Inequities in access to exercise facilities and relationship with diabetes burden from an equity perspective in Madrid, Spain

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TESIS DOCTORAL CON MENCIÓN INTERNACIONAL

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A Coki, por haber sido la
mejor compañera que se
puede tener en la vida.

“Cities have the capability of providing
something for everybody, only because, and
only when, they are created by everybody.”

Jane Jacobs

The Death and Life of Great American Cities

Agradecimientos

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LIST OF ABBREVIATIONS

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BMI	Body Mass Index
CI	Confidence Interval
EMR	Electronic Medical Record
FED	Federación Española de Diabetes (Spanish Federation of Diabetes)
GIS	Geographic Information System
HHH	Heart Healthy Hoods
ICPC	International Classification of Primary Care
IDF	International Diabetes Federation
LTPA	Leisure Time Physical Activity
MET	Metabolic Equivalent Task
MVPA	Moderate to Vigorous Physical Activity
PR	Prevalence Ratio
RR	Risk Ratio
SES	Socioeconomic Status
T2DM	Type 2 Diabetes Mellitus

UN	United Nations
WHO	World Health Organization

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ABSTRACT

Introduction

Physical activity, specifically exercise, exerts influence on the incidence and prevalence of major health problems, such as obesity, diabetes, and cardiovascular diseases. Among urban built environment resources, the availability of exercise facilities is important for supporting physical activity engagement; however inequitable distribution of exercise facilities exists throughout many cities. The empirical evidence for the associations between the neighbourhood exercise facility environment and health outcomes, especially Type 2 Diabetes Mellitus (T2DM), are weak and has received relatively little attention in public health research.

Objectives

This thesis examines the relationship between exercise facility availability, T2DM burden, and area-level socioeconomic status (SES) in in Madrid, Spain through three aims, presented as separate studies. The aims are to: (1) investigate the relationship between area-level socioeconomic status (SES) and accessibility to, and availability of, exercise facilities; (2) study the association between the availability of exercise facilities and the likelihood of obesity and T2DM in the adult population; and (3) examine the relationships between exercise facility availability and incidence of T2DM and its complications.

Methods

All exercise facilities in Madrid were identified and classified them into four types: public, private, low-cost, and sessional facilities. Facilities were geocoded using Google Maps and accessibility was operationalised as the street network distance to the nearest exercise facility from each of the 125,427 residential building entrances in Madrid. Exercise facility availability was defined as the count of exercise facilities in a 1000 m street network buffer around each portal. Area-level SES was measured using a composite index based on seven sociodemographic indicators. Health outcome data

were obtained from electronic medical records (EMRs) from more than 90% of Madrid residents aged 40-75 years, using data from 2017 for the cross-sectional studies (n=1,270,512) and 2015-2018 (n=1,412,759) for the longitudinal study. Health outcomes studied were obesity, T2DM, and macrovascular (cardiac ischemia and stroke) and microvascular (chronic kidney disease, retinopathy, and peripheral vascular disease) complications of T2DM. For the first study, I carried out a multilevel linear regression and a zero-inflated Poisson regression analysis to assess the association between area-level SES and exercise facility accessibility and availability in Madrid. For the second study, I used Poisson regression with standard errors clustered at census tract level to assess prevalence ratios (PR) of exercise facility availability (tertiles) with obesity and T2DM. Interactions by area-level SES and sex were also examined. For the third empirical study, I carried out Poisson regression models using robust standard errors clustered at the census tract level to estimate the relative risk (RR) for the association between exercise facilities and each health outcome. Analyses of interactions by area-level SES and sex were undertaken to identify potential effect modification.

Results

The first study showed that Madrid residents living in more disadvantaged areas had the shortest mean street network distance to the closest exercise facility, especially for accessing public and low-cost exercise facilities. Meanwhile those living in less disadvantaged areas had higher availability of exercise facilities, especially for private and sessional exercise facilities, compared with those more disadvantaged. The second study showed people living in areas with lower availability of exercise facilities had a higher prevalence of obesity and T2DM compared with those who had a higher availability of exercise facilities. Stratified analysis found an effect modification by area-level SES, with stronger associations for residents living in low-SES areas, and strongest for women living in low SES neighbourhoods. The third study found that residents living in areas with lower exercise facility availability presented with higher risk of T2DM and macrovascular and microvascular T2DM complications compared with those living in areas with higher availability of exercise facilities. Analysis showed stronger associations for those living in low SES areas with the lowest tertile of exercise facility availability and incidence of T2DM and its microvascular complications compared with those residents from high SES areas.

Conclusions

This thesis draws two main conclusions. First, exercise facility accessibility and availability are related to T2DM burden, not only for T2DM itself, but also for its main risk factor (obesity) and macrovascular and microvascular T2DM complications. Second, this set of studies have exposed how socioeconomic inequities play a role in these relationships, by conditioning harmful effects for residents from low SES areas in Madrid. This research generated new knowledge that can help shape exercise-based interventions to reduce health inequities, including increasing availability of exercise facilities in more disadvantaged areas alongside ensuring that the facilities are affordable and gender-appropriate.

Keywords

Physical activity, exercise facilities, inequities, diabetes, obesity, urban health, urban planning.

RESUMEN

Introducción

La actividad física, y especialmente el ejercicio, ejerce una influencia sobre la incidencia y la prevalencia de grandes problemas de salud, como la obesidad, la diabetes o las enfermedades cardiovasculares. Entre los diferentes recursos urbanos, la disponibilidad de instalaciones deportivas es importante como apoyo en la práctica de actividad física; sin embargo, las ciudades presentan una distribución de las instalaciones deportivas que no es equitativa. Hay una débil evidencia publicada sobre la asociación entre la disponibilidad de instalaciones deportivas en el barrio y los resultados de salud, especialmente la Diabetes Mellitus Tipo 2 (DMT2), debido a la falta de atención que ha recibido en la investigación en salud pública.

Objetivos

La presente tesis doctoral examina la relación entre la disponibilidad de instalaciones deportivas, la carga de DMT2, el nivel socioeconómico del área (NSE) el sexo en Madrid, España, a través de tres objetivos, presentados en tres estudios diferentes. Los objetivos son: (1) investigar la relación entre el NSE y la accesibilidad y la disponibilidad de instalaciones deportivas; (2) estudiar la asociación entre la disponibilidad de instalaciones deportivas y la prevalencia de obesidad y DMT2 en la población adulta; y (3) examinar la relación entre la disponibilidad de instalaciones deportivas y la incidencia de DMT2 y sus complicaciones.

Métodos

Fueron identificadas todas las instalaciones deportivas en Madrid, y clasificadas en cuatro grupos: públicas, privadas, low-cost, e instalaciones “sesionales”. Las instalaciones fueron geolocalizadas usando Google Maps. La accesibilidad fue operacionalizada como la distancia por la red de calles a la instalación deportivas más cercana desde cada una de los 125.427 portales residenciales de Madrid. La disponibilidad de instalaciones deportivas fue definida como el número de instalaciones en un área de 1.000 metros a través de la red de calles desde cada portal. El NSE fue medido usando un índice compuesto basado en siete indicadores sociodemográficos. Las variables de salud fueron obtenidas de las historias clínicas electrónicos de más del 90% de los residentes en Madrid de entre 40 y 75 años, usando datos de 2017 para los análisis transversales (N=1.270.512) y de 2015 a 2018 (N=1.412.759) para los análisis longitudinales. Los datos de salud estudiados fueron obesidad, DMT2, y las complicaciones macrovasculares (isquemia cardíaca e isquemia cerebral) y microvasculares (enfermedad renal crónica, retinopatía, y enfermedad vascular periférica) de la DMT2. Para el primer estudio realicé modelos de regression lineal multinivel y modelos de regresión zero-inflated Poisson para estudiar la asociación entre el NSE y la accesibilidad y disponibilidad de instalaciones deportivas en Madrid. Para el segundo estudio llevé a cado modelos de regresión Poisson con errores estándar agrupados a nivel de sección censal para obtener ratios de prevalencia de la disponibilidad de instalaciones deportivas (terciles) con obesidad y DMT2. Asimismo, se examinaron interacciones por NSE y sexo. Para el tercer studio llevé a cabo modelos de regresión Poisson con errores estándar agrupados a nivel de sección censal para obtener el riesgo relativo de la asociación entre la disponibilidad de instalaciones deportivas y la incidencia de DMT2 y sus complicaciones. Se llevaron a cabo análisis con interación por NSE y sexo para identificar una potencial modificación del efecto.

Resultados

El primer estudio mostró que los residentes en Madrid que viven en las áreas más desfavorecidas tienen la distancia media más pequeña a la instalación deportivas más cercana, especialmente para instalaciones públicas y low-cost. Mientras, aquellos que viven en áreas menos desfavorecidas tienen una mayor disponibilidad de instalaciones deportivas, especialmente privadas y sesionales, comparado con los residentes de áreas más desfavorecidas. El segundo estudio mostró que quienes viven en áreas con menor disponibilidad de instalaciones deportivas tienen una mayor prevalencia de obesidad y DMT2, comparado con quienes viven con una mayor disponibilidad. Los análisis estratificados mostraron una modificación del efecto por NSE y por sexo, con asociaciones más fuertes para residentes de áreas con menor NSE y aún más para mujeres que viven en barrios de bajo NSE. El tercer estudio encontró que los residentes de áreas con baja disponibilidad de instalaciones deportivas presentaban un mayor riesgo de desarrollar T2DM y complicaciones macrovasculares y microvasculares, comparados con quienes viven en áreas con mayor disponibilidad de instalaciones. Los análisis mostraron asociaciones más fuertes para quienes viven en áreas de bajo NSE y entre el tercil más bajo de instalaciones deportivas y la incidencia de T2DM y complicaciones microvasculares, comparados con quienes viven en áreas de alto.

Conclusiones

Esta tesis plantea dos conclusiones principales. La primera, que la disponibilidad de instalaciones deportivas está relacionada con la carga de diabetes, no solo con la DMT2 en sí, sino también con su principal factor de riesgo (obesidad) y sus complicaciones macrovasculares y microvasculares. Segundo, esta serie de estudios ha expuesto cómo las inequidades socioeconómicas juegan un papel en estas relaciones, condicionando efectos más dañinos para los residentes de áreas de bajo NSE en Madrid. Esta investigación ha generado un nuevo conocimiento que puede ayudar a configurar intervenciones basadas en el ejercicio físico para reducir las desigualdades en salud, incluyendo el incremento de la disponibilidad de instalaciones deportivas en las áreas más desfavorecidas, asegurando que estas instalaciones sean asequibles y con perspectiva de género.

Palabras clave

Actividad física, instalaciones deportivas, inequidades, diabetes, obesidad, salud urbana, planificación urbana.

CHAPTER 1.
INTRODUCTION

Nowadays, non-communicable diseases (NCD) have become the greatest challenge facing public health in the world, and are responsible for 41 million deaths annually, equivalent to over 7 out of 10 deaths globally (WHO, 2023). Among all the NCDs, diabetes is responsible for 2 million deaths per annum, and is the fourth leading cause of death globally, (WHO, 2021b). Type 2 Diabetes Mellitus (T2DM) is the most common type of diabetes mellitus and accounts for more than 95% of all diabetes cases. However, the burden of T2DM is not only limited to the disease itself but is also associated with other health conditions and complications associated with the causal chain of T2DM. Therefore, reducing T2DM cases, as well as improving diabetes management and control are major public health challenges.

Increasing physical activity, particularly exercise, is a key strategy for T2DM risk reduction (Gillies et al., 2007; Kriska et al., 2021), control (Colberg et al., 2016; Colberg & Swain, 2000), and cardiovascular disease prevention (Garber et al., 2011); making physical activity a key tool in the entire causal chain of T2DM. Exercise is defined as a physical activity that is planned, structured, repetitive and purposive with the objective of improving or maintaining one or more components of physical fitness (Caspersen et al., 1985). Moreover, exercise is usually supervised, which is associated with larger health improvements (Colberg et al., 2016; Garber et al., 2011). However, the high global prevalence of physical inactivity (Guthold et al., 2018) is one of the leading causes of mortality in the world, contributing to 3.2 million deaths globally annually (WHO, 2014).

Physical inactivity is strongly patterned by socioeconomic inequities, indicating social determinants need to be considered and addressed to face this challenge. The World Health Organization (WHO) defines the social determinants of health as *'the conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life'* (Commission on Social Determinants of Health, 2008). This conceptualisation provides a holistic view that addresses both structural and intermediate determinants of population health. Thus, using this perspective allows the study of the 'causes of the causes' of disease, adopting a broader picture of the causal chain that ranges from the structural determinants (such as socioeconomic and political context, or socioeconomic position) to the material conditions of life (such as living and working conditions or characteristics of the residential environment). When population health is considered using this lens, the urban environment and city design become important dimensions contributing to the health and wellbeing of populations. Urban health is a growing focus of interest to tackle health inequities, especially since the amount of people living in urban settlements globally is anticipated to increase to 60% by 2030 (United Nations, 2015) and is projected to increase even further to 68% by 2050 (United Nations, 2018). This has made addressing the urban determinants of health a global priority to improve the population health reducing health inequities (Badland & Pearce, 2019; UN Department of Economic and Social Affairs/Population Division, 2018; United Nations, 2015).

Physical activity determinants have been analysed from a social determinants perspective (Sallis et al., 2012), revealing that the different domains of physical activity have different drivers, levers, and outcomes. For example, the effect on health from leisure-time (recreation) physical activity differs from that accumulated from daily active commuting (transport), or that from the workplace (occupational) or household chores (domestic). Moreover, the mode, frequency, duration and intensity of physical activity influences health benefits from each type of physical activity (Strath et al., 2013). Thus, light physical activity engagement accumulated through a leisurely daily walk will generate different benefits compared with a supervised strength program session undertaken at an exercise facility. To gain a precise understanding of how the urban environment can improve equitable health outcomes by promoting active lifestyles among populations, it is essential to consider both the domain and dimensions of physical activity that are supported by resources such as sporting or exercise facilities. By analysing these factors, we can better comprehend the relationship between the urban environment and population health and develop effective strategies to promote physical activity and well-being among diverse communities.

When analysing the urban environment with consideration to the characteristics of the physical activity provided by the built environment, exercise facilities emerge as a significant contributor to health-related physical activity. Exercise facilities are indoor facilities, both public and private, offer physical activity programs, include monthly subscription and/or pay per session, such as gyms, fitness centres, and recreation centres. Their roles in preventing and controlling T2DM and its associated diseases are critical considering the type of activities offered at exercise facilities, including high intensity activities, which implies a high metabolic cost, which are generally supervised and programmed. However, the investigation of the role of exercise facilities and relationship with specific population health outcomes (e.g. T2DM) has not received enough attention.

Current limitations include that physical activity resources have been considered in the studies as a broad concept that includes parks and physical activity and recreational facilities together (Van Cauwenberg et al., 2018); the physical activity environment is commonly ascertained using secondary databases, rather than identification following predetermined criteria; little attention has been paid to the distribution of exercise facilities, or their impact on population health; and, the associations between a specific chronic disease, T2DM and its macrovascular and microvascular complications, and exercise facility accessibility and availability have not been examined.

Using a social determinants of health perspective, the overarching goal of this research is to investigate how exercise facility availability could be associated with T2DM and its related diseases in the adult population of Madrid, Spain.

Specifically, this PhD seeks to answer the following four research questions:

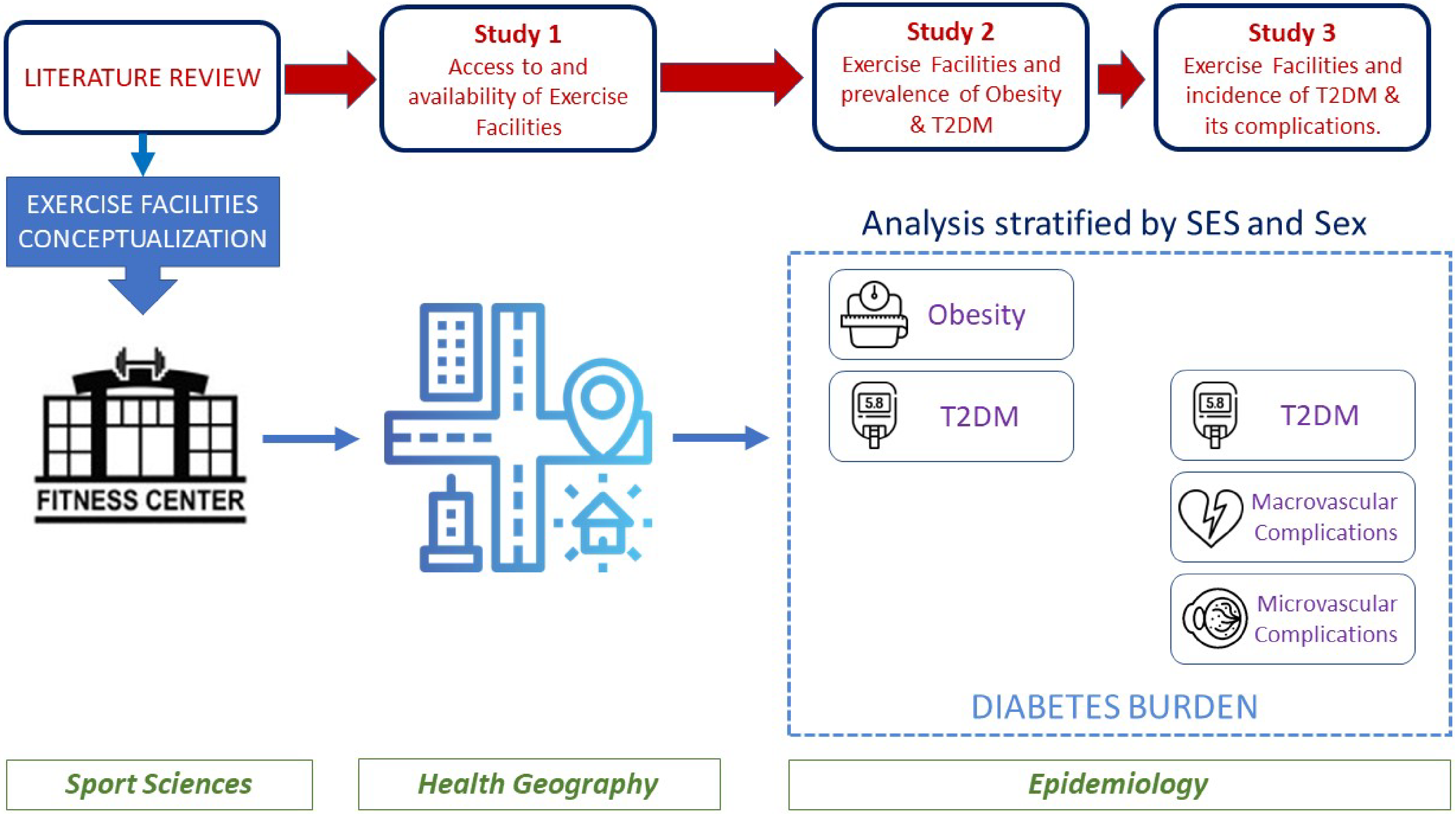
1. Does the distribution of exercise facilities in Madrid follow any social patterning?
2. Are any disparities in exercise facility availability associated with a differential prevalence of obesity and/or T2DM in the Madrid adult population?
3. Does the availability of exercise facilities influence the incidence of T2DM in the Madrid adult population? Is there an association with the incidence of macrovascular and microvascular complications in the diabetic population?
4. Does SES and/or sex exert any effect on the association between exercise facility availability and T2DM burden in the Madrid adult population?

The PhD thesis aims to answer research questions through a multidisciplinary approach that draws on knowledge and tools from different scientific fields. Firstly, drawing on the literature from sport sciences, I conceptualised physical activity resources based on the physical activity they provide and their impact on health, and from this, I conceptualised exercise facilities. Secondly, health geography was critical in measuring access to exercise facilities for the population. Finally, epidemiology, and more specifically social epidemiology, was used as a methodological approach to explore the impact of the environment on population health, taking a social justice perspective and exploring possible differences. This multidisciplinary approach contributes to a broader understanding of how physical activity and related infrastructure impact health inequities in the burden of T2DM.

Structure of the PhD thesis

This thesis is organised into eight chapters. **Chapter 1** corresponds to the present introduction. **Chapter 2** introduces a comprehensive literature review on the thesis topic based on the scientific evidence published, as well as a discussion of the current gaps in knowledge. **Chapter 3** presents the hypothesis, objectives, and specific aims of the thesis. **Chapter 4** contains an overview of the methods and data used in the thesis. **Chapters 5-7** are stand-alone research articles published in peer-reviewed journals. **Chapter 5** (Study 1) describes the social patterning of the distribution of exercise facilities in the city of Madrid, Spain from an equity perspective. **Chapter 6** (Study 2) explores the association between exercise facility availability and prevalence of obesity and T2DM in the Madrid adult population, as well as the effect modification of SES. **Chapter 7** (Study 3) shows the longitudinal effect of exercise facilities availability on the incidence of T2DM, and macrovascular and microvascular complications in the Madrid adult population. **Chapter 8** summarises the main results of the empirical studies and discusses the potential contributions to research and policy, alongside the strengths and limitations of this research and future lines of inquiry. Lastly, **Chapter 9** provides the final conclusions drawn from the entire thesis.

Figure 1. Structure of the PhD thesis and contributions of the scientific fields involved



Delimitations of the thesis

Like any scientific study, the definition of the objectives and hypotheses, together with the variables and available data, establish boundaries. First, the focus of this research was exercise facilities because, as already argued, they can influence moderate and vigorous leisure-time physical activity engagement, which is strongly associated with health outcomes. Second, the study population was based on the health outcomes of interest (i.e. T2DM and cardiovascular diseases). Consequently, following screening criteria for cardiovascular risk factors, the population was restricted to people aged between 40 and 75 years old at baseline to coincide when cardiovascular diseases and T2DM screening begins in Madrid. Third, the studies utilised quantitative methodologies that prevent us knowing the perception the population has of the exercise facilities alongside any barriers or preferences related to access could not be explored since that can only be answered from qualitative approaches.

Finally, one additional delimitation to note is the lack of information on the utilisation of exercise facilities by the population, which hinders our ability to understand the direct impact of facility availability on residents' health outcomes through increased physical activity levels. However, there is evidence suggesting that a higher availability of exercise facilities is associated with increased usage. Moreover, while our thesis does not provide information on the specific effects of exercise facility availability on residents' health outcomes through facility use, it does allow us to identify the overall impact of availability on health outcomes, including through increased access to various models of physical activity practice that promote the adoption of active lifestyles among residents, both within and outside of exercise facilities.

