results are reported. Adjustments were made for sex, age, educational level, and perceived financial status. To examine the moderating effect of perceived safety, the variables were first standardized to avoid possible multicollinearity issues. Separate models were fitted to test the two interaction terms. The terms were NDVI*Perceived safety and Walkability*Perceived safety.

Unstandardized coefficients (B) with 95% confidence intervals (CI) were reported to present a change in minutes/week of physical activity for every 1-unit change in the continuous exposure variables. All statistical analyses were performed in SPSS (version 28) and p-values <0.05 were considered statistically significant.

Ethical considerations

Participation in the study was voluntary, and all participants had the opportunity to withdraw from the study at any time. The National Institute of Public Health was responsible for collecting, saving, and anonymizing the data. The present study applied to and was approved by the Norwegian center for research data in July – August, 2021.

Results

Profile of the participants

The sample was comprised of 2623 men (46.3%) and 3047 women (53.7%). All characteristics of the participants are presented in Table 1. The majority of the participants were aged between 30-69 years (72.7%).

Table 1: Descriptive statistics. Characteristics of the total study sample.

Characteristics	**Total (n=5670)**
Potential covariates, N (%)	
Gender	
Male	2623 (46.3)
Female	3047 (53.7)
Missing	0
Age groups	
18-29	967 (17.1)
30-49	2067 (36.5)
50-69	2050 (36.2)
70+	586 (10.3)
Missing	0
Perceived financial status	
Hard	925 (16.3)
Easy	2726 (48.1)
Very easy	1733 (30.6)
Missing	286 (5.0)
Educational level	
High school or less	2214 (39.0)
University < 4 years	1359 (24.0)
University ≥ 4 years	2080 (36.7)
Missing	17 (0.3)

Table 2 presents the outcome, exposure, and moderating variables. Our sample was on average physically active 148,3 minutes/week and perceived their safety as 8.84 on a score of 0-10. The mean walkability score for inhabitants in the urban areas of Stavanger municipality was 0.28. The mean vegetation score (NDVI) was 0.65.

Table 2: Descriptive statistics. Exposure, outcome, and moderating variables of our study sample.

Characteristics	**Total (n=5670)**
Environmental exposures, mean (SD)	
Walkability score (-1 to +1)	0.28 (1.57)
Missing	0
NDVI (0-1)	0.65 (0.13)
Missing	0
Outcome variables, mean (SD)	
Weekly minutes of physical activity	148.43 (116.95)
Missing, n (%)	57 (1.0)
Potential moderator, mean (SD)	
Perceived safety (0-10)	8.84 (1.55)
Missing, n (%)	8 (0.1)

Physical activity levels

Results from linear regression analyses are shown in Table 3. Neighborhood greenness was positively related to physical activity levels in the unadjusted models (B = 40.39; 95% CI = 15.63-65.14). The association became weaker when adjusting for age, sex, educational level, and perceived financial status, but remained significant (B = 24.85; 95% CI = 0.29-49.41). A small but negative relationship was observed between the walkability score and physical activity levels in both the unadjusted (B = -1.91; 95% CI = -3.90-0.08) and the adjusted model (B = -1.18; 95% CI = -3.15-0.79). However, the results were not statistically significant.

Table 3: Linear regression of our analytical sample. Association between physical activity levels (min/week) and built environment characteristics.

Variable	**Total (n = 5307). Unstandardized B (95% CI)**
Unadjusted	
Walkability score	-1.91 (-3.90, 0.08)
NDVI	40.39 (15.63, 65.14) ***
Adjusted[a]	
Walkability score	-1.18 (-3.15, 0.79)
NDVI	24.85 (0.29, 49.41) *

[a] Adjusted for age, gender, educational level, and perceived financial status.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Moderation models

Table 4 presents the analysis of the association between walkability, amount of green space and physical activity, and the moderating role of perceived safety. These are the results of general linear models in SPSS. Model 1 presents NDVI (green space) as the exposure, and model 2 uses walkability. The moderation effect of perceived safety was about zero in both models and was not significant. There was found, however, a strong association between perceived safety on the levels of physical activity, both in the unadjusted and adjusted analysis. A one-unit increase in the safety score was associated with 8.29 (95% CI = 6.20-10.37) and 8.49 (95% CI = 6.43-10.56) more minutes of weekly physical activity in the unadjusted analysis. After adjusting for age, gender, educational level, and perceived financial status, the number of minutes went down to 6.12 (95% CI = 3.96-8.28) and 6.27 (95% CI = 4.13-8.42).

Table 4: Moderation models of our analytical sample. Moderation model 1 presenting the moderating effect of perceived safety on the association between green space access and physical activity levels (min/week).. Moderation model 2 presenting the moderating effect of perceived safety on the association between the walkability index and physical activity levels (min/week).