Study setting and context: The Heart Healthy Hoods Project

This thesis was undertaken under the umbrella of the Heart Healthy Hoods (HHH) project (www.hhhproject.es). The HHH, funded by the European Research Council, is a social epidemiology study that aims to study the association between the social and physical features of the urban environment and cardiovascular health in the municipality of Madrid (Franco et al., 2015). The HHH comprises four specific domains of urban environmental drivers: physical activity, food, tobacco and alcohol (Bilal et al., 2016).

Three complementary approaches were used to assess the four domains in the city of Madrid, Spain: inhabitant perceptions, geographic information systems and systematic social observation. This combination of different scientific strategies to assess the exposure of population health contributes to improving the understanding of the environmental drivers. Following the study goal, this environmental information collected was correlated with health data obtained from two different and complementary sources: first, a primary care-based cohort study; and second, a whole-population study including every citizen 40-75 years old using primary care Electronic Medical Records (EMR) (>99% coverage).

This thesis research expanded the HHH physical activity environment by examining exercise facilities as a component of urban physical activity, providing to the HHH Project evidence on the association of physical activity environment and diabetes related outcomes, alongside with a deeper knowledge related to specific exercise resources.

CHAPTER 2.

RESEARCH BACKGROUND AND FOUNDATION

2.1 Diabetes and the role of physical activity

2.1.1 Epidemiology of diabetes and public health significance: obesity, T2DM, and macrovascular and microvascular complications of diabetes

Diabetes mellitus is a major health concern worldwide. It is a leading cause of death with an estimated 2 million deaths directly caused by the disease annually (WHO, 2021b). Diabetes mellitus is a metabolic disorder with heterogenous aetiologies characterised by chronic hyperglycaemia and disturbances of carbohydrate, fat and protein metabolism resulting from defects in insulin secretion, insulin action, or both (WHO, 1999a). The diagnosis of diabetes mellitus is based on identifying the presence of hyperglycaemia. From the first report of the WHO in 1965 (WHO, 1965), to more recent international statements (Nathan et al., 2009; Sacks et al., 2011; WHO, 2011; WHO & IDF, 2006), the criteria for diabetes diagnosis must follow any of the following diagnostics: 1) an HbA1c (glycated haemoglobin) value ≥6.5% (48 mmol/mol); or 2) an FPG (fasting plasma glucose) value ≥7.0mmol/L (126 mg/dL); or 3) a 2-h post load glucose concentration ≥11.1 mmol/L (200 mg/dL) during an OGTT (oral glucose tolerance test); or 4) symptoms of diabetes and a casual plasma glucose concentration ≥11.1 mmol/L (200 mg/dL).

T2DM is the most common type of diabetes, representing 90% of all diabetes mellitus worldwide (IDF, 2021). It is caused by the inability of the body's cells to effectively use insulin (WHO, 2021a). The prevalence of T2DM is on the rise globally (see Figure 2) (Zhou et al., 2016), increasing by over 100% between 1990 and 2017 (Liu et al., 2020). However, this increase may be much higher due to the large number of undiagnosed T2DM cases that, according to some reports (IDF, 2021), could reach as many as one-third to one-half of the world's adult population. As shown in Figure 2, T2DM cases have risen dramatically in Spain, where the prevalence increased by 84% between 1993 and 2020 (Ministerio de Sanidad, 2020), with a higher increase in cases evident in men (159.18%). Other international reports have reported more alarming Spanish trend data. For example, the IDF Diabetes Atlas, shows Spain has the second highest age-adjusted diabetes prevalence in Europe for 2021, reaching 10.3% (IDF, 2021).

Figure 2. T2DM trends in the Spanish adult population (1993-2020)

Source: National Health Survey, 1993, 1995, 1997, 2001, 2003, 2006 and 2011, MSSSI/INE. European Health Survey in Spain, 2009 and 2014, INE/MSSSI. Extracted from INCLASNS (17/10/2022)
Observations: The data prior to 2011 refer to the population aged 16 and over. The results are inferred from the general population (weighted results).

The direct economic burden of disease costs of T2DM have been quantified in Spain as 5,809 million euros annually with indirect costs at 2,800 million euros, together comprising 8.2% of the annual national health budget (FED, 2021). Indeed, Spain is among 10 countries in the world with the highest total health expenditure related to T2DM in 2021 in adults (aged 20-79 years) (IDF, 2021).

T2DM burden refers not only to T2DM itself but also to other health conditions related to the disease. Excess body weight is one of the main risk factors of T2DM and several microvascular and macrovascular complications of T2DM such as cardiac ischemia, stroke or peripheral vascular disease, are relevant health variables when examining T2DM population health burden.

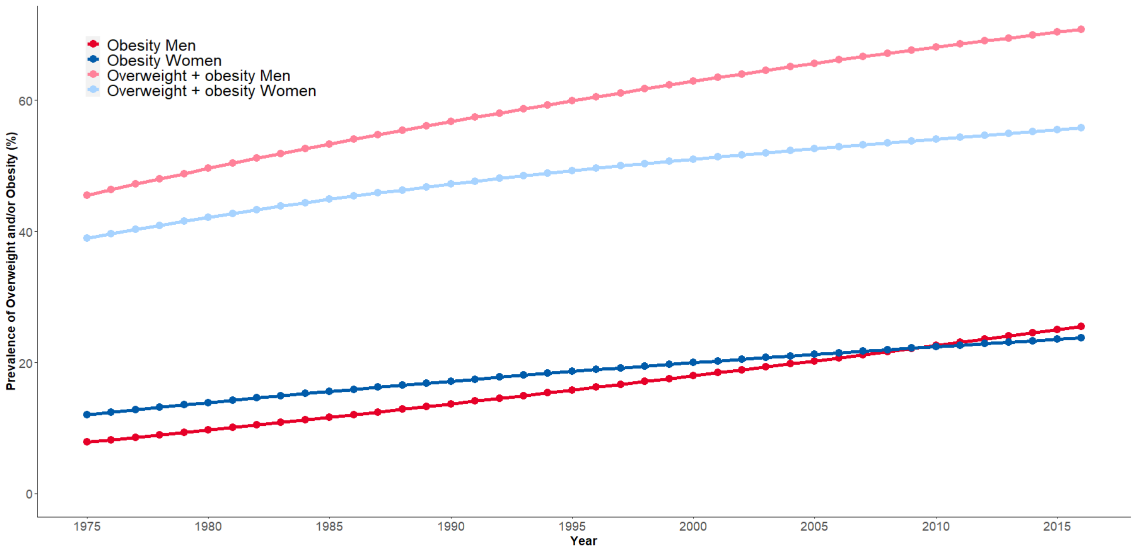
Overweight and obesity: a main risk factor of T2DM

Overweight and obesity are defined as excessive abnormal fat accumulation that may impair health, causing several chronic diseases and reducing life expectancy (WHO, 1999b). At the population-level, overweight and obesity are assessed using body mass index (BMI), a measure based on anthropometry, calculated by dividing body mass in kilograms (kg) over the square of height in meters (m^2) (WHO, 1995). In adults (for both women and men) overweight is stated when BMI is above 25 kg/m^2, and obesity is when

BMI is above 30 kg/m^2. Moreover, obesity is classified based on grades of severity: obese class I (BMI 30-34.9 kg/m2), obese class II (BMI 35.5-39.9 kg/m2), and obese class III (BMI ≥ 40) (WHO, 1995).

Obesity is considered the most important risk factor for many non-communicable diseases, including T2DM (WHO, 1999b), and one of the largest contributors to poor health in most countries, becoming a critical public health challenge worldwide (Di Cesare et al., 2016; Swinburn et al., 2019). The evolution of obesity and overweight is present in Europe, with country level disparities evident. Berghöfer et al. (2008) conducted a systematic review of the national and regional surveys conducted between 1990 and 2008, showing that countries from southern and eastern Europe have a higher prevalence of obesity, compared with western and northern European countries. Figure 3 shows the increasing trend of the prevalence of obesity in Spain between 1975 and 2016, which has risen by 224% for men and 97% for women (Bentham et al., 2017). Likewise, the overweight prevalence trend (including obesity) has been dramatically increasing, with a 56% increase for men and 43% for women, reaching a prevalence of 71% and 56% respectively in 2016.

Figure 3. Overweight and obesity trends in the Spanish adult population (1993-2020)



Source: Non-communicable Disease Risk Factor Collaboration (NCD-RisC). Extracted from https://ncdrisc.org/data-downloads.html (18/10/2022)

The burden of obesity and overweight for a society is not only related to poorer health-related quality of life (Anandacoomarasamy et al., 2009) but also to the economic burden that is compromising health care systems globally (Wang et al., 2011; Withrow

& Alter, 2010). According to the systematic review conducted by Withrow & Alter (2010), the direct costs of obesity treatment account for between 0.7% and 2.6% of a country's total national health care expenditures. Additionally, obesity increases the economic burden for societies through lost productivity and excessive absenteeism (Ananthapavan et al., 2014; Levy et al., 2010; Renehan & Buchan, 2014). A recent global study (Okunogbe et al., 2021) quantified that the costs related to obesity and overweight in Spain amount to more than 29 billion US$ in 2019, growing by 211% until 2060 to be equivalent to 2.4% of Spanish Gross Domestic Product (GDP).

Microvascular and macrovascular complications of T2DM

People living with T2DM are exposed to several health complications associated with poor control of the insulin deficit. The harmful effects of hyperglycaemia are generally classified into macrovascular and microvascular complications (Fowler, 2011).

The macrovascular complications of T2DM are cardiac ischemia and stroke. Both health events occur when the blood flow to the heart is cut off, due to a thrombus caused by ruptured atherosclerotic plaque that decreases the supply of oxygen and nutrients, which is called atherosclerosis. When this pathological process occurs in the coronary artery, it can cause cardiac ischemia; and if it develops in the brain, can trigger a stroke (Mendis et al., 2011). Cardiac ischemia is the leading cause of death globally, with 8.9 million deaths in 2019, followed by stroke with 6.2 million deaths in 2019 (WHO, 2020a). This trend is consistent in Spain, where cardiac ischemia and stroke were the two most common causes of death in 2019 (WHO, 2020a).

Retinopathy (disease of the retina), nephropathy (chronic kidney disease), and peripheral vascular disease are common microvascular complications of T2DM (Fowler, 2011; IDF, 2021). Diabetic retinopathy develops from osmotic stress from sorbitol accumulation, which is caused by higher glucose levels (Fowler, 2011). Diabetic nephropathy is preceded by lower degrees of microalbuminuria and, without intervention, people with T2DM could progress to proteinuria and overt diabetes nephropathy, also known as chronic kidney disease (Fowler, 2011). Finally, peripheral vascular disease is mainly caused by atherosclerosis. But, in this case, the reduction in blood supply occurs in arteries leading to areas other than the brain and heart, typically the legs and feet (Criqui et al., 2021).

Some have estimated a total direct cost of 57.74 million euros for macrovascular complications of diabetes and 579.79 million euros for microvascular complications (Lopez-Bastida et al., 2013) for Spain. Among patients with diabetes, those who develop cardiac ischemia represent an economic cost of more than double (US$16,872) that of T2DM patients without cardiovascular complications (US$8,066), and the increase for those patients with diabetes who develop a stroke is even greater (US$13,460) than those without cardio vascular disease (CVD) complications (Einarson et al., 2018).

2.1.2 Physical activity and exercise for prevention and control of T2DM and associated diseases

Physical activity: understanding physical activity assessment

Physical activity is defined as any bodily movement produced by skeletal muscles that result in energy expenditure (Caspersen et al., 1985). In order to understand physical activity, we must know the four dimensions that compose it, which are: (1) mode or type of activity, (2) frequency of performing the activity, (3) duration of performing the activity, and (4) intensity of performing an activity (Strath et al., 2013) (see Table 1). Generally, in public health research, physical activity is assessed according to three dimensions: frequency, duration (volume), and intensity. Frequency refers to how often the physical activity is accomplished and is usually measured in days per week. Duration is the amount of time spent performing physical activity and is usually quantified in minutes per week or minutes per session. Intensity relates to the amount of energy expended during the activity and is measured using Metabolic Equivalent of Task (MET). One MET is defined as 1 kcal/kg/hour and is roughly equivalent to the energy cost of sitting quietly. A MET also is defined as oxygen uptake in ml/kg/min with one MET equal to the oxygen cost of sitting quietly, equivalent to 3.5 ml/kg/min (Ainsworth et al., 2011).

Table 1. The four dimensions of physical activity for public health research

Dimensions of physical activity for public health research (Strath et al., 2013)		
Physical activity dimensions	**Definition and context**	**Examples**
Mode	Specific activity performed, as well as the context of physiological and biomechanical demands/types.	Walking Aerobic vs Anaerobic
Frequency	Number of sessions per day or week. In the context of health-promoting physical activity, frequency is often quantified as number of sessions.	Sessions per week Days of activity per week
Duration	Time of the activity bout during a specified time frame.	Min/Week Min/Session
Intensity	Rate of energy expenditure. Intensity is an indicator of the metabolic demand of an activity. It can be objectively quantified with physiological measures, subjectively assessed by perceptual characteristics, or quantified by body movement	METs/min/week Oxygen consumption Perceived exertion rate 3D body accelerations

The WHO physical activity guidelines (WHO, 2020b) recommends that adults should undertake at least 150–300 minutes of moderate-intensity aerobic physical activity (3-6 METs); or at least 75–150 minutes of vigorous-intensity aerobic physical activity (>6 METs); or an equivalent combination of moderate- and vigorous-intensity activity throughout the week, for substantial health benefits. And, for additional health benefits, the WHO (2020b) recommends increasing moderate-intensity aerobic physical activity to more than 300 minutes; or doing more than 150 minutes of vigorous-intensity aerobic physical activity; or an equivalent combination of moderate- and vigorous-intensity activity throughout the week.

Where physical activity occurs is central to understanding physical activity for public research purposes, as domains are strongly linked with the purpose of the activity. The four common domains applied in the literature are: occupational (work-related), domestic (housework, yard work, physically active childcare, chores), transportation (walking or bicycling to go somewhere) and leisure-time (discretionary or recreational time for hobbies, sports, and exercise) (see Table 2). Physical activity practice in leisure time is the one that typically produces the best health effects since it is associated with behaviour change as the intended goal. For instance, a meta-analysis carried out by

Samitz et al. (2011) has shown that leisure-time physical activity was the domain with the greatest reduction for all-cause mortality by unit of time. Table 2 describes the four domains with definitions and examples.

Table 2. Domains of physical activity for public health research

Domains of physical activity for public health research

Physical activity domains	Definition and context	Examples
Occupational	Work-related activities imply energy expenditure	Walking, carrying objects
Domestic	Daily-life domestic activities	Childcare, housework, chores, yard work
Transport	Purpose of going somewhere	Walking, bicycling, standing, climbing/descending stairs
Leisure Time	Discretionary or recreational activities	Running, play basketball, weight training, spinning...

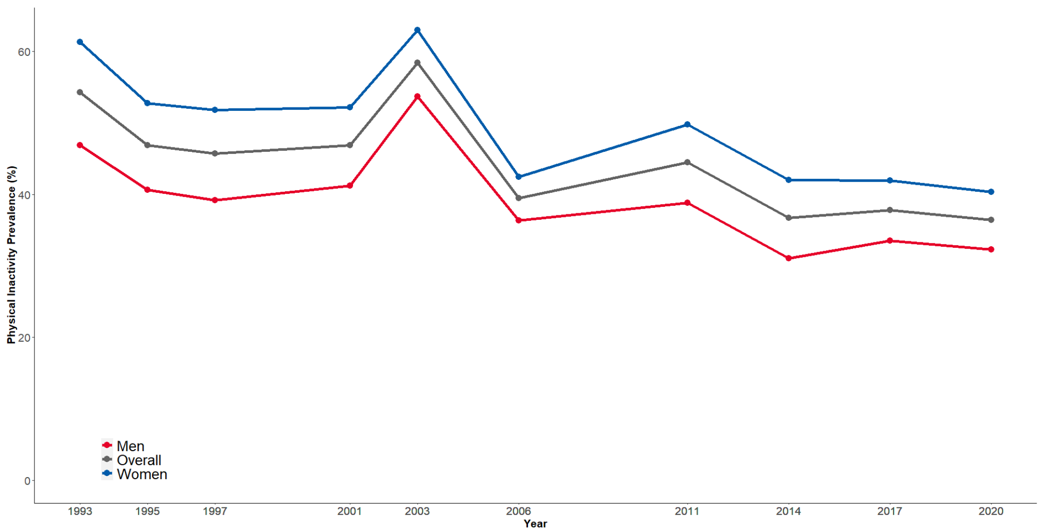
Exercise as the best application to health improvement

Physical activity is a key activity for improving health (Warburton & Bredin, 2017). Specifically, it has been highlighted as an important strategy for obesity control and prevention (Hemmingsson & Ekelund, 2007; Jensen et al., 2014), T2DM risk reduction (Gillies et al., 2007; Kriska et al., 2021), T2DM control (Colberg et al., 2016; Colberg & Swain, 2000; Sigal et al., 2004), and cardiovascular disease prevention (Thijssen et al., 2018). Exercise is physical activity that is planned, structured, repetitive and purposive with the objective of improving or maintaining one or more components of physical fitness (Caspersen et al., 1985). Although many types of physical activity generate important health benefits, numerous studies highlight exercise as the best form to improve health since it is associated with higher-intensity activities that entail a higher metabolic expenditure (Ainsworth et al., 2011; Blair et al., 2001; Lear et al., 2017). Furthermore, physical activity is a free leisure-time activity, whilst exercise which usually supervised, is associated with better effectiveness on health improvement (Colberg et al., 2016; Garber et al., 2011), with greater effects on reduction of obesity risk (Innes et al., 2019), T2DM risk and control (Gajanand et al., 2020; Umpierre, 2011), and cardiovascular diseases (Hunter et al., 2020).

2.1.3 Epidemiology of physical activity

Physical inactivity is a major global public health concern. In 2016 the global age-standardised prevalence of insufficient physical activity was 27.5% (Guthold et al., 2018). Currently, global physical inactivity and sedentarism cause 3.2 million deaths annually, predominantly through chronic diseases, especially cardiovascular diseases (F. W. Booth et al., 2012; Chau et al., 2012; Unick et al., 2017; WHO, 2014). A recent study estimated that 499.2 million new cases of preventable major NCDs would occur globally by 2030 if the prevalence of physical inactivity does not change, with direct healthcare costs of $520 billion (Santos et al., 2023). In Europe, 36.2% of adult residents were physically inactive, with the highest proportion in Southern Europe countries (Nikitara et al., 2020). Similar data have been reported for the Spanish population (see Figure 4).

Figure 4. Physical inactivity trends in the Spanish adult population (1993-2020)



Source: National Health Survey, 1993, 1995, 1997, 2001, 2003, 2006 and 2011, MSSSI/INE. European Health Survey in Spain, 2009 and 2014, INE/MSSSI. Extracted from INCLASNS (17/10/2022).
Observations: The data prior to 2011 refer to population of 16 and over. In 2003 and 2006 the change in the formulation of the question should be taken into account to interpret the results.
The results are inferred to the general population (weighted results).

According to the Survey of Sports Practice in Spain (Consejo Superior de Deportes, 2021), 40.4% of Spaniards did not engage in physical activity in 2020, with greater sedentariness among women (46.1%) than men (34.5%). The prevalence of sedentary lifestyles increases with age. For example, 24.3% of 25–34-year-olds, 29.5% of 35–44-year-olds, 37.8% of 45–54-year-olds, and 58.7% of >55-year-olds were sedentary in Spain. Moreover, physical inactivity in Spain follows a social gradient. A higher prevalence of sedentarism is found among people with lower educational levels (56.2%) compared with those with higher educational levels (26.5%) (Consejo Superior de Deportes, 2021).

2.2. Population prevention approach

2.2.1 Individual versus high-risk population prevention approach

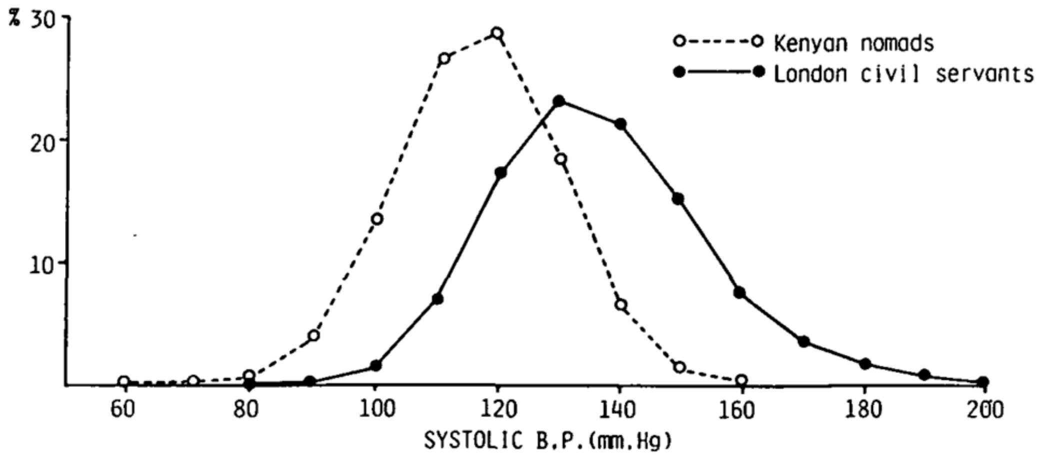
Historically, prevention strategies to tackle physical inactivity have centred on changing individual behaviours. However, over the last few decades, researchers, health professionals and policymakers have paid more attention to generating knowledge about more upstream approaches that might lead to more favourable outcomes, such as through acting on the social determinants of health. According to Geoffrey Rose (1985), to understand the disease aetiology we have to consider two different levels:

- The determinants of individual cases (e.g. why this person is obese?). Usually, most epidemiological studies look for these 'risk factors' of disease, focusing on the individual behaviours to identify an explanation (e.g. this person might be obese because of not getting enough physical activity).
- The determinants of population incidence rate (e.g. why there are so many people obese in my region while in other areas it is rare?). From this approach, the strategy is focused on the determinants of the population mean; it is a shift of the whole distribution (a mass influence) acting on the population (e.g. access to physical activity destinations, or different food systems).

These two different approaches are seen in the example that Geoffrey Rose wrote in his article *'Sick individuals, sick populations'* (Rose, 1985). If we used the individual approach, we could fully understand the cause of the differences between individuals', and they would be very similar in the two cases: a main reason based on genetic variability and a secondary one related to environmental factors and behaviours. However, this approach would prevent us from seeing the main question: why does hypertension not exist in Kenya and is it so common in London?

In this article Rose tells us that we must approach it from a population perspective, since the difference between the two groups is not found in the individual measurements but in a displacement of the sample. Rose argued that what makes two London civil servants differ in their systolic blood pressure (for example, different behaviours related to salt intake) may be different from what makes the average systolic blood pressure in London higher than the average blood pressure of Kenyan nomads (e.g. different transportation behaviours) (see Figure 5). This is a cornerstone to bear in mind for diabetes-related prevention approaches (Hill-Briggs et al., 2021).

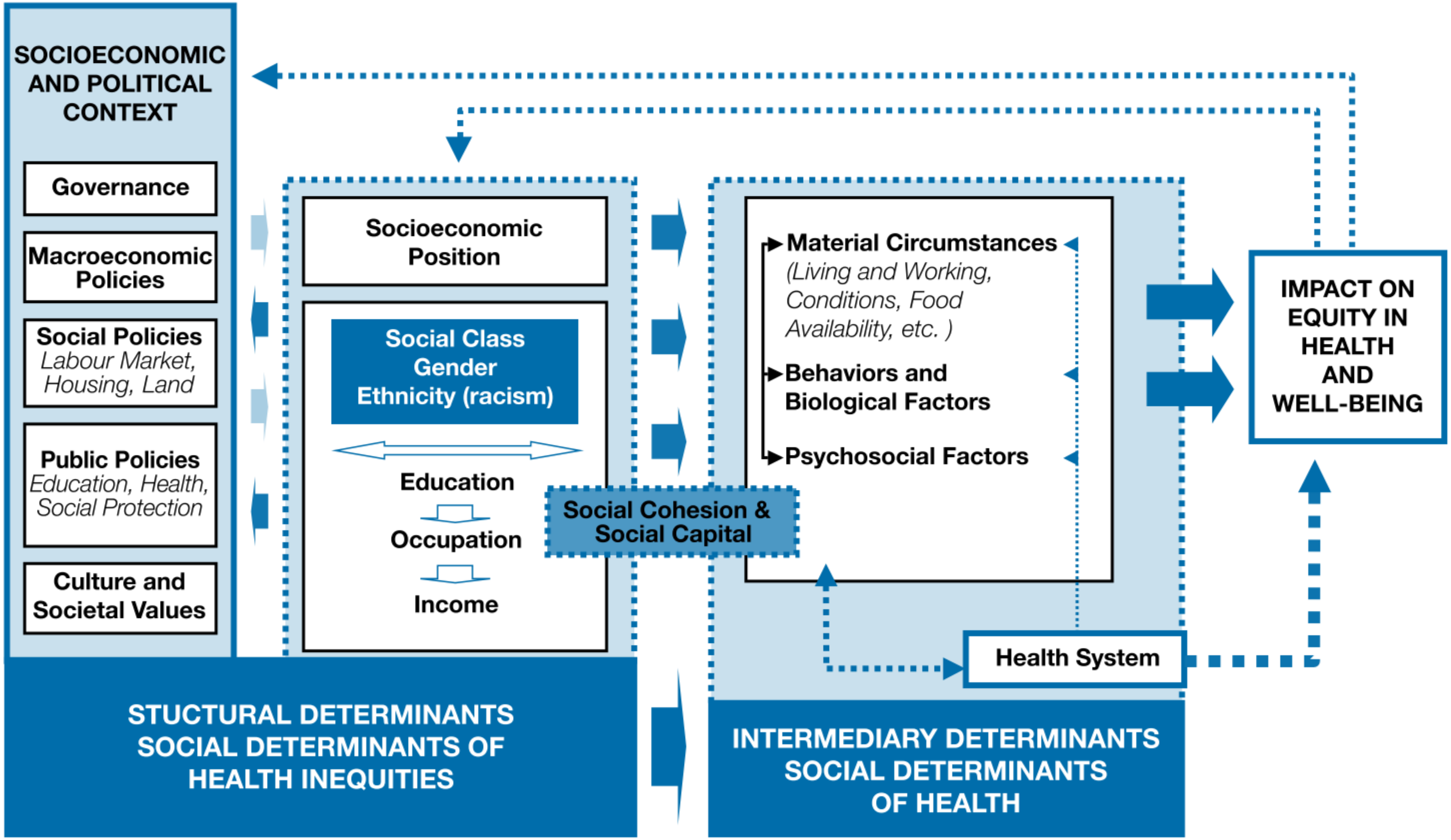
Figure 5. Distribution of systolic blood pressure in middle-aged men in Kenya and London city servants (Rose, 1985)



2.2.2 Social determinants of health

The WHO defines the social determinants of health as *'the conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life'* (Commission on Social Determinants of Health, 2008), and their influence is widely acknowledged in the scientific literature (Diez Roux, 2012; Marmot, 2005; Marmot & Bell, 2019). Likewise, in the approach to population health from a social justice perspective the difference between equality and equity must be emphasised. While both concepts promote fairness, implementation of one versus the other may lead to undesirable results for the most deprived populations. The WHO defines health inequalities as differences in health status or in the distribution of health determinants between different population groups. Health inequalities could occur due to different causes, including biological variations or free choice. However, health inequities refer to unnecessary, avoidable as well as unjust and unfair differences. Health inequities are attributable to the context primarily outside the control of the individual, such as the social determinants of health (Badland & Pearce, 2019; Solar & Irwin, 2010; WHO, 2010). The conceptual framework of the Commission on Social Determinants of Health summarises how all of these determinants affect population health (see Figure 6) (Solar & Irwin, 2010).

Figure 6. The conceptual framework of the Commission on Social Determinants of Health (Solar & Irwin, 2010)



Overall, numerous studies have shown an association between SES and physical activity (Ball, Carver, Downing, et al., 2015; Bauman et al., 2012; Beenackers et al., 2012; Kelly et al., 2006; Ombrellaro et al., 2018), excess body weight (Mayor, 2017; McLaren, 2007; Mohammed et al., 2019), T2DM (Bird et al., 2015; Hill-Briggs et al., 2021; Hwang & Shon, 2014; Kim et al., 2015), and cardiovascular diseases (Manrique-Garcia et al., 2011; McFadden et al., 2008; Safford et al., 2012). Typically, this evidence shows that the lower the SES of a person (i.e. more disadvantaged), the lower their physical activity levels and the higher prevalence of excess body weight, T2DM, and cardiovascular diseases.

This social gradient shows a relationship between socioeconomic position and health outcomes through disparities in physical activity and excess body weight. These disparities in population health, caused by social factors, are known as health inequities and must be addressed as they are unfair and preventable (Braveman, 2014). However, these social factors do not act independently, but intersect and interact on multiple levels to condition individual health outcomes. There are significant health inequities that need to be addressed, whatever the underlying processes driving these differences may be (Diez Roux, 2022). Social epidemiology seeks to identify and quantify the mechanisms behind these social determinants of health and inequities, to describe and infer large-scale social causality. Causality in this context relates to the set of contextual (e.g. public policies, cultural and social values…), socioeconomic (e.g. social class, gender…), physical (e.g. access to exercise facilities, land use…) and social (e.g. safety and violence, social cohesion…) determinants that condition the ability of individuals to lead an active lifestyle (Commission on Social Determinants of Health, 2008; Diez Roux et al., 2016) and achieve the physical activity recommendations (WHO, 2020b). From this approach, the way cities are designed, and their social and built elements, are a fundamental framework for addressing the social determinants of health.

2.3 Influence of urban built environment on the population health

The United Nations (UN) estimates that more than half of the world's population lives in urban settlements and this will increase 68% by 2050 (United Nations, 2018). This increase in urbanisation offers an opportunity for the government, private sector, and civil society to create more liveable cities and neighbourhoods that promote equity and healthy environments (Badland & Pearce, 2019; UN Department of Economic and Social Affairs/Population Division, 2018). Indeed, this ambition has been expressed through the UN Sustainable Development Goals (United Nations (2015) and, following this stream, the interest in neighbourhoods and health has been driven by an increasing interest on social inequities on health within public health and epidemiology, together with an growing urban health research uncovering new methodological challenges and research gaps outlining new directions (Diez Roux & Mair, 2010).

Over the last decades, science has been increasingly looking to social determinants, such as those in the neighbourhood, to identify the triggers of many non-communicable diseases. This evidence has revealed that place of residence is strongly patterned by the socioeconomic position of populations (Diez Roux, 2007), shaping a relevant number of variables that exert a great influence on health. The study of all these health determinants from urban health research provides a unique opportunity to build a comprehensive place-based resource investigation through the holistic connection between health and social and built environment, providing a better understanding of the 'system as a whole' (Badland & Pearce, 2019; Diez Roux et al., 2016). These invaluable insights enable the development of population-level strategies for addressing physical inactivity, T2DM, obesity and other chronic diseases (Anette et al., 2014; Brownson et al., 2006; National Institute of Healthcare and Excellence, 2011; Sallis et al., 1998; Zenk et al., 2019).

As stated before, the characteristics of the residential environment is one of the main social determinants of health (Ball, Carver, Jackson, et al., 2015; Diez Roux et al., 2016; Marmot & Bell, 2019). Epidemiology has searched in the environment for potential explanations for the changes in different health outcomes of populations (Bilal et al., 2018; Hill-Briggs et al., 2021). Among all of them, built environment is a key determinant to explain variations on physical activity participation between urban populations, as well as other health outcomes such as obesity or cardiovascular diseases (Coombes et al., 2010; Coutts et al., 2013; Gordon-Larsen et al., 2006; Hanibuchi et al., 2011; Kaufman et al., 2019a; Sallis et al., 1990, 2012; Van Cauwenberg et al., 2018). However, the differences between physical activity resources require an in-depth analysis of both their characteristics and the differential effect on health.

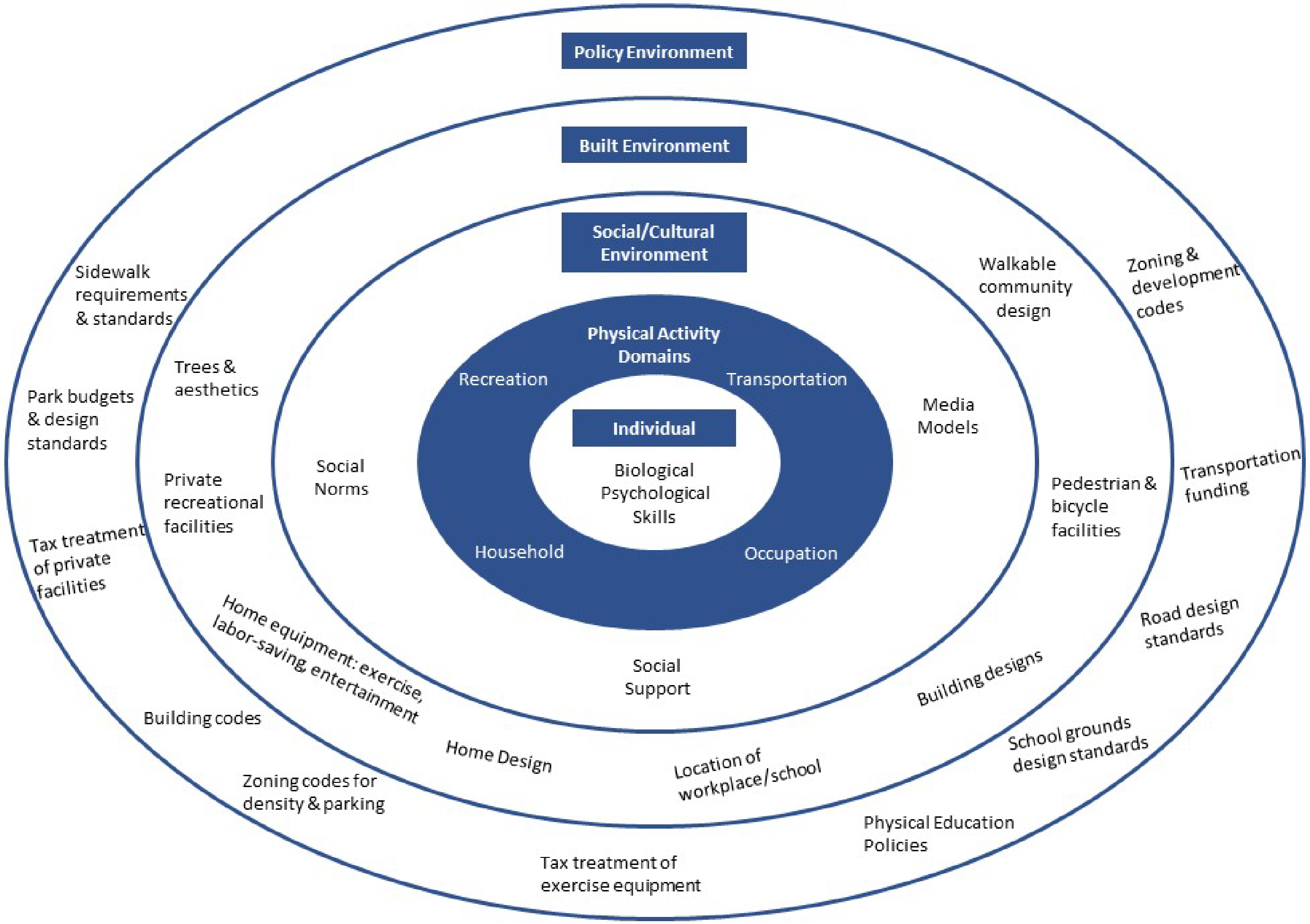
2.3.1 Urban destinations for physical activity: exercise facilities and their relevance on access to physical activity to improve health status

The socio-ecological framework of physical activity in urban settings

The most successful public health interventions have been based on an understanding of health behaviours and the contexts in which they occur (Glanz et al., 2002). The socio-ecological approach emphasises that health promotion should focus not only on intrapersonal behavioural factors but also on multiple-level interacting factors. The social-ecological approach goes beyond behavioural and environmental change strategies by offering a theoretical framework for understanding the dynamic interplay among persons, groups, and their psychophysical milieus (Stokols, 1996).

In earlier research, Sallis et al. (2012) analysed the determinants of the urban built environment and its influence on obesity, physical activity, and cardiovascular disease from a socioecological approach. Following their framework (see Figure 7), exercise facilities were a relevant feature of the environment, even more so, due to their interaction with the physical activity domain. According to this framework, it is beneficial to studying the characteristics of the physical activity resources available within cities and neighbourhoods, as well as correctly framing the domain of physical activity to identify the appropriate setting.

Figure 7. An ecological model of four domains of physical activity (modified from Sallis et al., 2012)



Urban destinations for physical activity

The urban environment provides different destinations for physical activity engagement, and the study of their differences and peculiarities is crucial to obtain a correct approach to tackle health disparities in their populations (see Table 3). Streets are circumstantial providers of physical activity through active transport (Sugiyama et al., 2012). Walkability commonly considers the combination of street connectivity, land use mix and residential density - referred to as the 3Ds of walkability (density, diversity and design) (Cervero & Kockelman, 1997). Walkability has been associated with transport-related physical activity and light intensity physical activity (Hajna et al., 2015). However, although it is not their primary function, streets can also be used for exercise purposes (e.g., jogging, running, etc).

Urban parks have been studied as a pathway between green spaces and physical activity within cities (Fontán-Vela et al., 2022). Urban parks are relevant urban providers of physical activity (James et al., 2015). However, since physical activity engagement is not its main objective, their design does not usually have resources for the practice of physical exercise, and they lack personnel and information for adequate and safe practice.

Among the urban resources for physical activity, there are a broad group of destinations that are often aggregated to "physical activity facilities". Generally, this term is used to identify destinations that have been built specifically for the practice of physical activity in the cities. However, under this term, there is variation among the different types of facilities that influence the practice of physical activity and, even more so, exercise. Generally, physical activity facilities are classified into two groups: one related to informal physical activity facilities, and another group composed of more formal facilities that offer exercise programs and services. The first group are spaces built and designed for the practice of physical activity, and their use is restricted to that. However, these spaces are associated with free practice, generally associated with sports practice, especially team sports (e.g. football, basketball, etc.). This makes access to practice highly dependent on the social capital of the individual and his community, which is associated with SES and generates great inequality between populations (Baladastian et al., 2021).

Table 3. Characteristics of urban destinations for physical activity

Urban destinations for physical activity	
Urban resources	**Characteristics**
Streets	Are not designed for physical activity practice. Associated with light physical activity. Physical activity due to active transport.
Parks and green spaces	Relevant space for practice of physical activity, but it is not its main use. Are not designed primarily for exercise. Unsupervised physical activity.
Open sport courts	Designed specifically for physical activity. Free practice, without supervision. Related to sports practice, heavily dependent on social capital.
Exercise Facilities	Greater provider of structured MVPA. Exclusive use for exercise. Supervised activity by trainers.

Finally, among the physical activity facilities, there are certain resources that can be defined as indoor facilities, both public and private, which offer physical activity programs, either with a monthly subscription and/or pay per session (e.g. gyms, fitness centres, recreation centres). This type of facility (exercise facilities) provides a place that allows for physical activities that are related to exercise. Hence, physical activity that is a form of exercise is that which is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective (Caspersen et al., 1985). In addition to tending to be structured, exercise also implies that there is a higher metabolic cost (Ainsworth et al., 2011), which produces greater health benefits compared with other activities that imply a lower metabolic cost and/or without planification and/or supervision (e.g. walking, running) (Blair et al., 2001; Lear et al., 2017). Additionally, exercise facilities have staff trained in exercise theory to advise and plan users' training; this has been associated with greater improvements in cardiometabolic health (Hunter et al., 2020). Despite this, relatively little research has examined the distribution of access to and availability of exercise facilities, such as gyms or swimming pools, by SES (Mason et al., 2018).

2.3.2 Assessing the spatial accessibility of exercise facilities

The concept of access in public health research

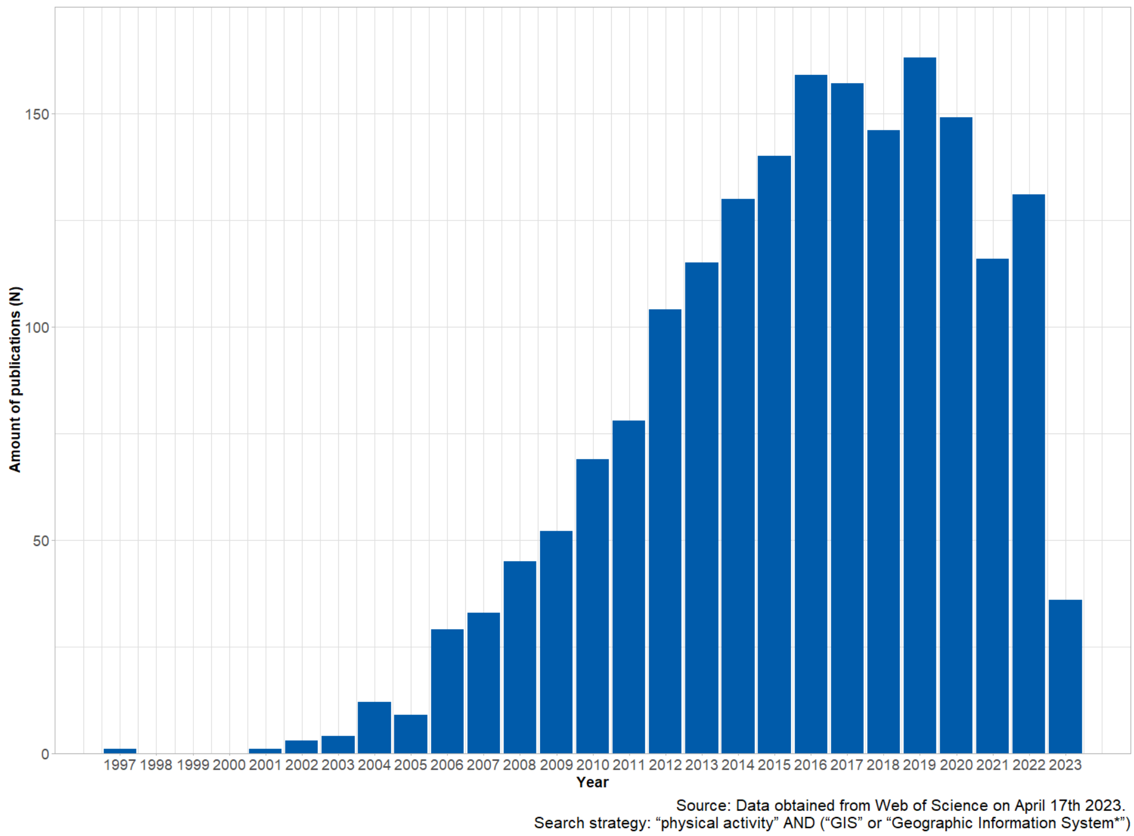
Health geography has important cross overs with urban health research, spatial epidemiology and public health. For the purposes of urban health and the evaluation of the impact of the environment on health, spatial accessibility is a fundamental element that has been widely discussed (Apparicio et al., 2017). Accessibility has been defined in various ways (Geurs & Ritsema van Eck, 2001) however, several geography scholars have described two different dimensions of access, that have not been habitually distinguished leading to certain confusions (Guagliardo, 2004; Khan, 1992; Luo & Wang, 2003): *spatial access*, which is related to the specific geographic measure of spatial/distance variable, as a barrier or a facilitator; and *aspatial access*, which is conditioned by social rather than geographical barriers/facilitators.

The Anderson model of the determinants of use described a set of variables related with need, predisposing factors and enabling factors (Andersen, 1968). Later, Penchansky & Thomas (1981) defined access as *“a concept representing the degree of "fit" between the clients and the system”* and, building on the Andersen model (Andersen, 1968), defined five more specific areas under the umbrella concept of access: *availability*, which is related to the supply of health services, including the number and type of existing services; *accessibility,* defined as the relationship between the location of supply and the location of people (considering transportation resources, travel time, distance and cost); *accommodation,* the relationship between how is organised the supply resources to accept people (e.g. appointment systems, hours of operation, walk-in facilities) and people’s capacity to accommodate to these factors along with the people' perception of their appropriateness; affordability, which refers to both the price of the services and the people's ability to respond to them, as well as the relationship with the people's perception of the value of the service; and *acceptability*, which refers to specific people reactions to such facility attributes (e.g. culture, values, gender and/or sex of the workers), as well as to providers willingness to serve certain populations.