Variable	**Total (n = 5307). Unstandardized B (95% CI)**
Moderation model 1 – unadjusted	
NDVI	29.35 (4.41, 54.29) *
Perceived safety	8.29 (6.20, 10.37) ***
NDVI * perceived safety	0.18 (-2.66, 3.02)
Moderation model 1 - adjusted [a]	
NDVI	17.45 (-7.36, 42.26)
Perceived safety	6.12 (3.96, 8.28) ***
NDVI * Perceived safety	-0.27 (-3.08, 2.54)
Moderation model 2 – unadjusted	
Walkability	-1.33 (-3.33, 0.67)
Perceived safety	8.49 (6.43, 10.56) ***
Walkability * Perceived safety	-0.70 (-3.65, 2.25)
Moderation model 2 – adjusted [a]	
Walkability	-0.66 (-2.64, 1.32)
Perceived safety	6.27 (4.13, 8.42) ***
Walkability * Perceived safety	-0.33 (-3.25, 2.58)

[a] Adjusted for age, gender, educational level, and perceived financial status.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Discussion

This cross-sectional study has examined the association between walkability, access to green space, and levels of physical activity in Stavanger, Norway. In addition, we investigated if perceived safety moderated any such associations. We found that neighborhood green space was related to increased levels of physical activity. No such associations were found for walkability, and perceived safety did not act as a moderator for the associations under study.

Green space and physical activity

Identifying whether green space can promote physically active lifestyles is important knowledge for urban planners and policymakers (Ministry of Health and Care Services, 2020). As stated by James et al. (2015), green spaces may be a universal arena that creates possibilities for movement and active living across ages, genders, and people of different SEP. Our study enhances prior understanding by demonstrating that greener neighborhood environments were associated with higher physical activity levels (Astell-Burt, Mitchell, et al., 2014; James et al., 2015).

The observed positive relationship between neighborhood green space and physical activity corresponds with the results of most previous research, as green space facilitate multiple activities (Astell-Burt, Feng, et al., 2014; Markevych et al., 2017). This supports the suggestion that increasing green spaces can be part of the solution to the pandemic of inactivity. The association was statistically significant, even when we adjusted for age, gender, and socioeconomic status. However, the confidence interval (95% CI = 0.29-49.41) was large, making the results less certain.

NDVI was chosen as a green space measure because it is a useful and valid metric of neighborhood greenness (Rhew et al., 2011). The strength of NDVI, in comparison to predefined land cover maps, is that it includes all vegetation. This also covers small gardens, forests, and green pathways – which can all be suitable arenas for activities (Markevych et al., 2017). However, the NDVI score does not provide any knowledge of other qualities of green spaces. Size and other qualities like lighting and maintenance of green spaces seem to be factors affecting their use and health benefits (Bird et al., 2018; Jansen et al., 2017; Lachowycz & Jones, 2013), although the evidence is still inconclusive (Jimenez et al., 2021; van den Berg et al., 2015). As the literature suggests – the quality of green space and health outcomes should be more thoroughly investigated in a Norwegian context (Nordbø et al., 2018).

NDVI is also an objective measure of green space, which may have some drawbacks. Perceptions of green space are found to be a stronger predictor for usage than objective measures in a Dutch (Bloemsma et al., 2018) and a recent Norwegian study (Fongar et al., 2019). Understanding how and why residents interact with their neighborhood green spaces seems to be important in planning processes, so that the green spaces can fulfill their role in facilitating physical activity and improving health.

Walkability and physical activity

The walkability features – mixed land use, street connectivity, and residential density - are used frequently in existing research as these variables are found positively associated with physical activity (Dixon et al., 2021; Kärmeniemi et al., 2018). This has been found in recent studies, both with objective measurements of physical activity (Twardzik et al., 2019) and subjective measures like ours (Gascon et al., 2019).

We found, on the contrary, a small but negative association between walkability and physical activity, but the results were not statistically significant. An explanation for our results could be the way physical activity was defined and measured in this study. The relationship between walkability and physical activity may differ depending on the physical activity construct or measure used, such as general physical activity, walking, or active transportation. Previous research has found walkability features to be more positively related to active transportation than overall physical activity (Grasser et al., 2013; McCormack & Shiell, 2011; Smith et al., 2017). Our study used a measure of overall physical activity without finding significant results. This may be because total physical activity levels capture indoor activities like housework or training in a gym, which are activities not influenced by the built environment. Even though outdoor walking is the most performed activity by Norwegian people, surveys find indoor activities like strength training and swimming also to be popular (Statistics Norway, 2021).