Geographic Information systems software

Over the past few decades, there has been increasing emphasis on the importance of spatial factors in health research. The latest advancements in geospatial technologies have made it easier to obtain and share accurate data with precise geolocation (i.e. address) and timing information, which can be relevant to public health research. By analysing these data, researchers have gained new insights into the prevalence, transmission, and treatment of various diseases and related exposures (Richardson et al., 2013). In recent years, the use of Geographic Information Systems software (GIS) to study the access to physical activity in different environments has become increasingly popular in physical activity from a public health perspective. Figure 8 illustrates the rise in the number of publications using GIS in physical activity research.

Figure 8. Number of publications using GIS in physical activity research per year (Source: Web of Science. Data updated to April 17th, 2023)



In essence, GIS is a set of computer-based techniques, tools, and software that help with the creation, storage, management, organisation, analysis, visualisation, and sharing of spatial and thematic data gathered from various sources (Longley et al., 2005; Richardson et al., 2013). It is part of a broader group of geospatial resources, including remote sensing and others, that allow for the acquisition and examination of different environmental issues. These geospatial resources, especially GIS, enable the combination and integration of multiple interdisciplinary layers of spatial data, such as health, environmental, social, or demographic data, for interactive spatial analysis and modelling (Richardson et al., 2013).

Measuring exercise facility availability

Research on physical activity access and the effect on population health have shown inconsistencies on the conceptualisation of "access". First, quite a few studies evaluate access to sports facilities through self-perceived measures, which may result in inaccurate associations due to potential same source bias. For example, individuals with lower levels of physical activity may be predisposed to identify their environment as less conducive to physical activity, even if the urban environment itself is in good condition. Therefore, it is desirable to avoid environmental assessment based only on the self-perception of study participants and instead use objective assessment strategies.

In the investigation of the physical activity environment, different objective methods have been used to identify sports resources. Secondary databases have been the most used sources, such as national census of sports facilities (Pascual, Regidor, Arco, et al., 2013), or industry and business registers (Powell et al., 2006). However, the use of secondary databases prevents us from being able to correctly identify physical activity resources associated with specific types of physical activity (e.g. MVPA, supervised activity). Therefore, considering the differences in the effect on health based on the type of physical activity, is recommended to collect information on physical activity resources following pre-set specific criteria.

Second, is how to quantify the resources. Several studies define access as the number of facilities available per 1,000 population (Pascual, Regidor, Arco, et al., 2013), others as the number of facilities available at a range of distances around zip code (Powell et al., 2006) or residents' home (Hillsdon et al., 2007), or if the facilities were pay- or free-for-use (Estabrooks et al., 2003). Therefore, the study of the health impact of exercise facility availability from this geographical approach is a relevant gap in the published evidence.

Based on the definition of spatial access and availability from Penchansky & Thomas (1981), GIS provides us a rigorous solution through the definition of buffers around the households of the study subjects. The empirical evidence suggest that these buffers are best established 1,000 metres from the place of residence, since this is the distance people are most likely to walk to fulfil daily activities (Koohsari et al., 2015). This measure is even more meaningful for assessing the physical activity environment since has been demonstrated that 1,000 metres from home to an exercise facility is the distance with the highest correlation with MVPA (Eriksson et al., 2012) and has been widely used in the literature (Eriksson et al., 2012; Kaufman et al., 2019b; Mason et al., 2018).

2.4. Knowledge gaps

The research related to contextual factors associated with the T2DM burden in urban environments is growing. However, these studies are mostly conducted in Anglo-Saxon countries and cities, such as the United States, Australia, and the United Kingdom, and are largely lacking in southern Europe (Bilal et al., 2019) for example. Understanding sociocultural differences for physical activity participation among countries and regions is needed to strengthen placed-based evidence (Bottenburg et al., 2005).

Traditionally the physical activity environment has been studied as a homogenous set of destinations. 'Physical activity facilities' has been broad conceptualised to identify every urban resource that could provide physical activity to the population. Indeed, it is not uncommon to find both parks and physical activity and recreational facilities grouped together (Van Cauwenberg et al., 2018). However, there is growing evidence of the differential effect that different types of physical activity have on health (Blair et al., 2001; Lear et al., 2017).

Exercise facility information is commonly drawn from secondary databases, such as industry classifications or business registers, instead of following specific pre-determined criteria. Relatively little research has examined the distribution of exercise facilities and whether availability is associated with health disparities (Mason et al., 2018). More specifically the spatial distribution of exercise facilities in urban settings has not been objectively measured. Although it has been widely studied that the distribution of physical activity spaces (e.g. green spaces, parks, recreational facilities) is conditioned by variables related to the socioeconomic position of the residents, this hypothesis has not been tested with exercise facilities. To investigate how socioeconomic status could be associated with the access to and availability of exercise facilities may increase our understanding of the role of social inequities in access to exercise in urban settings. Specifically, we need to know more about how exercise facility availability is associated with obesity (risk factor), T2DM (disease), and cardiometabolic conditions in those with diabetes (complications) through high quality research designs.

In summary, empirical evidence on the exercise facility environment and its influence on population health are in its infancy, with several gaps to fill. This thesis seeks to contribute to this field of knowledge in several ways. First, by investigating the exercise facility patterning in Madrid. Second, providing exercise facility-specific evidence. Third, investigating the association between accurate exercise facility availability and a comprehensive burden of T2DM, comprising risk factors, T2DM itself, and its complications. And fourth, investigating, not only cross-sectional associations but also longitudinal relationships to provide stronger evidence of this causal pathway.

CHAPTER 3.

HYPOTHESIS AND OBJECTIVES

3.1 Hypothesis of the thesis

Living in areas with higher availability of exercise facilities is associated with higher levels of physical exercise. Hence, populations resident in these areas can be expected to have a lower prevalence and incidence of obesity, T2DM, and microvascular and macrovascular complications of diabetes. Likewise, area-level socioeconomic status and sex are relevant confounders in this association, modifying the effect of exercise facilities on the health of the population based on the deprivation of the resident population.

2.6 Thesis research question

The research question of this thesis is:

How does exercise facility availability help to reduce health inequities and flatten the social gradient of T2DM burden?

2.7 Specific aims of the thesis

1. Characterise the socio-spatial patterning of exercise facilities by investigating the associations between area- level socioeconomic status with access to and availability of different types of exercise facilities and its spatial distribution using the case study of Madrid.
2. To examine the association between the availability of exercise facilities and the likelihood of obesity and T2DM in the adult (40–75 years old) population of Madrid; and to examine interactions with area-level SES and sex.

3. To examine the association between exercise facility availability and T2DM incidence in the adult (40-75 years old) population of Madrid; examining effect measure modification by area-level SES and sex.
4. To examine the association between exercise facility availability and macrovascular (cardiac ischemia and/or stroke) and microvascular (chronic kidney disease, retinopathy, and/or peripheral vascular disease) complications in adults with T2DM, as well as the effect measure modification by area-level SES and sex.

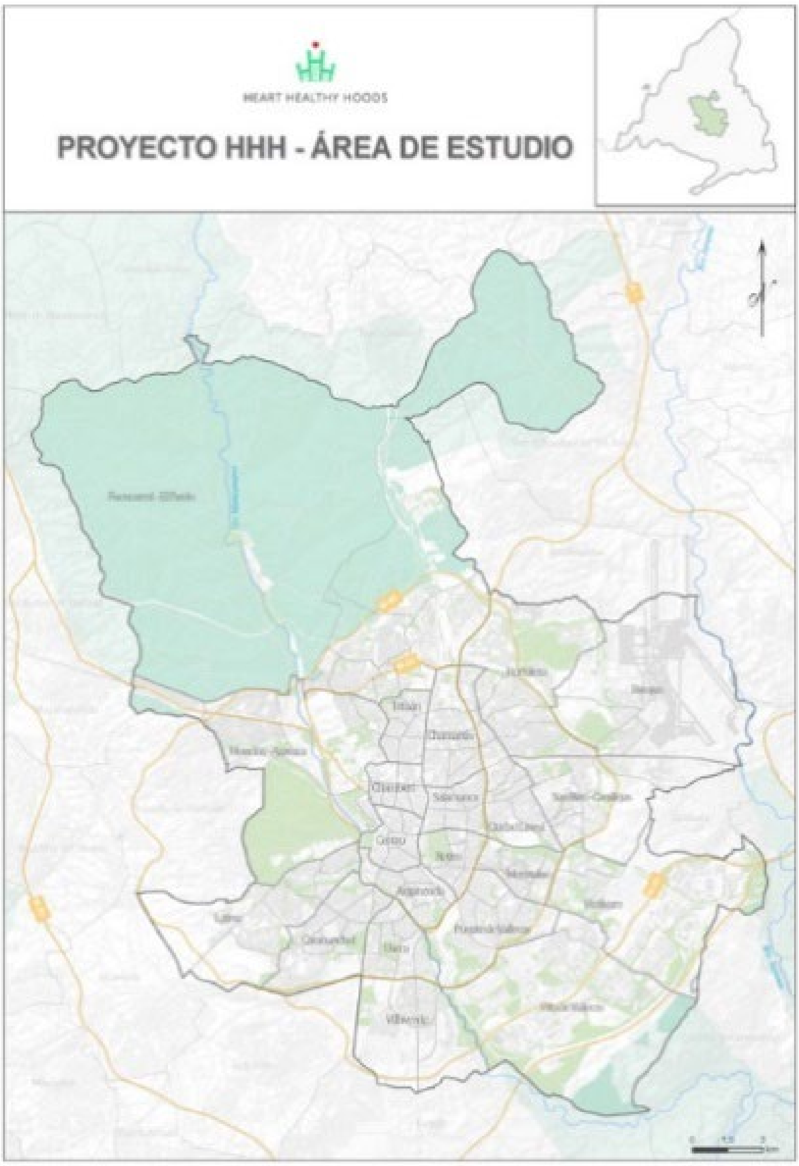
CHAPTER 4.

METHODS OVERVIEW

4.1 Study area

The study area comprises the municipality of Madrid (Figure 9). Madrid is the capital city and largest municipality of Spain. Approximately 7 million residents reside in the municipal area of Madrid (National Institute of Statistics, 2017), which is the third largest city in Europe after London and Paris. Madrid is divided into 21 districts that house 128 neighbourhoods. Within each neighbourhood, there are small geographical administrative units of approximately 1500 people each, called census sections (N = 2415) (INE, 2014).

Figure 9. Municipality of Madrid, Spain. The study area of the thesis



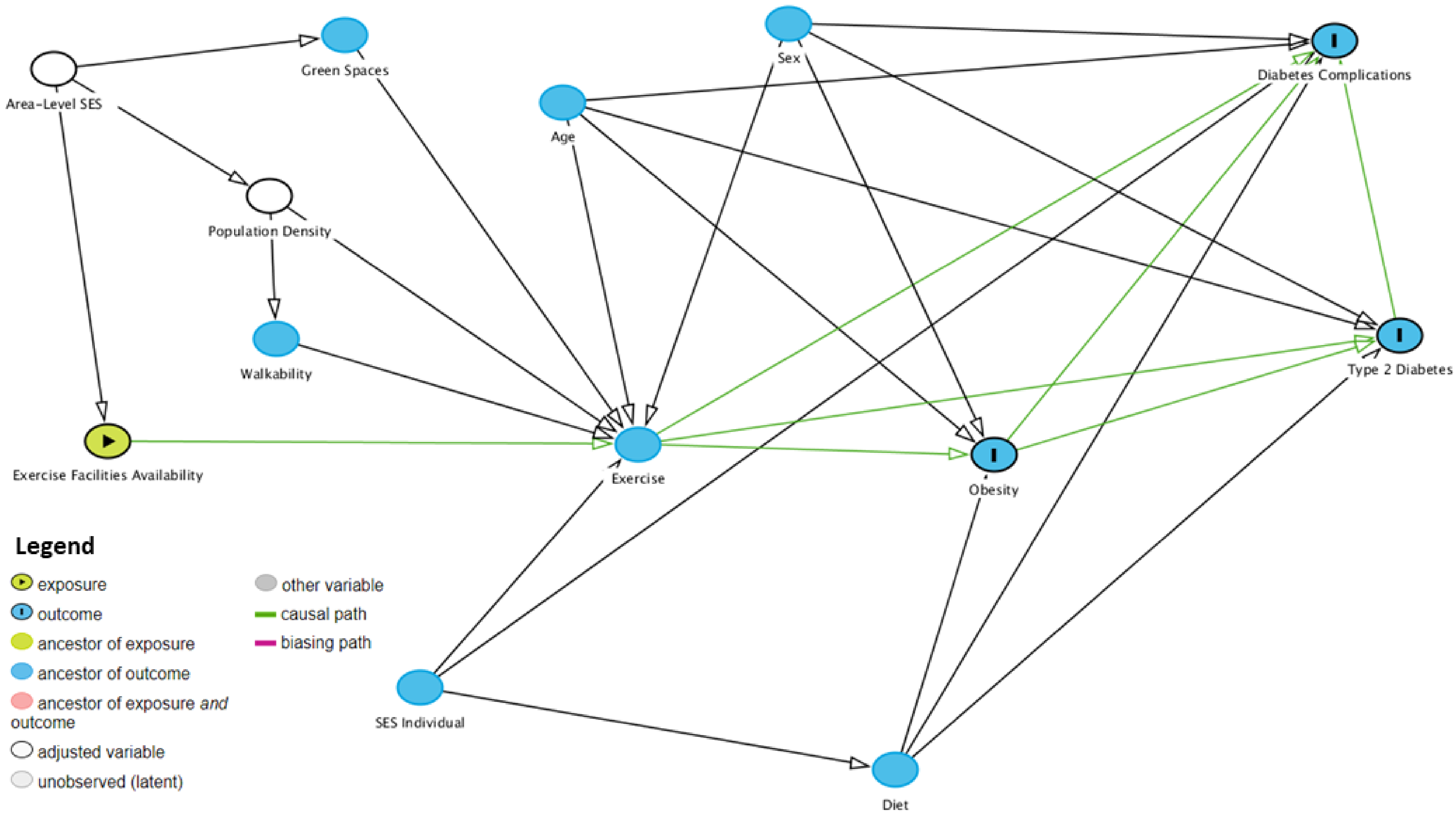
4.2 Ethics

This thesis was conducted under the umbrella of the HHH study and in accordance with the Declaration of Helsinki. The studies received Institutional Review Board (IRB) approval from the Ethics Research Committee of the Madrid Health Care System on May 12, 2015 (ERC-2013-StG-336893). The certificate can be consulted in the Appendix.

4.3 Variables and data sources

Below the variables, measures and data sources used in this thesis are briefly explained. Please note, the information contained in this Chapter is explained in detail within the three studies and their supplementary material that follow. A directed acyclic graph exploring the potential causal associations in this thesis research is displayed in Figure 13.

Figure 10. Directed Acyclic Graph of variables and analysis used the thesis



Exercise facility availability

Exercise facility definition and database

Exercise facilities were defined as those built resources, both public and private, which offered physical activity programs, both with monthly subscriptions or pay per session (Cereijo et al., 2019). Exercise facility information was collected between April and October 2015. Initially all exercise facilities across Madrid were identified by Google Maps. These facilities were visited physically to source additional information. Data collection was carried out by four trained researchers. Quality assurance was carried out by repeating the above process in two districts using different trained data collectors.

The final database collected comprised 595 exercise facilities with assessments across five facility characteristic variables: (1) Name of the facility; (2) Address; (3) Monthly price; (4) Type of programs and services offered; and (5) Ownership (public vs private). According to their characteristics, exercise facilities were further classified into four types, as described in Table 4. Previous studies have used similar classifications (Hillsdon et al., 2007; Powell et al., 2006).

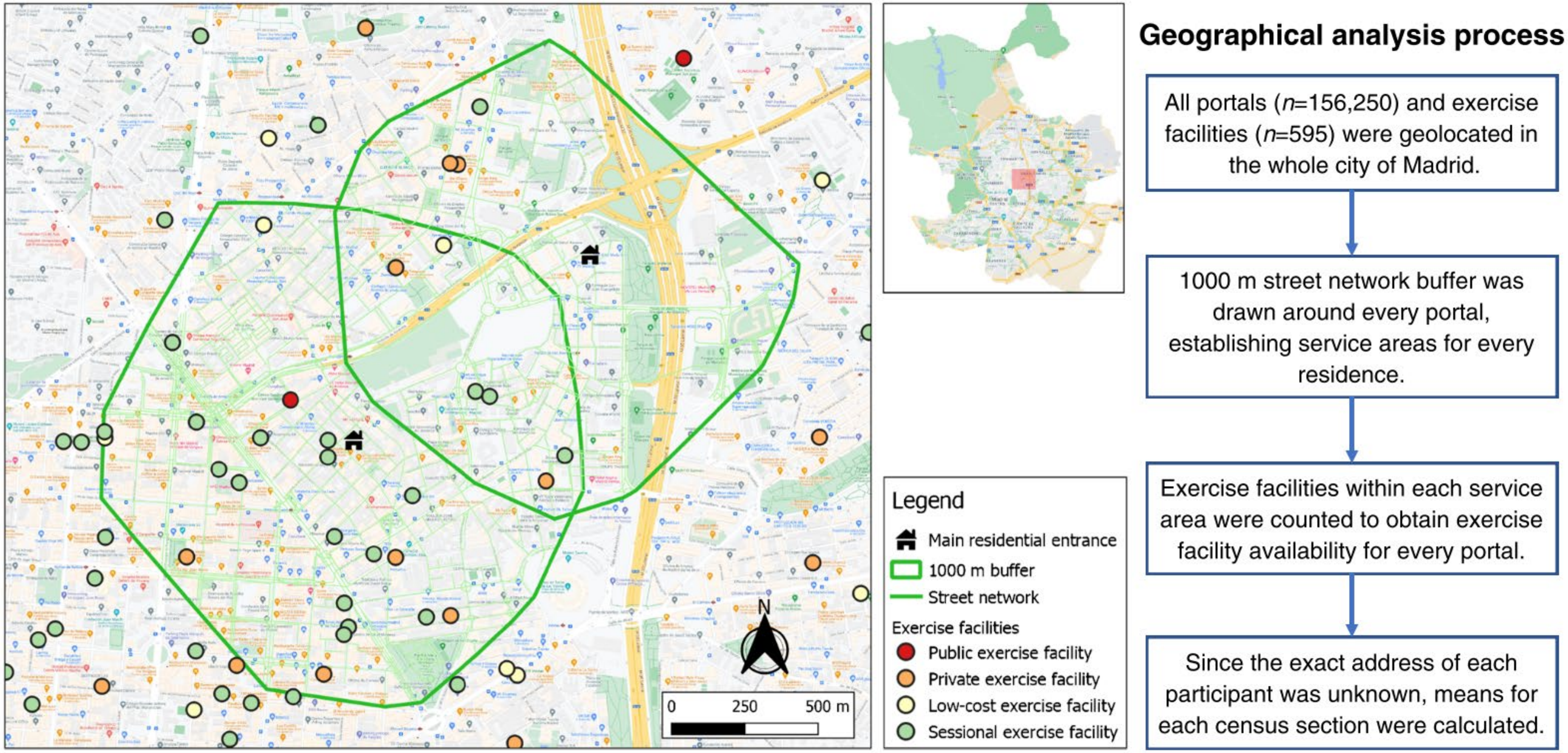
Table 4. Description of exercise facilities and their characteristics

Exercise facility type	Definition	*N (%)*
All the facilities	Any built resource, both public and private, which offered physical activity programs, both with monthly subscriptions and pay per session.	595
Publicly owned	Monthly payment option. Public ownership	59 (10%)
Privately owned	Monthly payment ≥ 30€/month. Private ownership	222 (37%)
Low cost	Monthly payment < 30€/month. Private ownership	63 (11%)
Sessional	Facilities with Pay-per-session (e.g. Pilates Studios, Dance Schools, electrostimulation centres). Private ownership.	251 (42%)

Exercise facilities access measures

Street network analysis using GIS software was used to assess access to exercise facilities. According to Penchansky & Thomas (2015), accessibility incorporates the physical location of services concerning individuals and resources required, such as transport and monetary or time costs to reach a service; meanwhile, availability refers to the supply of health services, including the number and type of existing services. To assess accessibility to exercise facilities (used only for the first study) the street network distance from each portal (origin) to the nearest exercise facility (destination) was calculated. To assess availability, I calculated the count of exercise facilities using a 1,000 meters street network buffer around each portal (see Figure 11).

Figure 11. Diagram of the geographical analysis to calculate the availability of exercise facilities (Cereijo et al., 2022).



Area-Level Socioeconomic Status

An Area-Level Socioeconomic Status Index was constructed as a composite index using seven socioeconomic indicators: (1) low education; (2) high education; (3) part-time employment; (4) temporary employment; (5) manual occupational class; (6) average housing prices (per m^2); and (7) unemployment rate. These indicators were selected based on the four domains present in the Spanish Commission to Reduce Health Inequalities (education, wealth, occupation and living conditions) (Ministerio de Sanidad Servicios Sociales e Igualdad, 2015b). Occupation and living conditions indicators were assessed at the neighbourhood level. The Area-Level Socioeconomic Status Index was calculated for each census section of the study area. Further details regarding index construction are described in Table 5.

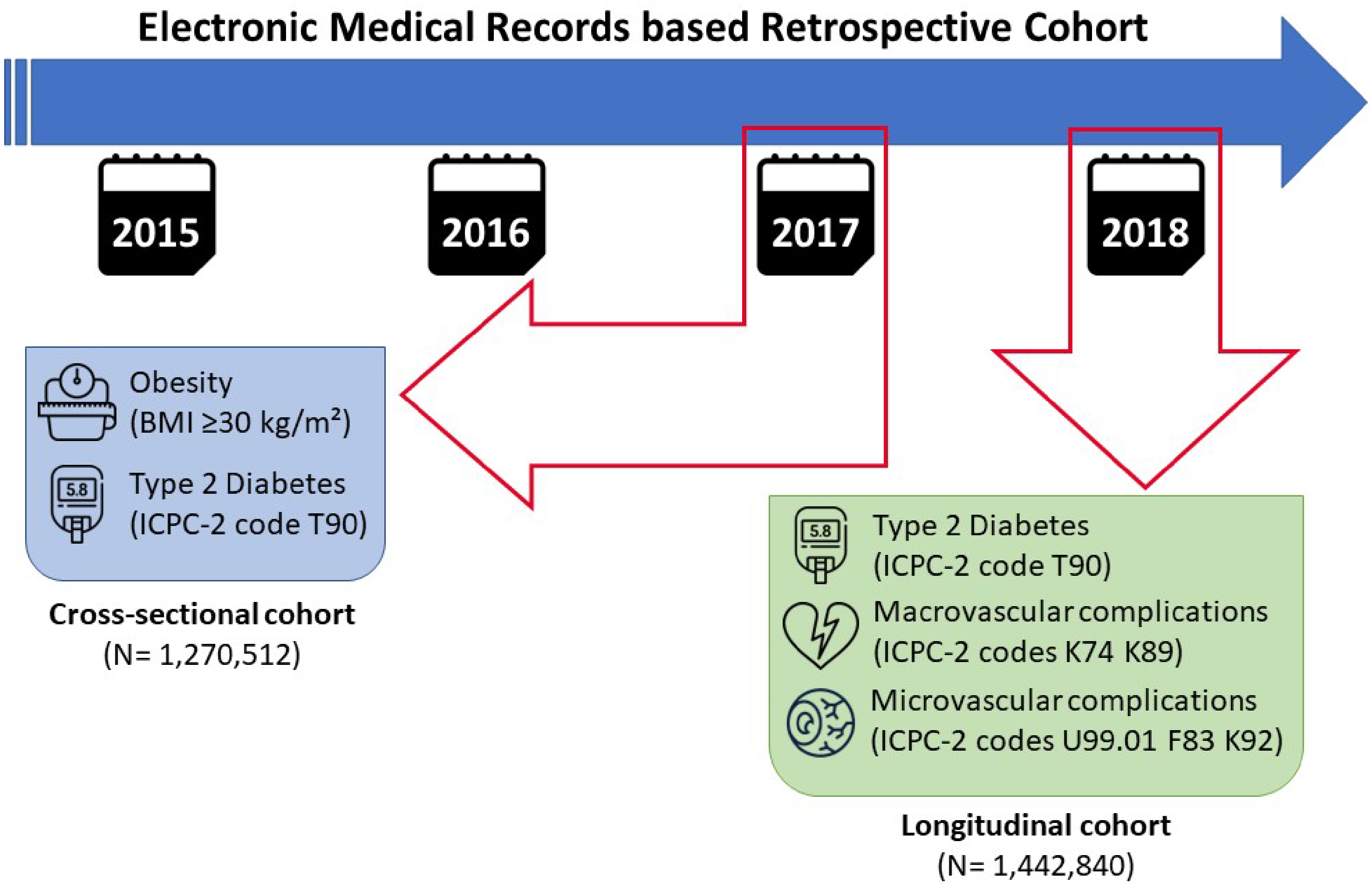
Table 5. Area Level Socioeconomic Status indicators description

Construct	Domain	Indicator	Operationalization	Source	Level
SES	Education	Low Education	Residents with mandatory studies or below / all residents aged 25 years or above	Padron	Census Section
		High Education	Residents with a university education or above / all residents aged 25 years or above	Padron	Census Section
	Occupation	Part-time Jobs	Workers in part-time jobs / all workers	Social Security	Neighbourhood
		Temporary Jobs	Workers in temporal jobs / all workers		
		Manual Occupation Class	Workers in manual or unskilled occupations / all workers		
	Wealth	Housing Prices	Average sale price of housing per m^2	Idealista Report	Census Section
	Living Conditions	Unemployment Rate	Residents registered as unemployed / all residents aged 16–64 years	Employment Service	Neighbourhood

Health outcomes

The main data sources of health outcomes analysed in this thesis were based on clinical diagnoses (recorded by primary care physicians during their usual clinical care) extracted from EMRs for the study sample (see Figure 12).

Figure 12. Electronic Medical Records (EMR) database



Diagnoses were coded according to the International Classification of Primary Care (ICPC-2; www.who.int/standards/classifications/other-classifications/international-classification-of-primary-care). Obesity was defined as BMI ≥30 kg/m2 and was objectively measured. T2DM was defined using the T90 diagnosis code ('diabetes non-insulin dependent'). T2DM diagnoses in the Primary Healthcare Service of Madrid dataset have been previously validated with a kappa of 0.99, with a sensitivity of 99.5% and a specificity of 99.5% (De Burgos-Lunar et al., 2011). The primary composite outcome of the complications analysis was an incident case of macrovascular (cardiac ischemia and/or stroke) and microvascular (chronic kidney disease, retinopathy and/or peripheral vascular disease) complications in someone free of these diseases at baseline. These complications were also identified using the following ICPC-2 codes: ischemia (K74), stroke (K89), chronic kidney disease (U99.01), retinopathy (F83), and peripheral vascular disease (K92).

Covariates

The main covariates used in this research were population density, age, and sex. Population density was defined by habitants/km^2 based on information sourced from the National Institute of Statistics (INE, 2014). Information regarding age and sex was obtained from the EMRs.

CHAPTER 5.
Study 1:

Access to and availability of exercise facilities in Madrid: an equity perspective

5.1 Background of Research Study 1

Research Study 1 enabled us to explore the social pattering of exercise facility access in the entire city of Madrid, Spain. The present fifth chapter presents the publication of the first study of the research, which seeks to respond to the first research question and specific aim of the thesis, describing the spatial access to exercise facilities in terms of accessibility and availability.

Before this research, no published research examined the relationship between area-level disadvantaged and access to exercise facilities in terms of accessibility and availability overall, and by type of exercise facility. Furthermore, another relevant contribution of this study was the examination and classification of exercise facilities based on price, subscription type and ownership.

I conducted this study in the entire city of Madrid, using each main residential building entrance (N=125,440) as a spatial unit of analysis. The outcome of the study consisted of all exercise facilities in Madrid (N=595), which were classified into four types: public, private, low-cost and sessional. The main exposure of the investigation was a composite area-level SES index created using seven socioeconomic status indicators. We carried out multilevel models to assess the association between area-level SES and access to exercise facilities in terms of (1) access (meters to the closest exercise facility) and (2) availability (amount of exercise facilities in a 1,000m street network buffer around each portal). Appendix gives further details regarding SES index construction.

5.2 Research Study 1

Access to and availability of exercise facilities in Madrid: an equity perspective.

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Status: Published in the International Journal of Health Geographics; 2019 18:15.

Author contribution: Luis Cereijo, Pedro Gullón y Manuel Franco conceived the idea. Usama Bilal developed the area-level socioeconomic status index. José Antonio Santacruz y Luis Cereijo collected and clean the database of exercise facilities. Luis Cereijo y Pedro Gullón carried out the statistical analysis. Alba Cebrecos carried out the spatial analysis and the cartography. Luis Cereijo drafted the manuscript. All authors provided critical intellectual contributions. All authors read and approved the final manuscript.

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International Journal of Health Geographics

RESEARCH

Open Access

Access to and availability of exercise facilities in Madrid: an equity perspective

Luis Cereijo[1,2,3], Pedro Gullón[1,4*], Alba Cebrecos[1], Usama Bilal[4], Jose Antonio Santacruz[2], Hannah Badland[3] and Manuel Franco[1,5]

Abstract

Background: Identifying socioeconomic determinants that are associated with access to and availability of exercise facilities is fundamental to supporting physical activity engagement in urban populations, which in turn, may reduce health inequities. This study analysed the relationship between area-level socioeconomic status (SES) and access to, and availability of, exercise facilities in Madrid, Spain.

Methods: Area-level SES was measured using a composite index based on seven sociodemographic indicators. Exercise facilities were geocoded using Google Maps and classified into four types: public, private, low-cost and sessional. Accessibility was operationalized as the street network distance to the nearest exercise facility from each of the 125,427 residential building entrances (i.e. portals) in Madrid. Availability was defined as the count of exercise facilities in a 1000 m street network buffer around each portal. We used a multilevel linear regression and a zero inflated Poisson regression analyses to assess the association between area-level SES and exercise facility accessibility and availability.

Results: Lower SES areas had a lower average distance to the closest facility, especially for public and low-cost facilities. Higher SES areas had higher availability of exercise facilities, especially for private and seasonal facilities.

Conclusion: Public and low-cost exercise facilities were more proximate in low SES areas, but the overall number of facilities was lower in these areas compared with higher SES areas. Increasing the number of exercise facilities in lower SES areas may be an intervention to improve health equity.

Keywords: Exercise, Socio-economic status, Exercise facilities, Inequities, Urban health

Background

Physical inactivity and sedentarism are major health concerns, as they are estimated to cause 3.2 million deaths globally annually, predominantly through chronic diseases, especially cardiovascular diseases [1–4]. Several studies have shown a social gradient in physical activity. For example, in Spain, those with the highest level of education also have the highest physical activity levels (73.4% classified as sufficiently active), compared with those with medium or low education levels (63.1% and 38.8% classified as sufficiently active, respectively) [5]. Moreover, this social gradient represents a health equity issue in the prevalence of overweight and obesity in Madrid; residents that live in areas of lower SES have higher prevalence of obesity and overweight [6].

Population approaches [7] seek to change the distribution of risk factors within a population, through changing social determinants or environmental factors. An example of this is the neighbourhood built environment [8, 9]. Systematic variation in the characteristics of the area of residence can contribute to disparities in physical activity [10]. For instance, access to physical activity resources may vary according to the sociodemographic characteristics of the neighbourhood, such as the predominant ethnic group, the median income level, deprivation or the ageing distribution [10–14]. These may contribute to some of the differences shown

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between physical activity accumulation and individual-level socio-economic status [5].

Living closer to destinations that support physical activity (e.g. parks) has been associated with higher levels of physical activity [15–19]. In one hand, previous studies have showed how facility-rich environments encourage physical activity through the visual stimuli provided by the facilities presence and the numerous exercise models that they offer [20]. Secondly, it is usual that people report travel problems as a reason for quitting exercise programs [21]; living close to sport facilities reduces some psychological and physical barriers to exercise, such as travel time and traffic-related stress [20].

Evidence exists showing greater local access to sports facilities, such as gyms and sports fields, is independently associated with lower levels of adiposity [22]; other research has shown associations between the availability of exercise facilities and exercise [20]. Areas with a higher combined availability of local exercise facilities and parks have lower odds of obesity [23]. Moreover, activities supported through exercise facilities (e.g. gyms) tend to be structured and at moderate to vigorous intensity (MVPA) [24], which produces greater health benefits [25, 26]. Moreover, the structured nature of the activities of this type of facilities make this activity more related with exercise. To wit, a physical activity that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective [27]. Despite this, relatively little research has examined the distribution of access to and availability of exercise facilities, such as gyms or swimming pools, by SES [22].

Previous studies show a clear social gradient in the practice of physical activity [28]. In low SES areas, where crime, or perceptions of crime, is often higher [29], exercise facilities play an important role in supporting health behaviours, as the streetscape and public open spaces may not be safe and aesthetically pleasing [30]. Identifying whether there are inequities in access and availability of exercise facilities by area-level disadvantage is an important step to informing urban planning policies that can improve population health through the pathway of physical activity engagement. While some studies have looked at perceptions of exercise facility availability and its relationship with physical activity, fewer studies have used objective indicators [31, 32]. Of these studies, some lack a classification of facility types [22, 33], and those that do have a classification, have not included variables that condition access, such us price, ownership or services, but instead utilise a general typology classification [20, 34]. This is problematic because it does not allow us to know differentiated tendencies depending on the different types of facilities, specially between public and private facilities.

However, a gap in the exercise facility literature relates to the concepts of accessibility and availability. According to Penchansky and Thomas [35], accessibility incorporates the physical location of services in relation to individuals and resources required, such as transport and monetary or time costs to reach a service; meanwhile availability refers to the supply of health services, including the number and type of existing services [35]. Some studies define accessibility as the number of facilities available at a range of distances (buffers) around residents' homes [34] or by zip code [14]; others as the number of facilities available per 1000 population [36], or whether facilities were pay- or free-for-use [13]. We argue examining accessibility and availability simultaneously provides a more nuanced understanding of the exercise facility environment for a given region. Yet, to our knowledge, no research has examined both concepts of exercise facilities within the same study.

Building on these gaps in the evidence, the aim of the study was to investigate the associations between area-level socioeconomic status with access to and availability of different types of exercise facilities and its spatial distribution using the case study of Madrid.

Methods

Study setting

The study is part of the Heart Healthy Hoods project, which broadly aims to study associations between the social and physical urban environment with cardiovascular health and inequity across Madrid, Spain [37].

This study was conducted across the municipality of Madrid, the capital of Spain. Madrid has a population of 3.2 M residents and is divided into 21 districts that house 128 neighbourhoods. Within each neighborhood there are small geographical administrative units of ~1500 people each, called census sections (N = 2415) [38]. Madrid's socio-spatial configuration is one of the most segregated in Europe [39].

Exposure: area-level socioeconomic status

The main exposure used in this study was a composite area-level socioeconomic status index created using seven socioeconomic status indicators: (1) low education; (2) high education; (3) part-time employment; (4) temporary employment; (5) manual occupational class; (6) average housing prices (per m^2); and (7) unemployment rate. These indicators were selected based on the four domains present in the Spanish Commission to Reduce Health Inequalities [40] (education, wealth, occupation and living conditions). Occupation and living conditions indicators were assessed at the neighbourhood level. The area-level disadvantage index was calculated for each census section of the study area. The index has been used in other research [41], and further details regarding index construction are described in Additional file 1. For the purposes of this paper, the index was collapsed into deciles, where 1 = most disadvantaged census sections and 10 = least disadvantaged census sections.

Outcomes: exercise facilities

Exercise facilities were defined as indoor exercise facilities, both public and private, which offered physical activity programs, both with monthly subscription or pay per session (e.g. fitness clubs, sport centres, dance clubs, Pilates studios). Informal facilities (e.g. public parks or outdoor playing fields), cycling paths, private clubs (e.g. exercise facilities not accessible to the public, schools, or private sport clubs) were excluded.

Exercise facility information was collected by *'MAS Servicios Integrales'* between April and October of 2015. All exercise facilities across Madrid were identified by Google Maps. Information about the programs and services were sourced through telephone and face-to-face interviews with facility managers. All facilities were visited physically to check the information collected. Data collection was carried out by four trained observers. Quality assurance was carried out by repeating the above process again in two districts using different trained data collectors.

The database used in this study comprised of 595 exercise facilities with five variables on facility characteristics. These were: (1) Name of the facility; (2) Address; (3) Monthly price; (4) Type of sports programs and services offered; (5) Ownership (public vs private). The exercise facilities were further classified into four exercise facility 'types', as described in Table 1. Similar classifications have been used in previous studies [14, 34].

Portal

We identified all residential building entrances in the city from CARTOCIUDAD [42] by identifying all external access identifiers located in a residential land use (total n of 125,440. We exclude entrances whose nearest facility was located more than 6 km away (N = 13), as these entrances were located in the edge of the city of Madrid, and their closest exercise facility might not be in the city in Madrid, but in a surrounding small region. All the spatial measures were calculated using ArcGIS 10.1 software.

Measure of accessibility to exercise facilities

We calculated the distance from each portal (origin) to the nearest exercise facility (destination) using a street network analysis; this better represents the true spatial distance between points when compared with a Euclidean distance [43]. We calculated the distance to "any" exercise facility less than 6 km, and the distance to the nearest facility of each type (Table 1).

Measure of availability of exercise facilities

We calculated the availability (count) of exercise facilities in total and by type using a 1000 m street network buffer. There is empirical evidence suggesting 1000 m is the distance people are most likely to walk to fulfil daily activities [43]. In fact, previous studies showed that 1000 m from home to an exercise facility is the distance with the highest correlation with moderate to vigorous physical activity [44], and this distance has previously been applied in exercise facility research [22, 44, 45].

Mapping of spatial distribution

Two cartographic maps were developed to facilitate the visualization of the spatial distribution of exercise facilities in terms of accessibility and availability. Those maps were made from the calculation of the average distance to the nearest exercise facility (accessibility) and number

Table 1 Descriptive analysis of the exercise facilities about accessibility and availability

Exercise facility type	Definition	*N*	Accessibility			Availability		
			Median (m)	IQR		Median (count)	IQR	
All the facilities		595	369.89	222.94	603.89	5	2	9
Publicly owned	Monthly payment option. Public ownership	59	1058.35	713.39	1466.25	0	0	1
Privately owned	Monthly payment ≥ 30€/month. Private ownership	222	611.42	353.53	1042.11	2	0	4
Low cost	Monthly payment < 30€/month. Private ownership	63	1092.23	666.42	1791.08	0	0	1
Sessional	Facilities with Pay-per-session (e.g. Pilates Studios, Dance Schools, electrostimulation centres…). Private ownership	251	594.35	328.49	1036.33	2	0	4

IQR interquartile range; *m* meters

of exercise facilities 1000 m around (availability) of each census section.

Statistical analyses

To study the association between accessibility to the nearest exercise facility and area-level SES we used linear mixed models with log transformed distance as the dependent variable and the SES index as the independent variable. This was a three-level model with a random intercept for neighbourhood and for census section. We included the independent variable (SES Index) operationalized as deciles, with the first decile (lowest SES) as the reference, group. To study the relationship between availability of exercise facilities and area-level SES, we used a Zero Inflated Poisson (ZIP) model. We chose a ZIP model instead of a mixed effects Poisson due to the high number of 0's in the distribution of the dependent variable. We estimated robust standard errors clustered by census section to take into account the intra-census section correlation. We ran all models for all facilities and stratified by type of facility. All analyses were conducted using Stata/SE 14.1 for Mac (StataCorp., College Station, TX, USA).

Results

Overall, the median distance to the nearest exercise facility (any type) from each portal was 364 m (IQR = 220 m–596 m). By type, low-cost facilities were furthest away (median distance = 1090 m, IQR = 663 m–1789 m), and sessional facilities were most proximate (median distance = 596 m, IQR = 331 m; 1035 m) (Table 1).

All portals had two or more exercise facilities of any type located within 1000 m, and half of the portals had at least five facilities available at this distance. However, half of the portals had neither public exercise facilities nor low cost facilities available within 1000 m. Private and sessional facilities had the highest availability, with at least two exercise facilities available within 1000 m for half the portals.

Exercise facility accessibility and SES

Overall, there was a social gradient in public, private and sessional facilities, where portals in low SES areas have better accessibility to the nearest exercise facility compared with higher SES areas (Fig. 1b–d). However, this association differed by type of facility. Areas with lower SES had higher accessibility to public exercise facilities (Fig. 1b). Similar patterns, though less strong, were observed for privately owned facilities (Fig. 1c) and low-cost facilities (Fig. 1d). In the case of sessional facilities, this gradient was unclear. Despite this, portals in the lowest SES areas (decile 1) had the lowest accessibility to the nearest exercise facility. This was shown for all types of exercise facilities when compared with the next least-deprived SES decile.

The spatial distribution of area-level SES and average distance to the nearest exercise facilities by type is shown in Fig. 2. The portals of the down-town area of Madrid (inside the M-30 orbital motorway of Madrid) show shorter distances to exercise facilities. Public exercise facilities are more accessible in the southern areas of the city when compared with the north, meanwhile the sessional exercise facilities show the opposite relationship. Low-cost and private exercise facilities were located most proximally in the downtown and southeastern areas. Private exercise facilities were located most proximally in the southwestern region.