Another explanation for our finding could be that although walkability is high in a neighborhood area, this does not directly imply that the residents perceive that the area is walkable. The walkability index is a simplification of reality, and other measures like traffic, quality of sidewalks, lighting, and noise could also influence how walkable a neighborhood is perceived. For instance, densely built neighborhoods usually have more facilities but also more traffic (Lee & Maheswaran, 2010), making it less enjoyable to take a walk or bike ride there. This could be an explanation as to why the walkability measurement did not seem to facilitate physical activity in our study.

Perceived safety as a moderator

Our study investigated if the association between qualities of the built environment and physical activity levels were moderated by perceptions of safety. The hypothesis was that feeling unsafe in the neighborhood could be a barrier to being outside and hence, being physically active. This was based on earlier studies finding activity-friendly built environments to be associated with higher physical activity levels among people who perceived their neighborhoods as safe (Bracy et al., 2014; Evenson et al., 2012; Foster et al., 2016; Weimann et al., 2017). However, our results did not support the hypothesis, adding to the inconsistent empirical evidence of the moderator mechanism of perceived safety (Loh et al., 2019; Ruijsbroek et al., 2015). Findings have also been moderate in a review of longitudinal studies (Kärmeniemi et al., 2018) and in a review of reviews (Dixon et al., 2021). Moreover, a Dutch study (2015) found evidence that changes in social safety may be more relevant to levels of general health than to physical activity. This could question the relevance of our hypothesis, making the negative health effect of feeling unsafe more dangerous to our general health than to restricting physical activity.

Another probable reason for our finding is that our study sample in general had a high perception of safety. The mean value of safety in our sample was 8.84, close to the score of 8.92 in the whole Rogaland sample (Skogen et al., 2020). The small variation in neighborhood safety scores could have limited the ability to observe statistically significant interactions, which could underestimate the interaction between built environment exposures and physical activity levels.

That said, we did observe a positive relationship between perceived safety and physical activity levels. A one-point higher score of safety seemed to contribute to 6 more minutes of physical activity weekly in our study sample. This finding is supported by several studies (Evenson et al., 2012; Foster et al., 2016; Lee & Maheswaran, 2010). For example, Foster et al. (2016) found an 18-minute increase in weekly physical activity levels with a similar scale. This finding is important because feeling safe is a prerequisite for good health (Ruijsbroek et al., 2015), and underlines the importance of creating safe and activity-friendly neighborhoods. However, the amount of green spaces or the degree of walkability does not seem to be the most important factors in this matter. There are many other potential moderating factors of the living context, like cultural factors, community activity, infrastructure, and traffic (Lachowycz & Jones, 2013), which can be more important for the perception of safety. Future research should investigate these connections further.

Strengths and limitations

The strength of this study is the large sample size which increases the likelihood of a representative sample. However, the study is limited by the constraints of a cross-sectional study design which excludes any inferences of causality. Furthermore, the study relies on self-reported measures which are prone to recall bias and social-desirability bias. With a response rate of 45.2 %, one cannot rule out the risk of selection bias. However, the response rate is considered high compared to other similar surveys (Skogen et al., 2020). A limitation of the study is the higher proportion of highly educated participants compared to the average Norwegian adult population (50,6% versus 35%) (Statistics Norway, 2022). This can limit the transferability of our results. However, the use of objectively measured exposures eliminates the risk of single-source bias, which is a methodological strength of our study.

When assessing physical activity, the aim is usually to identify four dimensions: duration, frequency, intensity, and type of activity performed (Ainsworth et al., 2015). The participants of our study had a mean value of 148 minutes of weekly physical activity – almost in line with WHO's recommended 150 minutes (Bull et al., 2020). However, these numbers are not comparable because our data did not consider activity intensity which is included in the WHO recommendation. Only duration and frequency were included in this study, which only makes the results comparable to other studies that use the same physical activity measures. However, the questions in the NCPH survey in have been validated against objective measures of physical activity and the International Physical Activity Questionnaire (Kurtze et al., 2007).

Another limitation to our study is that we did not consider whether the activity was performed in the neighborhood or another setting. This can at least partially explain the inconsistent findings in previous research (Lachowycz & Jones, 2013). It could imply that people also perform physical activity in gyms or in their living rooms, and not just outdoors. However, recent research shows that most adults' daily physical activity is performed in their neighborhood or home locations (Kelso et al., 2021), and outdoor walking is the activity Norwegian people perform the most (Hansen et al., 2015).

Although there is a lack of consensus on how to define the walkability index of exposure, we operationalized the GIS measures based on previous empirical work and used the three most frequently used variables (Frank et al., 2010). Using this kind of objectively measured walkability is a methodological strength of the study, as it offers less measurement error.

The use of diverse measures of perceived safety in earlier studies has made limitations on the consistency of results (Foster & Giles-Corti, 2008) and it may not be sufficiently valid. The mean score in our sample of 8.84 suggests a lack of variability and a potential ceiling effect. It could therefore be necessary to develop improved measures to be able to evaluate perceived safety adequately. Our measure was also based on one single question which could reduce its benefit in comparison to other studies using more complex measures. Still, we were able to find an association between perceived safety and physical activity. Our data indicates that the perception of safety in people's neighborhoods can facilitate or prevent physical activity.