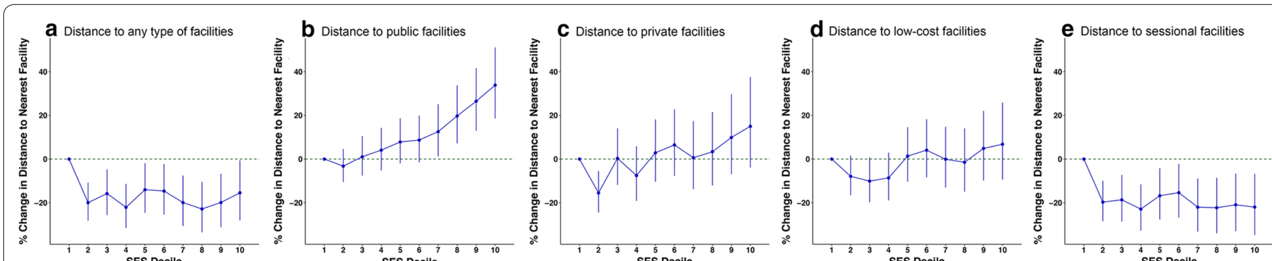

Fig. 1 Area-level SES and accessibility to nearest exercise facility. *Note* Distance = logarithm of distance to nearest facility; SES = socio-economic status

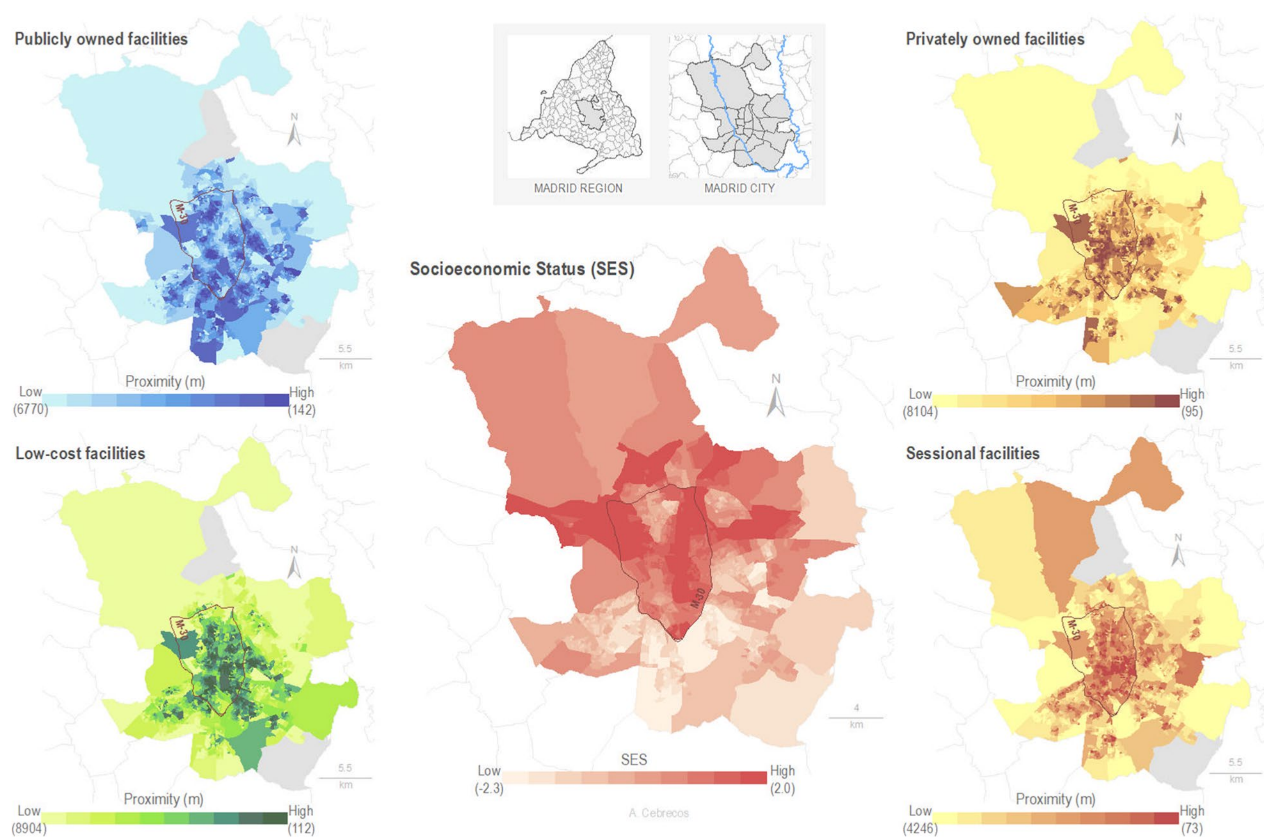

Fig. 2 Spatial distribution of census section average distance from each portals to the nearest exercise facilities by type, and Area-Level Socio-Economic Status Index by deciles in the census section (N = 2415) of the city of Madrid. *Note* m = meters; SES = socio-economic status

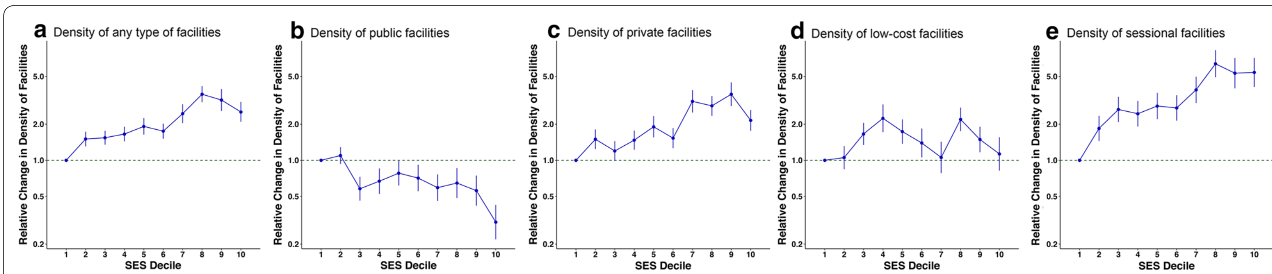

Fig. 3 Area-level SES and availability of exercise facilities. *Note* IRR = incidence rate ratio; SES = socio-economic status

Exercise facility availability and SES

There is a reverse social gradient in the association to availability of exercise facilities (Fig. 3), as there is a higher density of facilities in higher SES areas. The strongest associations with availability were shown for private and sessional exercise facilities, with the number of facilities increasing in areas of higher SES. This patterning was not present when public or low cost exercise facilities were considered.

Figure 4 shows differences in the spatial distribution of the availability of exercise facility types between the downtown area of Madrid and the periphery of the city. Downtown and northern areas (high SES) have greater availability of all types of exercise facilities. Public facilities have a higher level of availability when compared with other facility types, especially in the southern part of the city. Private and low-cost facilities have higher availability in the lower SES areas of the south than sessional facilities, which are more present in the higher SES areas of the north.

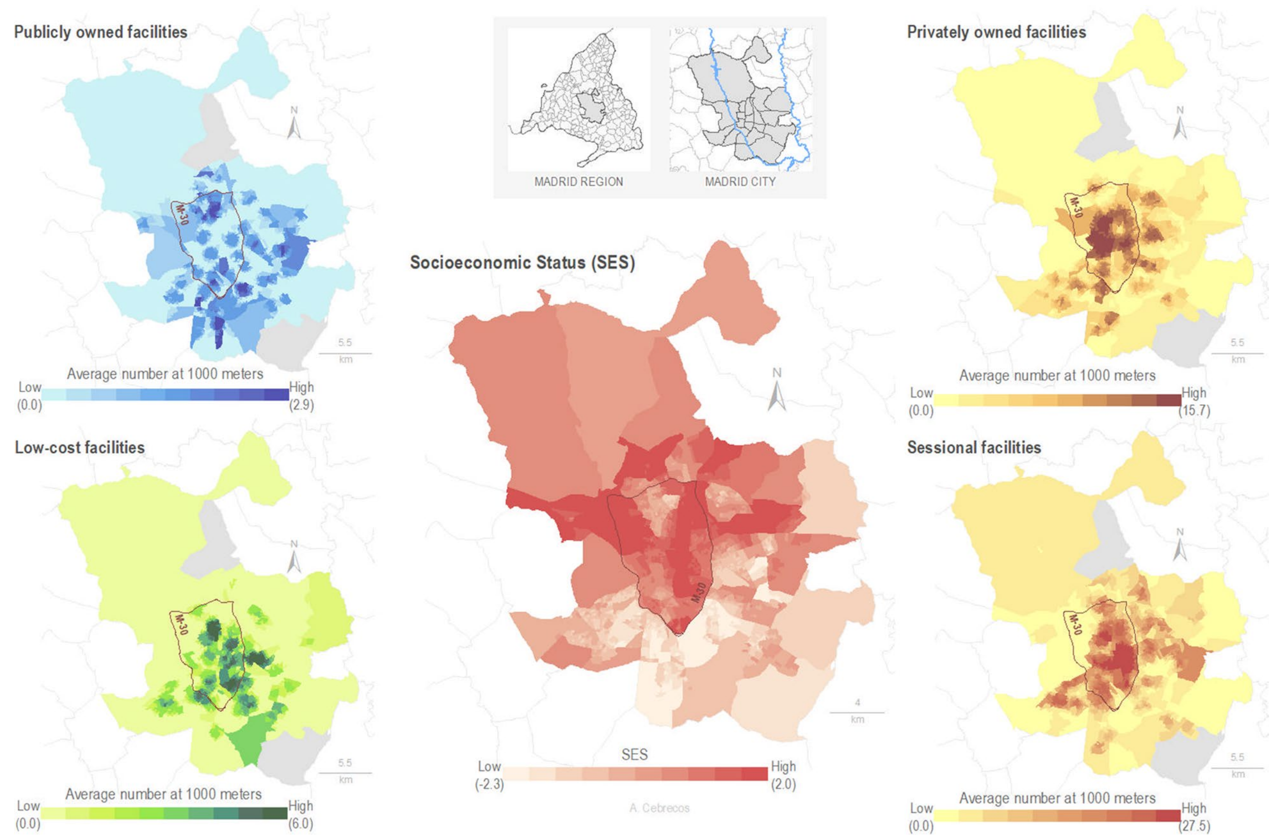

Fig. 4 Spatial distribution of census section average availability from each portal to exercise facilities by type using a 1000 m street network buffer, and Area-Level Socio-Economic Status Index by deciles in the census section (N = 2415) of the city of Madrid. *Note* SES = socio-economic status

Discussion

This study showed that, while people in Madrid living in low SES areas had better access to exercise facilities, residents in higher SES areas had greater availability of exercise facilities. The relationship between accessibility and area-level SES varied depending on the type of exercise facility, yet all types (except sessional facilities) presented a social gradient where distances generally tended to be more proximal in low SES areas. This gradient was most strong for the publicly owned and low-cost facilities. The availability analysis showed an increased likelihood of having more than one facility available as area-level SES increased. This pattern was clearest with private and sessional facility types. Our paper builds on this novelty research by further classifying exercise facilities into types, collecting primary data, and examining the socio-spatial patterning of exercise facilities by access and availability.

Our results are consistent with previous research that showed a negative association between area-level SES and proximity, in terms of distance, to recreational facilities [46–48], green spaces [47, 49, 50], and playgrounds [51, 52]. However, other studies have shown a greater proximity of green spaces for high SES areas, but not for other facilities [53–55]. This suggests that exercise facilities accessibility could act as a barrier of social disadvantaged, as an "advantage in the disadvantaged [41, 56].

Our availability results are consistent with previous studies that demonstrated higher density of facilities in areas of higher SES [13, 14, 34, 57]. Other studies, developed in different countries, found that there are more facilities in lower-SES areas [58, 59], while others have reported mixed or null results [60]. A previous study carried out in Madrid with older adults and secondary data sources showed similar availability of exercise facilities to those of our study. It concluded that reduced availability of exercise facilities in disadvantaged populations was a contributor to physical inactivity in older adults [36].

While the low SES areas had better accessibility and lower availability of exercise facilities, the higher SES areas presented opposite relationships. This could be explained by a high concentration of exercise facilities in the centre of Madrid, where census sections tended to have higher SES; on the other hand, the neighbourhoods on the periphery of the city (lower SES, especially in the south) have a more dispersed distribution of exercise facilities.

Strengths and limitations

This is the first multilevel study that: (1) analysed exercise facilities, in terms of accessibility and availability, and examined this in relation to area-level disadvantage; and (2) classified and examined exercise facilities based on price, subscription type and ownership.

The results show the importance of doing research that incorporates both access and availability measures simultaneously, and when combined with SES, can reveal different (and sometimes opposite) social-spatial patterning and social gradients. Examining the different types of exercise facilities yielded diverse results when considered by area-level SES, particularly in relation to generating a better understanding of the (in)equities of delivery. Another strength was the use of primary data for exercise facilities and accessibility and availability measures in Madrid. Finally, using the whole municipality of Madrid provided a high level of population variation to examine the socio-spatial distribution of exercise facilities.

Some limitations of this study should be highlighted. This research did not take into account the impact of the accessibility and availability of exercise facilities with behaviours of the population, such as facility use or physical activity engagement. There have also been concerns that area-level SES measures may not be suitable proxies for individual-level SES because of potential disagreement between contextual and compositional effects [61]. Because of the absence of individual data, portals were used to estimate accessibility and availability of exercise facilities from the residences of the Madrid population; however, exercise facilities around workplaces and/or study centers, may also be important but were not investigated. Finally, our focus was exercise facilities, therefore, we might have missed other physical activity destinations, such as playgrounds or parks. However, we chose to restrict to study exercise facilities since the activities supported in exercise facilities (e.g. gyms) tend to be more structured and include moderate to vigorous intensities (MVPA) [24], which produces greater health benefits [25, 26].

Policy recommendations

Presence of exercise facilities have a great importance on the physical activity engagement of the populations. Not only for the type of the structured activities provided [24], but also for the impact on the neighbourhood environment [20].

In one hand, previous studies have pointed how the facility-rich environment encourage physical activity through the visual stimuli provided by the own facilities and the numerous role models presence thanks to the nearby facilities [20]. Secondly, is usual that people report inconvenience and travel problems as reasons for quitting of exercise programs [21]; to live near facilities reduce some psychological and physical barriers to exercise, such as travel time and traffic-related stress [20].

Previous studies have reported a positive relationship between the availability of exercise facilities and moderate to vigorous physical activity [62] and a negative relationship with adiposity [22]. Therefore, the low availability of exercise facilities detected in areas with low SES brings a double disadvantaged scenario for those populations, such as in the southern districts of Villaverde and Puente de Vallecas, as well as some areas in the southeast part of the city.

An increase of opportunities for physical activity in more disadvantaged areas, either through subsidy systems of private facilities or increasing the availability of public facilities, could produce an upturn in the aggregate demand of physical activity. This planned growth should focus on low fixed price or no cost facilities, as those with a variable price (such as sessional) are negatively related to participation in physical activity [63], and may be a barrier for those who are disadvantaged people.

Research agenda

Future studies should try to extend our findings using individual-level behavioural data to better understand how exercise environment is associated with facility use and physical activity engagement. In future, a wider range of internal characteristics of the facilities should be assessed (e.g. service quality, cultural appropriateness, timetabling), alongside understanding how these attributes are associated with facility use. Also, a qualitative approach to evaluate the characteristics of exercise facilities could improve our understanding of the barriers/enablers people face when selecting (or not) exercise facilities to attend, and whether this differs by SES.

Conclusions

Our findings showed that associations between accessibility and availability of exercise facilities with area-level SES varied depending on facility type. Areas with lower SES demonstrated better accessibility in general to exercise facilities, whereas higher SES areas had greater facility availability, especially when privates and sessional types were considered.

Relatively little research to date has examined exercise facilities, when compared with evidence focussing on other physical activity locations, such us parks or neighbourhoods. This study makes an important contribution to knowledge about the socio-spatial delivery of exercise facilities in our cities.

Additional file

Additional file 1. Area Level Socioeconomic status indicators.

Abbreviations
SES: socio-economic status; MVPA: moderate to vigorous physical activity.

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Authors' contributions
LC, PG and MF conceived the idea. UB developed the area-level socioeconomic status index. JAS and LC collected and clean the database of exercise facilities. LC and PG carried out the statistical analysis. AC carried out the spatial analysis and the cartography. LC drafted the manuscript. All authors provided critical intellectual contributions. All authors read and approved the final manuscript.

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Availability of data and materials
The data that support the findings of this study are available from MAS Servicios Integrales but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of MAS Servicios Integrales.

Ethics approval and consent to participate
We conducted this study in accordance with the Declaration of Helsinki, and received ethical approval by the Madrid Primary Care Research Committee. There were no human subjects involved in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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CHAPTER 6.
Study 2:

Exercise facilities and the prevalence of obesity and type 2 diabetes in the city of Madrid

6.1 Background of Research Study 2

The second research study seeks to cover the second aim of the thesis, exploring (1) the association between exercise facility availability and prevalence of obesity and T2DM in the adult population of Madrid, Spain; and (2) potential effect modification exerted in the association by area-level SES and sex. Chapter 6 presents the publication of this research in Diabetologia. This was the first study exploring exercise facility availability and obesity and type 2 diabetes associations through area-level SES effect modification.

I carried out this research covering the whole adult population of Madrid in 2017 (N=~1.3M inhabitants) across the entire city. The independent variable of the analysis was exercise facility availability, defined as the count of exercise facilities in a 1,000m street network buffer, measured using GIS. Health outcomes were obtained from EMRs of 1,320,000 residents of Madrid aged 40-75 years. T2DM was defined using the T90 diagnosis code ('diabetes non-insulin dependent'), whose diagnoses have been previously validated with a κ of 0.99, with a sensitivity of 99.5% and a specificity of 99.5%. Obesity was defined as BMI ≥30 kg/m2 and was objectively measured. Further supplementary information can be found in Appendix.

6.2 Research Study 2

Exercise facilities and the prevalence of obesity and type 2 diabetes in the city of Madrid

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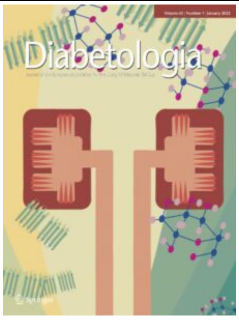	**Journal**	Diabetologia
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ARTICLE

Exercise facilities and the prevalence of obesity and type 2 diabetes in the city of Madrid

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Abstract

Aims/hypothesis We aimed to study the association between the availability of exercise facilities and the likelihood of obesity and type 2 diabetes in the adult population of Madrid, Spain.

Methods We analysed the electronic medical records of all 1,270,512 residents of Madrid aged 40–75 years in 2017. Exercise facility availability was defined as the count of exercise facilities in a 1000 m street network buffer around each residential building entrance. Poisson regression with standard errors clustered at census tract level was used to assess prevalence ratios of exercise facility availability tertiles and obesity and type 2 diabetes. We also examined stratified results by tertiles of area-level socioeconomic status (SES) and sex.

Results People living in areas with lower availability of exercise facilities had a higher prevalence of obesity (prevalence ratio [PR] 1.22 [95% CI 1.20, 1.25]) and diabetes (PR 1.38 [95% CI 1.34, 1.43]). We observed effect modification by area-level SES ($p<0.001$), with stronger associations for residents living in low-SES areas and no association for residents living in high-SES areas. Associations with type 2 diabetes were stronger among women compared with men, while associations with obesity were similar by sex.

Conclusions/interpretation People living in areas with low availability of exercise facilities had a higher prevalence of obesity and type 2 diabetes, and this association was strongest in low-SES areas and for women. Understanding the potential role of exercise facilities in driving inequities in obesity and type 2 diabetes prevalence may inform interventions to reduce health inequities.

Keywords Electronic medical records · Exercise · Inequities · Obesity · Social determinants · Type 2 diabetes · Urban health

Abbreviations

EMR	Electronic medical record
HHH	Heart Healthy Hoods
PR	Prevalence ratio
SES	Socioeconomic status

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Research in context

What is already known about this subject?

- The prevalence of obesity and type 2 diabetes and the availability of exercise facilities are socially patterned
- Other neighbourhood features, including walkability and green spaces, have been found to be associated with physical activity, obesity and type 2 diabetes
- The relationship between exercise facility availability and the prevalence of obesity and type 2 diabetes has received less attention

What is the key question?

- Are there associations between exercise facility availability and the prevalence of obesity and type 2 diabetes, and do these associations differ by area-level socioeconomic status (SES) or sex?

What are the new findings?

- People living in areas with lower exercise facility availability had a higher prevalence of obesity and type 2 diabetes
- The association between exercise facilities and prevalence of obesity and type 2 diabetes was stronger in low-SES areas and for women

How might this impact on clinical practice in the foreseeable future?

- Understanding the role of exercise facilities in driving health inequities in obesity and type 2 diabetes may point at targets for intervention in underserved communities

Introduction

Increased physical activity is linked to reductions in risks of type 2 diabetes and obesity [1–3]. Neighbourhood features (e.g. parks, green spaces, physical activity facilities) are important determinants of physical activity [4], especially in more disadvantaged neighbourhoods [5, 6]. Population-level approaches targeting neighbourhood environment features may be promising strategies to address type 2 diabetes and obesity [7, 8], especially in light of existing type 2 diabetes [9] and obesity [10] social gradients. For example, social determinants of health are key drivers of type 2 diabetes and related outcomes [11].

Increased physical activity opportunities at the neighbourhood level are associated with lower obesity [12] and type 2 diabetes risk [13]; for example, higher availability of green and open spaces is associated with lower type 2 diabetes prevalence [14, 15] and incidence [16, 17]. However, few studies have investigated relationships between the availability of exercise facilities and obesity and type 2 diabetes [12, 18]. Exercise facility programmes tend to be structured and occur at moderate to vigorous intensity [19], eliciting health benefits [20]. Therefore, higher availability of exercise facilities potentially increases opportunities for structured exercise, which is associated with a lower prevalence of obesity [12] and greater reductions in HbA_{1c}, compared with delivering physical activity advice alone [21].

We previously demonstrated a social gradient for exercise facility availability in Madrid [22] and for type 2 diabetes prevalence, incidence and control [9]. Previous research has shown that amenities conducive to physical activity, including parks and green spaces, can reduce health inequities [23]. Moreover, there has been limited research exploring exercise facility differences by sex, and the little available evidence shows that women are less likely to use exercise facilities than men [24]. Thus, examining relationships between exercise facilities and type 2 diabetes and obesity by area-level socioeconomic status (SES) and sex can help identify potential interventions to address these inequities by focusing on populations most in need.

The study aims were as follows: (1) to examine the association between availability of exercise facilities and the likelihood of obesity and type 2 diabetes in the adult (40–75 years old) population of Madrid; and (2) to examine interactions with area-level SES and sex.

Methods

Study design A population-based retrospective cohort study using data from primary care electronic medical records (EMRs) in Madrid, Spain was conducted. This study was developed based on the REporting of studies Conducted using

Observational Routinely-collected Data (RECORD) statement [25]. The study followed a multilevel design using variables at the individual (age, sex, obesity and diabetes) and neighbourhood level (population density, SES and exercise facility availability).

Setting This study is part of the Heart Healthy Hoods (HHH) project, which broadly aims to study associations of the social and physical urban environment with cardiovascular health and inequity in Madrid, Spain [26]. This study was conducted across the municipality of Madrid. In 2017 Madrid had a population of 3.2 million residents and it is divided into 21 districts that are composed of 128 neighbourhoods. Within each neighbourhood there are small geographical administrative units of ~1500 people each, called census tracts (*secciones censales*) (N=2415) [27]. Further information about the demographic composition of the administrative units in Spain is shown in electronic supplementary material (ESM) Table 1.

Study population The HHH cohort is based on real-world data from primary care, including information about 1,305,050 residents. The individuals in the HHH cohort represented 91% of the total population of the age group included in this study (40–75 years) living in Madrid [27]. The study population was selected according to the HHH project criteria [28] as individuals: (1) registered at one of the 128 primary healthcare centres in the municipality of Madrid; (2) who live in the municipality of Madrid; (3) aged 40–75 years; (4) registered in the EMRs of the Primary Health-care Service of Madrid (AP-MADRID) in 2017, with no missing data for obesity and/or diabetes.

Health outcomes Diagnoses (recorded by primary care physicians during their usual clinical care) were extracted from EMRs for all individuals. These diagnoses were coded according to the International Classification of Primary Care (ICPC-2; www.who.int/standards/classifications/other-classifications/international-classification-of-primary-care). Type 2 diabetes was defined using the T90 diagnosis code ('diabetes non-insulin dependent'). Type 2 diabetes diagnoses in the Primary Health-care Service of Madrid dataset have been previously validated with a κ of 0.99, with a sensitivity of 99.5% and a specificity of 99.5% [29]. Obesity was defined as BMI ≥30 kg/m^2 and was objectively measured.

Exercise facilities Exercise facilities were defined as venues that offered exercise programmes, whether free, monthly subscription or pay per session (e.g. fitness clubs, sports centres, dance clubs, Pilates studios), and regardless of whether they were publicly or privately owned. Exercise facility information was collected by 'MAS Servicios Integrales', a fitness consultancy firm, between April and October of 2015. All exercise facilities meeting these criteria across Madrid were identified using Google Maps. Information about the programmes and services was sourced through telephone and face-to-face interviews with facility managers. More information about data collection can be found elsewhere [22]. The final exercise facility dataset comprised 595 facilities with information collected for five characteristics: (1) facility name; (2) facility physical address; (3) monthly price; (4) types of programmes and services offered; (5) ownership (public vs private) (see ESM Table 2).

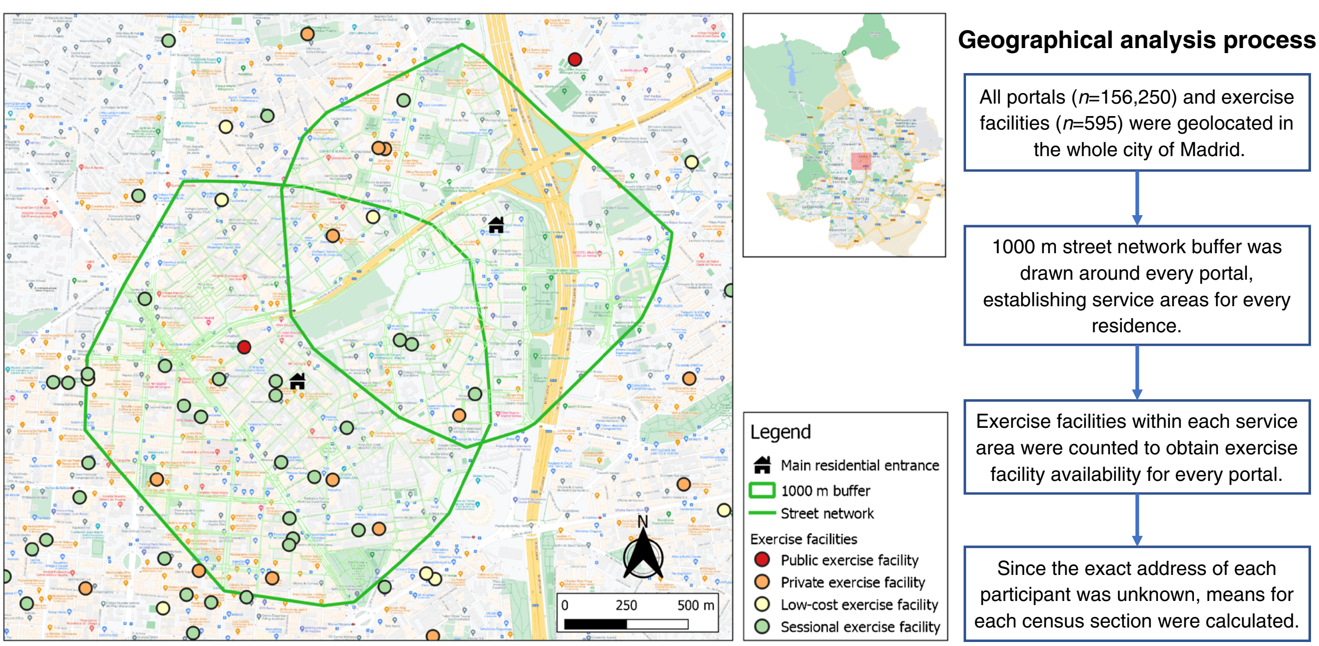

Fig. 1 Diagram of the geographical analysis to calculate the availability of exercise facilities

Availability measures We captured residential building entrances (hereafter called portals) in Madrid (Fig. 1). This was done by identifying all external access points to residences located in residential land use using the GEOPORTAL of the Madrid City Council [30]. Spatial measures were calculated using QGIS 3.10.5 software. Based on the definition by Penchansky and Thomas [31], exercise facility availability was calculated as the count of facilities within a 1000 m street network buffer from each portal. All portals in a census tract were aggregated and a mean count of exercise facilities for each census tract was calculated. The 1000 m buffer has been used in exercise facility research [12, 22, 32, 33] and is regarded as an appropriate walking distance for undertaking daily activities [34]. Also, a 1000 m street network distance from home to an exercise facility showed the highest correlation with moderate to vigorous physical activity [32]. Census tracts were stratified into tertiles of exercise facility availability. Sensitivity analyses using deciles of exercise facility availability were also conducted. Boundaries of the geographic information data were from 1 January 2017.

Area-level SES Area-level SES was obtained from a composite area-level SES index created using seven SES indicators: (1) low education; (2) high education; (3) part-time employment; (4) temporary employment; (5) manual occupational class; (6) average housing prices (per m^2); and (7) unemployment rate. The SES index was calculated for each census tract across Madrid and was collapsed into tertiles (low, medium, high). The index has been used in previous studies [9, 22], and further details regarding index construction are described in ESM Table 3.

Statistical analysis The analysis was undertaken in three steps. First, key demographic and clinical characteristics of the population were described. Second, Poisson regression models with robust standard errors clustered at the census tract level were applied to estimate the prevalence ratio (PR) for the association between the exposure (exercise facilities) and each outcome (type 2 diabetes, obesity). We initially created an unadjusted model (Model 0), then adjusted the model by age and sex (Model 1), together with population density (Model 2), and finally adjusted by area-level SES (Model 3). Third, to identify any potential effect modification from area-level SES with the availability of exercise facilities, we introduced an interaction term between area-level SES and availability of exercise facilities, using a Wald test to get a *p* value for each interaction. Results were presented for the whole sample and stratified by sex, using the highest tertile of exercise facilities available as the reference. All analyses were conducted using Stata/SE 14.1 for Mac (StataCorp, College Station, TX, USA).

Ethics This study was carried out under the umbrella of the HHH study and in accordance with the Declaration of Helsinki guidelines. The study received Institutional Review Board (IRB) approval from the Ethics Research Committee of the Madrid Health Care System on 12 May 2015.

Results

After excluding those with missing data on residential location (*n*=34,538), our final sample included 1,270,512 individuals for the type 2 diabetes analysis and 213,719 adults for the obesity analysis. The distributions by area-level SES and availability of exercise facilities of participants between those with and without missing values of obesity were similar. Table 1 shows the final sample characteristics. A social gradient was evident for type 2 diabetes, whereby type 2 diabetes was more prevalent in low-SES areas (9.1%), compared with medium- (7.1%) and high-SES (5.0%) areas, and in men (8.6% compared with 5.8% in women). Obesity presented a similar distribution to type 2 diabetes. People living in lower-SES areas had a higher prevalence of obesity (43.7%) when compared with medium- (37.7%) and higher-SES areas (30.6%). Men had higher prevalence of obesity (39.4%) than women (37.5%). Availability of exercise facilities also showed a social gradient (low [median facilities = 5; IQR 3–8], medium [median = 7; IQR 4–12] and high SES [median = 12; IQR 4–18]).

We found a significant relationship of exercise facility availability with obesity and type 2 diabetes prevalence: people living in areas at the lowest tertile of exercise facility availability had a significantly higher prevalence of obesity ($PR_{Tertile\ 3\ vs\ 1}$ = 1.22 [95% CI 1.20, 1.25]) and type 2 diabetes ($PR_{Tertile\ 3\ vs\ 1}$ = 1.38 [95% CI 1.34, 1.43]). However, these associations were attenuated, but remained significant, after adjustment by area-level SES (Model 3; obesity, $PR_{Tertile\ 3\ vs\ 1}$ = 1.03 [95% CI 1.01, 1.05]; type 2 diabetes, $PR_{Tertile\ 3\ vs\ 1}$ = 1.03 [95% CI 1.00, 1.06]; see Table 2). Models 2 and 3 show the independent effects of exercise facility availability on the prevalence of obesity and type 2 diabetes. The independent effect for the third tertile (higher availability of exercise facilities) is 14% (PR 1.03 vs the total effect of PR 1.22) for obesity and 8% (PR 1.03 vs the total effect of PR 1.38) for type 2 diabetes.

Effect modification of area-level SES and sex Figure 2 shows a statistically significant effect modification of area-level SES on the relationship between exercise facility availability and obesity and type 2 diabetes (*p* value for interaction <0.001). For those living in the lowest area-level SES, a lower availability of exercise facilities was associated with a higher prevalence of obesity ($PR_{Tertile\ 3\ vs\ 1}$ = 1.13 [95% CI 1.08, 1.18]) and type 2 diabetes ($PR_{Tertile\ 3\ vs\ 1}$ = 1.17 [95% CI 1.11, 1.20]). We found no association between exercise facility

Table 1 Characteristics of the study sample

Characteristic	Overall		High availability of exercise facilities[a]		Medium availability of exercise facilities[a]		Low availability of exercise facilities[a]	
	Men	Women	Men	Women	Men	Women	Men	Women
n	574,440	696,072	186,071	237,381	191,709	230,864	196,660	227,827
Age, years	51.0 (45.0–60.0)	53.0 (46.0–63.0)	52.0 (45.0–61.0)	54.0 (47.0–64.0)	52.0 (45.0–60.0)	53.0 (46.0–63.0)	51.0 (45.0–59.0)	52.0 (45.0–62.0)
Area-level SES, index value	−0.200 (−0.783–0.649)	−0.160 (−0.754–0.678)	0.554 (−0.201–0.805)	0.593 (−0.176–0.825)	−0.582 (−1.015–0.061)	−0.561 (−0.993–0.063)	−0.459 (−1.032–0.556)	−0.454 (−1.019–0.563)
Population density, habitants/km^2	30,000 (17,400–43,000)	30,200 (17,600–43,300)	39,600 (26,700–52,900)	39,500 (26,700–52,800)	30,800 (20,000–41,400)	30,700 (20,000–41,300)	20,400 (9420–32,900)	20,400 (9420–32,900)
Exercise facilities, *n*	6.57 (3.13–11.59)	6.90 (3.30–12.08)	14.44 (11.81–19.67)	14.51 (11.90–19.87)	6.72 (5.50–8.08)	6.77 (5.53–8.10)	2.26 (1.39–3.21)	2.29 (1.39–3.21)
Type 2 diabetes	49,458 (8.6)	40,247(5.8)	14,674(7.9)	11,781 (5.0)	17,604 (9.2)	14,521 (6.3)	17,180 (8.7)	13,945 (6.1)
Obesity[b]	34,721 (39.4)	47,056 (37.5)	9265 (36.3)	12,543 (33.2)	12,507 (40.2)	17,214 (38.6)	12,949 (41.0)	17,299 (40.1)

Data displayed are median (IQR) or *n* (%)

[a] Exercise facility availability was defined as count of exercise facilities in a 1000 m street network buffer around each portal, and divided into high, medium and low tertiles

[b] A subgroup of *n*=213,719 individuals (*n*=88,224 men and *n*=125,495 women) was included in the obesity analysis

Table 2 Association of exercise facility availability with prevalence of obesity and type 2 diabetes in Madrid

Exercise facility availability	Model 0: crude	Model 1: adjusted by age and sex	Model 2: adjusted by age, sex and population density	Model 3: adjusted by age, sex, population density and SES
Obesity				
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	1.14 (1.12, 1.16)**	1.14 (1.11, 1.16)**	1.17 (1.14, 1.19)**	1.00 (0.98, 1.02)
Low density	1.17 (1.15, 1.20)**	1.17 (1.15, 1.20)**	1.22 (1.20, 1.25)**	1.03 (1.01, 1.05)**
Type 2 diabetes				
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	1.22 (1.18, 1.25)**	1.24 (1.20, 1.27)**	1.29 (1.25, 1.33)**	0.98 (0.95, 1.00)*
Low density	1.17 (1.13, 1.22)**	1.27 (1.23, 1.32)**	1.38 (1.34, 1.43)**	1.03 (1.00, 1.06)*

Data are presented as PR (95% CI)

*$p < 0.05$, **$p < 0.01$

Ref., tertile of reference

availability and the prevalence of obesity or type 2 diabetes for people living in high-SES areas. When stratified by sex, we found a stronger association between exercise facility availability and type 2 diabetes for women ($PR_{\text{Tertile 3 vs 1}}$ = 1.24 [95% CI 1.16, 1.32]) compared with men ($PR_{\text{Tertile 3 vs 1}}$ = 1.10 [95% CI 1.04, 1.17]).

Sensitivity analysis Analysis by deciles of exercise facility availability showed a linear and gradual association between facility availability and both health outcomes, with the exception of the highest decile (see ESM Table 4).

Discussion

In this study of ~1.3 million adults in Madrid (Spain), we found that residents living in areas with lower availability of exercise facilities had higher levels of obesity and type 2 diabetes. These associations were strongest in lower-SES areas. To our knowledge, this is the first study exploring exercise facility availability and obesity and type 2 diabetes associations through area-level SES effect modification.

These results are consistent with previous studies that described higher prevalence of obesity [12] and type 2 diabetes [18] in residents living in areas with lower availability of exercise facilities. Importantly, we found that the association between exercise facility availability and the prevalence of obesity and type 2 diabetes was largely attenuated after adjusting for area-level SES. This has two important implications. First, it indicates that part of the social gradient in obesity and type 2 diabetes prevalence may be explained by the differential distribution of exercise facilities. A potential pathway of these associations may be through increased physical activity; previous studies in Madrid with older adults (50–

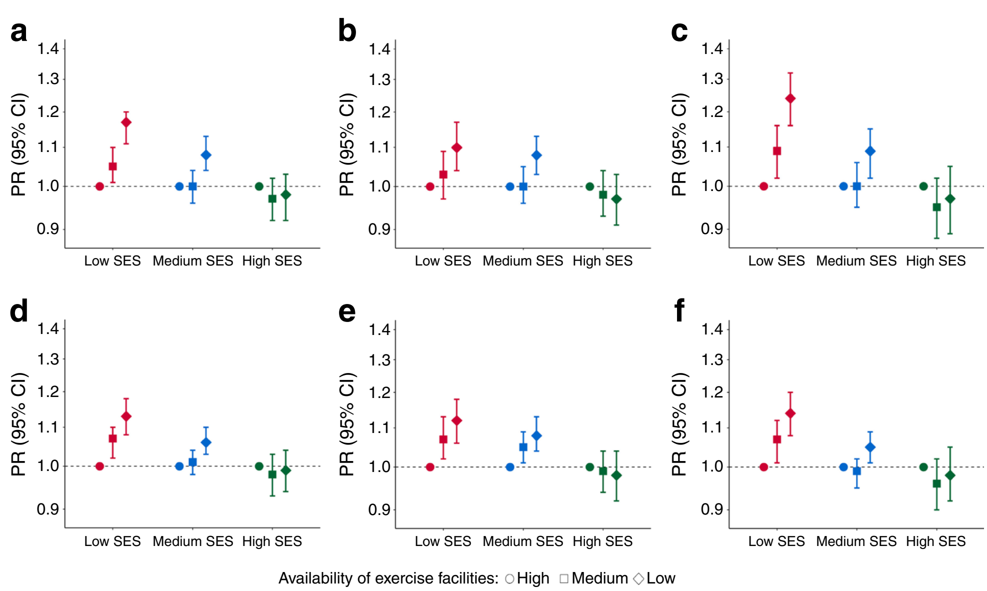

Fig. 2 Association of exercise facility availability with (**a**–**c**) type 2 diabetes and (**d**–**f**) obesity, adjusted by age and population density. Interactions by area-level SES are presented. Overall data are shown (**a**, **d**), as well as data stratified by sex: men (**b**, **e**); women (**c**, **f**). Dashed lines at PR 1.0 represent the reference group (highest availability of exercise facilities). There was a statistically significant effect modification of area-level SES on the relationship between exercise facility availability and obesity and type 2 diabetes (p value for interaction <0.001)

74 years) showed that availability of exercise facilities was a mediator between neighbourhood economic context and physical inactivity [35]. Second, these patterns indicate that areas with the highest prevalence of obesity and type 2 diabetes are areas characterised by low SES and with a low availability of exercise facilities. These findings may have potential policy implications as they indicate that exercise facilities may be able to partially mitigate SES inequities.

In the stratified models, prevalence of obesity and type 2 diabetes was greater among people who lived in lower-SES areas and with a lower level of exercise facility availability. Taken together, a lack of exercise facilities may contribute to the social gradient among more deprived populations. Investigating the interaction of characteristics of the built environment and SES is crucial to understanding the extent of health inequities and designing potential interventions to prevent these inequities [36].

Sex inequities were also identified. The magnitude of obesity and type 2 diabetes PRs was higher among women from low-SES areas and with low availability of exercise facilities, when compared with the equivalent male population. When type 2 diabetes was considered, the PR for women living in low-SES areas with low availability of exercise facilities was double that for men living in areas with the same characteristics. Similar sex inequities have been reported in research examining adiposity and availability of exercise facilities [12], and green space availability and diabetes [37].

A strength of the study is including the entire adult population of a major European city (Madrid) where almost 1,400,000 adults live [28]. This large sample size minimised selection bias compared with surveys or regular cohort studies [38], and allowed us to capture geographic and demographic variation across a city. The diagnosis of type 2 diabetes in our EMRs was previously shown to have high validity [29] and obesity was classified objectively.

The current study also presents several limitations. First, cross-sectional studies of neighbourhood environment are prone to reverse causation, as individuals with lower BMI may choose to live in areas with more exercise facilities. Although self-selection bias is a concern in neighbourhood and health studies, its effect is not clear and should be confirmed in future studies [39, 40]. Second, the study did not consider the physical activity levels of participants, so we cannot confirm whether presence of exercise facilities is associated with exercise facility use. However, studies have found that greater availability of exercise facilities in neighbourhoods was associated with higher levels of overall physical activity [35, 41, 42]. Third, since our focus was on indoor exercise facilities, it is likely we missed other physical activity destinations, such as outdoor sports courts, parks and pavements/footpaths. Fourth, the measurement of our outcomes relied on EMR data, which may be subject to bias. However, a validation study conducted using these same datasets found type 2 diabetes diagnoses accurate ($\kappa = 0.99$). We have no information on the validity of the diagnosis of obesity. Finally, there were temporal differences across the datasets (2015, 2017 for EMRs; 2017 for area-level SES). Although the area-level SES has not changed significantly over the last few years, it is possible that variations in the exercise facilities have not been captured.

Research agenda Study findings opened two lines of inquiry for improving our understanding of the associations between exercise facilities and health outcomes. Future studies should seek to confirm the results presented in this research using individual-level behavioural data captured through longitudinal studies to better understand how the presence of exercise facilities is associated with facility use and physical activity engagement, and related inequities. Integrating qualitative methods to evaluate the characteristics of exercise facilities would be helpful to gain a better understanding of barriers and enablers for using exercise facilities, and whether these differ by sex and SES.

Policy recommendations Our study showed the highest prevalence of obesity and type 2 diabetes in low-SES areas with the lowest availability of exercise facilities. This finding suggests that obesity and type 2 diabetes prevention efforts should focus in these areas to reduce health inequities. Preventive efforts should also include mechanisms to reduce sex inequities in access to exercise facilities, as we found stronger associations with type 2 diabetes for women.

Conclusions Our findings from ~1.3 million adult Madrid residents demonstrated that neighbourhoods with lower availability of exercise facilities had a higher prevalence of obesity and type 2 diabetes, and this was most evident for women and for people living in low-SES neighbourhoods. These findings provide knowledge that may help inform interventions to reduce health inequities.

Supplementary Information The online version contains peer-reviewed but unedited supplementary material available at https://doi.org/10.1007/s00125-021-05582-5.

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Data availability The datasets generated during and/or analysed during the current study are not publicly available due to ethical restrictions but are available from the researchers of the HHH project Manuel Franco (manuel.franco@uah.es) and Isabel del Cura (isabel.cura@salud.madrid.org) on reasonable request.

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Authors' relationships and activities The authors declare that there are no relationships or activities that might bias, or be perceived to bias, their work.

Contribution statement LC and PG conceived the idea. UB developed the area-level socioeconomic status index. LC collected and cleaned the database of exercise facilities. LC and PG carried out the statistical analysis. LC carried out the spatial analysis and the cartography. LC drafted the manuscript. PG, UB, DV, IDC, HB and MF contributed to discussion and data interpretation and edited and reviewed the manuscript. LC, PG and MF are the guarantors of this work and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. All authors have approved the final version.

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CHAPTER 7.

Study 3:

Exercise facility availability and incidence of type 2 diabetes and complications in Spain: a population-based retrospective cohort 2015-2018

7.1 Background of Research Study 3

The Study 3 were developed to cover the third and fourth objectives of the thesis research. This longitudinal study allowed us to confirm causal association between exercise facility availability and T2DM, by a 4-years follow up of the whole adult population of Madrid aged between 40 and 75 years. Specifically, the objective of the research was to explore (1) association between exercise facility availability and 4-years incidence of T2DM in adult population of Madrid; (2) association between exercise facility availability and 4-years incidence of macrovascular and microvascular complications among diabetic adult population of Madrid; (3) explore possible disparities in both associations by area-level SES and sex.

This has been the first research exploring the influence of differences in access to exercise facilities in the place of residence and incidence of T2DM and macrovascular and microvascular complications of T2DM. Likewise, this research has provided a value information by social stratification to have a better understanding on the differential impact of exercise inequities on the incidence of T2DM and its complications.

As the previous studies, I carried out this study in the entire city of Madrid. The main exposure of the study was the count of exercise facilities in a 1,000m street network buffer, measured by GIS. For the incidence analysis, we followed ~1.4M adults (representing > 95% of the population of 40–75 year-olds living in Madrid at the start date of the study), obtaining from EMRs the diagnosis of T2DM and its complications. T2DM was defined using the T90 diagnosis code (‘diabetes non-insulin dependent’), whose diagnoses have been previously validated with a κ of 0.99, with a sensitivity of 99.5% and a specificity of 99.5%. T2DM complications were also identified using the following ICPC-2 codes: ischemia (K74), stroke (K89), chronic kidney disease (U99.01), retinopathy (F83), and peripheral vascular disease (K92). Further supplementary information can be found in Appendix.

7.2 Research Study 3

Exercise facility availability and incidence of type 2 diabetes and complications in Spain: a population-based retrospective cohort 2015-2018

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Author contribution: Luis Cereijo and Pedro Gullón conceived the idea. Usama Bilal developed the area-level socioeconomic status index. Luis Cereijo developed and cleaned the exercise facility database. Luis Cereijo carried out the spatial analysis. Luis Cereijo carried out the statistical analysis, with the collaboration of Usama Bilal and Pedro Gullón. Luis Cereijo drafted the manuscript. All authors contributed to discussion, data interpretation, and edited and reviewed the manuscript. Manuel Franco acquired the funds for the development of the study. Luis Cereijo, Pedro Gullón and Manuel Franco are the guarantors of this work and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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Exercise facility availability and incidence of type 2 diabetes and complications in Spain: A population-based retrospective cohort 2015–2018

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ABSTRACT

Background: To study the association between exercise facility availability and type 2 diabetes incidence and its complications, and to explore effect modification by socioeconomic status (SES) and sex in the Madrid adult population.