The usual practice when examining health effects of area-based attributes is to use buffers around home addresses, or like in our study, use postal code areas. It is then possible to face "the uncertain geographic context problem" (Kwan, 2012). This is when effect measures of spatial attributes are affected by how neighborhoods are geographically delineated. This information bias makes it important to pay attention to a potential confounding effect on research results, and it could explain why research findings on the built environment and health outcomes are often inconsistent.

Finally, although we adjusted for the most important confounders in our analyses, other variables not available in the NCPH survey could confound the results. This includes, amongst others, motivation for physical activity, traffic, noise, and maintenance of the built environment.

Conclusion

We found an association between neighborhood green space and increased levels of physical activity in Stavanger, Norway. The same association was not observed for walkability in our study sample. Perceived safety when out walking did not moderate any associations, rather, a direct association with increased physical activity levels was found. Our results underscore the importance of providing neighborhood green spaces and fostering safety to support physical activity. Preserving areas under pressure, such as parks, nature, and other green spaces, as well as walking paths, should be emphasized. This is important for policymakers, planners, and public health professionals to consider and integrate into their work. Future studies should aim to further investigate how perceptions of safety are associated with physical activity, and there is especially a need for more prospective studies considering these associations in the Nordic context.

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Appendix 2: NSD approval.

NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

Pathways linking green space to self-reported health and subjective well-being among residents in Stavanger

Referansenummer

314018

Registrert

01.07.2021 av Emma Charlott Andersson Nordbø - emma.charlott.andersson.nordbo@nmbu.no

Behandlingsansvarlig institusjon

Norges miljø- og biovitenskapelige universitet – NMBU / Fakultet for landskap og samfunn / Institutt for folkehelsevitenskap

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Emma Charlott Andersson Nordbø, emma.charlott.andersson.nordbo@nmbu.no, tlf: +4767231269

Type prosjekt

Forskerprosjekt

Prosjektperiode

01.05.2021 - 31.12.2023

Status

16.08.2021 - Vurdert

Vurdering (1)

16.08.2021 - Vurdert

Det er vår vurdering at behandlingen vil være i samsvar med personvernlovgivningen, så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet 16.08.2021 med vedlegg, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte.

TYPE OPPLYSNINGER OG VARIGHET
Data skal utelukkende hentes fra Fylkeshelseundersøkelsen i Rogaland. Prosjektet vil behandle alminnelige personopplysninger og særlige kategorier av personopplysninger om helseforhold frem til 31.12.2023.

LOVLIG GRUNNLAG

Deltakere i Fylkeshelseundersøkelsen i Rogaland har samtykket til at opplysningene gjenbrukes til forskning som kan gi mer kunnskap om befolkningens helse og faktorer som påvirker helsen, forutsatt at behandlingen er i samsvar med gjeldende lover og forskrifter. Formålet med dette prosjektet er å undersøke sammenhengen mellom tilgang til og ulike kvaliteter ved grøntområder og selvrapportert helse og livskvalitet. NSD vurderer at prosjektets formål er forenlig med formålet for videre bruk, og dermed at samtykket er dekkende, jf. personvernforordningens fortalepunkt 33.

Lovlig grunnlag for behandlingen er dermed den registrertes uttrykkelige samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a, jf. art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 2.

PERSONVERNPRINSIPPER
NSD vurderer at behandlingen av personopplysninger vil følge prinsippene i personvernforordningen:

- om lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte fikk tilfredsstillende informasjon om og samtykket til gjenbruk av personopplysninger til lignende forskningsformål
- formålsbegrensning (art. 5.1 b), ved at personopplysninger behandles for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet.

DE REGISTRERTES RETTIGHETER
NSD vurderer at informasjonen om behandlingen som de registrerte mottok oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Kollektiv informasjon om gjenbruk av data i dette forskningsprosjektet vil offentliggjøres på NORDGREENs prosjektside ved NMBU.

I den grad de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18) og dataportabilitet (art. 20).

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Ekstern forsker ved Sveriges Lantbruksuniversitet (SLU) vil ha innsyn i datamaterialet. Vi anbefaler at ansvarsforhold, sikring og eventuelt eierskap av data er avklart mellom NMBU og samarbeidspartner, og at forholdet formaliseres.

For å forsikre dere om at kravene oppfylles, må prosjektansvarlig følge interne retningslinjer/rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilken type endringer det er nødvendig å melde:
https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema
Du må vente på svar fra NSD før endringen gjennomføres.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Kontaktperson hos NSD: Eva J. B. Payne

Lykke til med prosjektet!

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
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