Methods: A multilevel longitudinal design, based on a population-based retrospective cohort including 1,214,281 residents of Madrid (Spain) aged 40–75 years from 2015 to 2018. Outcomes were type 2 diabetes incidence and macrovascular (cardiac ischemia and/or stroke) and microvascular (chronic kidney disease, retinopathy, and/or peripheral vascular disease) complications in those with diabetes at baseline. Exercise facility availability was defined as the count of exercise facilities in a 1000 m street network buffer around each participant's residence. Poisson regression models with robust standard errors were used to estimate the risk ratios (RR). Interactions were explored with SES tertiles and by sex.

Results: Residents living in areas with lower exercise facility availability showed higher risk of type 2 diabetes ($RR_{tertile3vs1}$ = 1.25, CI95% 1.21–1.30) as well as macrovascular ($RR_{Tertile\ 3vs1}$ = 1.09 CI95% 1.00–1.19), and microvascular ($RR_{Tertile\ 3vs1}$ = 1.10 CI95% 1.01–1.19) complications. Associations were strongest in low SES areas for type 2 diabetes ($RR_{tertile3vs1\text{-}LOW\text{-}SES}$ = 1.22, CI95% 1.12–1.32; $RR_{tertile3vs1\text{-}HIGH\text{-}SES}$ = 0.91, CI95% 0.85–0.98) and microvascular complications ($RR_{tertile3vs1\text{-}LOW\text{-}SES}$ = 1.12, CI95% 0,94–1,33; $RR_{tertile3vs1\text{-}HIGH\text{-}SES}$ = 0.88, CI95% 0.73–1.05).

Conclusions: Living in areas with lower availability of exercise facilities was associated with a greater risk of type 2 diabetes and its complications. Increasing exercise opportunities, particularly in low SES areas, could help reduce the social gradient of diabetes and its complications.

Abbreviations: CI, Confidence Interval; EMR, Electronic Medical Records; ICPC, International Classification of Primary Care; RR, Risk Ratio; SES, Socioeconomic Status; RECORD, Reporting of studies Conducted using Observational Routinely-collected Data; IQR, Interquartile Range Interval.

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1. Background

Type 2 diabetes incidence doubled between 1990 and 2017 worldwide (Liu et al., 2020); it is now one of the leading causes of mortality with an estimated 1.5 million deaths annually (WHO, 2021). Diabetes burden includes not only the disease itself, but also microvascular and macrovascular complications associated with poor control of diabetes, including coronary heart disease, ischaemic stroke, chronic kidney disease, retinopathy, and peripheral vascular disease (IDF, 2021). Physical activity, and exercise, in particular, have been highlighted as key strategies for diabetes risk reduction (Gillies et al., 2007; Kriska et al., 2021), diabetes control (Colberg et al., 2016; Colberg and Swain, 2000; Sigal et al., 2004), and cardiovascular disease prevention (Thijssen et al., 2018).

It is essential to work at the population level by intervening on social determinants of health to successfully address the burden of disease (Rose, 1985). Universal 'upstream' or population-level interventions can help mitigate the social gradient of diabetes (Bilal et al., 2018b) and cardiovascular diseases (Gullón et al., 2020). For example, disparities in the availability of physical activity resources at the neighbourhood-level are important determinants of type 2 diabetes, cardiovascular diseases, and physical activity (Bilal et al., 2018b; Eriksson et al., 2012; Van Cauwenberg et al., 2018), with the strongest relationships existing for those most disadvantaged (Gaskin et al., 2014). Specifically, access to exercise facilities might provide additional benefits compared with other physical activity settings (e.g. parks or other non-supervised settings), as exercise facilities typically offer supervised moderate to vigorous physical activity programs. Engaging in supervised physical activity programs has been associated with greater reductions in HbA1c compared with unsupervised and/or low-intensity physical activities (Umpierre, 2011). However, the main focus of exercise facility research to date has been on elite sports performance outcomes (Andrews et al., 2005), rather than the public health benefits.

Previous work has shown that exercise facility availability is associated with the prevalence of type 2 diabetes, with a stronger relationship evident for residents living in more disadvantaged areas (Cereijo et al., 2022). Other research has found associations between the availability of physical activity resources and the risk of type-2 diabetes and different cardiovascular diseases (Chandrabose et al., 2019; Christine et al., 2015; Malambo et al., 2016). However, the study of the mechanistic pathway of the physical activity environment and its influence on diabetes burden is lacking in Southern Europe (Bilal et al., 2019). Furthermore, relatively little research has examined the influence of exercise facility availability and diabetes burden, and even less have utilised a longitudinal design (Bilal et al., 2018a; Christine et al., 2015). Understanding how exercise facilities influence diabetes incidence and macrovascular and microvascular complications will provide valuable knowledge regarding the importance of exercise resources in primary and tertiary prevention of diabetes.

Building on these gaps in the literature, this study aimed to: (1) examine the association between exercise facility availability and type 2 diabetes incidence in the adult (40–75 years old) population of Madrid; (2) examine the association between exercise facility availability and macrovascular (cardiac ischemia and/or stroke) and microvascular (chronic kidney disease, retinopathy, and/or peripheral vascular disease) complications in adults with diabetes; and (3) examine effect measure modification by area-level socioeconomic status (SES) and sex.

2. Methods

Study Design. This study followed a multilevel longitudinal design, based on a population-based retrospective cohort. It used data from primary care electronic medical records (EMR) in the city of Madrid, Spain between 2015 and 2018. The information related to health outcomes was collected by the primary care physicians during the study period as part of the ordinary follow-up of patient care. All data were extracted from the primary care EMR on February 23, 2022. This study has been reported based on the Strengthening the Reporting of studies Conducted using Observational Routinely-collected Data (RECORD), an extension to the STROBE statement to address reporting items specific to observational studies using routinely collected health data, such as EMRs (Benchimol et al., 2015) (see the RECORD checklist in the Supplementary Table 1).

Setting. This study was conducted in the city of Madrid (Spain), as part of the larger Heart Healthy Hoods project (www.hhhproject.es) (Bilal et al., 2016). In 2015 Madrid had a population of 3.1M residents, divided into 2420 census tracts *(secciones censales)*, the smallest unit of spatial aggregation at which the census releases demographic data, with around ~ 1500 residents in each (Ayuntamiento de Madrid, 2022). Further information about the structure and characteristics of the administrative units in Spain is shown in the Supplementary Table 2.

Study Population. The cohort was based on real-world data from primary care including information from 1,442,840 residents, representing >95% of the population of 40–75 year-olds living in Madrid at the start date of the study. The sample was selected according to the HHH Project criteria (Bilal et al., 2016), being individuals who: (a) lived in the Municipality of Madrid and were registered at one of the 128 primary health care centres in the Municipality of Madrid; (b) were aged 40–75 years; (d) were registered in the EMRs of the Primary Health-care Service of Madrid (AP-MADRID) in 2017, and had no missing data for diabetes and/or macrovascular and microvascular complications.

Following screening criteria for cardiovascular risk factors (Bilal et al., 2016), we further restricted the EMR dataset to people born after January 1, 1975 (≥40 years at 2015) as screening for cardiovascular risk factors in Madrid begins at this age. After excluding all participants with geolocation data missing (n = 43,477) and those who moved during the study period (n = 185,082), the final study sample was 1,214,281 participants. Excluded participants (n = 228,559) followed a similar distribution of age and health outcomes, overall and by sex, to the final study sample (see Supplementary Table 3).

As described in Fig. 1, we defined two cohorts for this analysis: Incidence Analysis Cohort, composed of all participants who met the inclusion criteria and did not have type 2 diabetes at baseline (n = 1,127,346); Complications Analysis Cohort, composed of all participants who met the inclusion criteria with any type of prevalent diabetes at baseline, but free of diabetes complications (i.e. cardiac ischemia, stroke, chronic kidney disease, retinopathy, and peripheral vascular disease) (n = 73,627).

Health Outcomes. Diagnoses were extracted from EMRs for all individuals, as recorded by primary care physicians during their usual clinical care. These diagnoses were coded according to the International Classification of Primary Care (ICPC-2). The primary outcome of the incidence analysis was type 2 diabetes incidence (T90), defined as a new case in someone free of type 2 diabetes at baseline. Type 2 diabetes diagnoses in the Primary Health-care Service of Madrid dataset have been previously validated with a kappa of 0.99, with sensitivity (99.5%) and specificity (99.5) (De Burgos-Lunar et al., 2011). The primary composite outcome of the complications analysis was an incident case of macrovascular (cardiac ischemia and/or stroke) and microvascular (chronic kidney disease, retinopathy and/or peripheral vascular disease) complications in someone free of these diseases at baseline. These complications were also identified using the following ICPC-2 codes: ischemia (K74), stroke (K89), chronic kidney disease (U99.01), retinopathy (F83), and peripheral vascular disease (K92). We also analysed the association between exercise facilities availability and these complications separately (see Supplementary Table 4).

Exercise facilities availability. Exercise facilities (N = 595) were defined as venues that offered exercise programs, regardless if activities were offered on a free, monthly subscription, or pay per session (e.g. fitness clubs, sports centres, dance clubs, Pilates studios) membership basis, and regardless of being publicly or privately owned. Exercise facility information, including location, was collected by 'MAS Servicios

Integrales', a fitness consultancy firm, between April and October of 2015. Further information regarding data collection can be found elsewhere (Cereijo et al., 2019, 2022) and in Supplementary Table 5.

The final exercise facility dataset comprised 595 facilities with information collected across five characteristics: (1) facility name; (2) facility physical address; (3) monthly attendance price; (4) types of programs and services offered; and (5) ownership type (public vs private).

Based on the definition by Penchansky and Thomas (1981), exercise facility availability was calculated as the count of facilities within a 1000 m street network buffer from each residential building entrance in Madrid (hereafter called portals). These portals were captured by identifying all external access points to residences located on residential land parcels using the GEOPORTAL of the Madrid City Council (Instituto Geográfico Nacional, n.d.). Spatial measures were calculated using QGIS 3.10.5 software. Portals in a census tract were aggregated and the mean count of exercise facilities for each census tract was calculated. The 1000 m buffer is regarded as an appropriate walking distance for undertaking daily activities, has been used in exercise facility research (Cereijo et al., 2019, 2022; Eriksson et al., 2012; Mason et al., 2018), and has the highest correlation with moderate-to-vigorous physical activity (Eriksson et al., 2012). Census tracts were stratified into tertiles based on

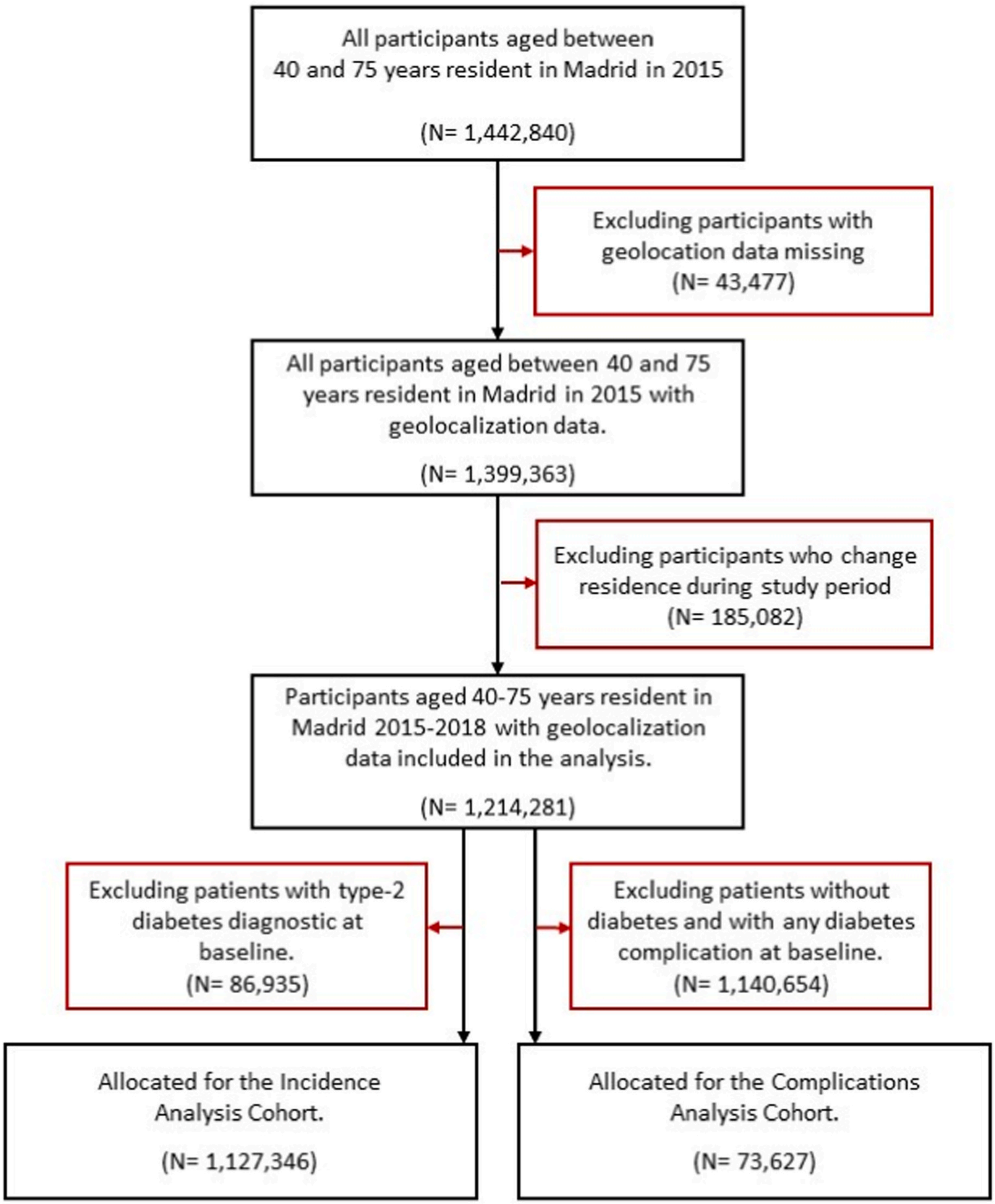

Fig. 1. Flow chart of the study sample and subpopulations definition.

exercise facility availability. Sensitivity analyses were carried out using deciles of exercise facility availability.

Area-Level Socioeconomic Status. We used an index composited using seven area-level socioeconomic status indicators: (1) Low education; (2) High education; (3) Part-time employment; (4) Temporary employment; (5) Manual occupational class; (6) Average housing prices (per m^2); and (7) Unemployment rate. The selection of these indicators follows the four domains in the Spanish Commission to Reduce Health Inequalities, being education, wealth, occupation and living conditions (Ministerio de Sanidad Servicios Sociales e Igualdad, 2015). The index has been applied to each census tracts across Madrid and census tracts collapsed into tertiles (low, medium, high SES). The index has been used in previous studies (Bilal et al., 2018b; Cereijo et al., 2019, 2022), and further details regarding index construction are described in Supplementary Table 6.

Statistical Analysis. The analysis was carried out in three steps. First, we described the clinical and demographic characteristics of both cohorts. Second, to estimate the cumulative incidence resulting in estimates of the risk ratios (RR), Poisson regression models with robust standard errors clustered at the census tract were carried out between exposure (tertiles of exercise facility availability) and each outcome for the Incidence Analysis Cohort and the Complications Analysis Cohort. We initially created an unadjusted model (Model 0), then adjusted the model by age, sex, and population density (Model 1, and finally adjusted by area-level SES (Model 3).

Third, to identify any potential effect modification from area-level SES with the availability of exercise facilities, we carried out a three-way interaction between the availability of exercise facilities, area-level SES, and sex, using a Wald test to get a p-value for each interaction. Results were presented for the whole sample and stratified by sex, using the highest tertile of exercise facilities available as the reference group.

Further sensitivity analyses were conducted. Firstly, we carried out an analysis by deciles of exercise facility availability to examine potential non-linear relationship between exercise facility availability and type 2 diabetes, macrovascular and microvascular complications. Secondly, we carried out an analysis between tertiles of exercise facility and incidence excluding those participants who did not develop any of the health outcomes investigated during follow-up and died during the study period ($n = 12,682$; $>1\%$), to test a potential competing risk of death.

All analyses were conducted using Stata/IC 14.2 for Windows (StataCorp., College Station, TX, USA), and plots were conducted with R V3.6.1.

Ethics. The HHH study was conducted according to the guidelines laid down in the Declaration of Helsinki and received IRB approval from the Ethics Research Committee of the Madrid Health Care System on May 12, 2015.

3. Results

Table 1 shows the characteristics of the study sample stratified by tertiles of exercise facility availability. Overall, men showed a greater risk of type 2 diabetes after 4 years of follow-up (2.1%) than women (1.2%). Macrovascular and microvascular complications followed the same pattern by sex with a greater 4-year incidence for men compared with women for macrovascular and microvascular complications over time. Areas with a lower availability of exercise facilities present higher incidence cases of type 2 diabetes, macrovascular and microvascular complications than areas with medium and low availability.

Table 2 shows the results of the main analysis. Areas within the lowest tertile of exercise facilities had a 25% increased risk of 4-year incidence of type 2 diabetes ($RR_{Tertile\ 3vs1} = 1.25$ 95%CI 1.21–1.30), a 9% increased risk of 4-year incidence of macrovascular complications ($RR_{Tertile\ 3vs1} = 1.09$ CI95% 1.00–1.19), and a 10% increased risk of 4-year incidence of microvascular complications ($RR_{Tertile\ 3vs1} = 1.10$ CI95% 1.01–1.19) (Model 2). Nevertheless, all associations were attenuated after adjustment by area-level SES (Model 3).

The sensitivity analysis conducted by deciles of exercise facility availability showed a gradual and linear association between exercise facility availability and type 2 diabetes, except the lowest decile. The results for macrovascular and microvascular complications showed slight variations across the deciles, although they do not modify the overall gradient view of the association (see Supplementary Table S7). Sensitivity analysis carried out excluding those participants who did not develop any of the health outcomes investigated during follow-up and died during the study period showed changes negligibly and therefore, the competing risk of death was not relevant for this study (see Supplementary Table S8).

Fig. 2 shows the results of the analysis examining effect measure modification by area-level SES. Analysis interacted by SES tertiles showed that low SES areas have a higher association between lower exercise facility availability and incidence of type 2 diabetes ($RR_{Tertile\ 3vs1} = 1.22$ CI95% 1.12–1.32) as compared with those living in high SES areas with lower availability of exercise facilities ($RR_{tertile3vs1} = 0.91$, 95%CI 0.85–0.98) (p-value for interaction <0.001). Results of the interaction with SES and sex (p-value for interaction <0.001) showed a greater association for men living in lower SES areas and with lower exercise facility availability ($RR_{Tertile\ 3vs1} = 1.26$ CI95% 1.13–1.40) than women ($RR_{Tertile\ 3vs1} = 1.17$ CI95% 1.04–1.32). However, those living in high SES areas showed an inverse association with a lower incidence of type 2 diabetes when living with a lower availability of exercise facilities ($RR_{tertile3vs1} = 0.91$, 95%CI 0.85–0.98).

Analysis for microvascular complications showed the same effect modifications for area-level SES. Areas with lower SES have a stronger association between lower exercise facility availability and 4-year incidence microvascular complications ($RR_{Tertile\ 3vs1} = 1.12$ 95%CI 0.94–1.33), compared with high SES areas with lower availability of exercise facilities ($RR_{tertile3vs1} = 0.88$, CI95% 0.73–1.05) (p-value for interaction <0.17) (see Fig. 3). Similar to the previous analysis, people living in high SES areas showed a lower risk when living in areas with lower availability of exercise facility than those living with higher exercise facility availability ($RR_{Tertile\ 3vs1} = 0.88$ 95%CI 0.73–1.05).

Results of the analysis of microvascular complications interacted with SES and sex (p-value for interaction <0.001) showed a greater association for men living in lower SES areas and with lower exercise facility availability ($RR_{Tertile\ 3vs1} = 1.28$ CI95% 1.01–1.62) than women ($RR_{Tertile\ 3vs1} = 0.93$ 95%CI 0.72–1.20). Likewise, analysis interacted with SES and sex for macrovascular complications (p value for interaction <0.001) showed stronger association for men from areas with low SES and exercise facility availability ($RR_{Tertile\ 3vs1} = 1.17$ CI95% 0.92–1.50) than women living in similar areas ($RR_{Tertile\ 3vs1} = 1.12$ CI95% 0.81–1.54).

4. Discussion

This four-year longitudinal study found associations between exercise facility availability and diabetes burden, with the strongest associations existing for people living in low SES areas, especially for men. People living in areas with a lower availability of exercise facilities have a greater risk of type 2 diabetes, although this association was attenuated after adjusting for SES. We also found that people with type 2 diabetes living in areas lacking exercise facilities have a higher incidence of macrovascular (cardiac ischemia and/or stroke) and microvascular diabetes complications (chronic kidney disease, retinopathy, and/or peripheral vascular disease), although this association was weaker when compared with diabetes incidence. To our knowledge, this is the first study that has examined associations between exercise facility availability and diabetes burden, including not only disease risk, but also the incidence of macrovascular and microvascular complications over time.

Our findings showed that people living in areas with fewer exercise

Table 1
Characteristics of the study sample.

	INCIDENCE ANALYSIS COHORT						COMPLICATIONS ANALYSIS COHORT					
	OVERALL			Low Availability	Medium Availability	High Availability	OVERALL			Low Availability	Medium Availability	High Availability
	Overall	Men	Women				Overall	Men	Women			
	(N = 1127346)	(N = 512120)	(N = 615226)	(N = 374344)	(N = 373863)	(N = 379139)	(N = 73627)	(N = 40986)	(N = 32641)	(N = 26091)	(N = 25918)	(N = 21618)
Age												
Median	53	52	54	52	53	54	64	62	66	63	64	64
(IQR)	(46.0, 62.0)	(45.0, 61.0)	(46.0, 63.0)	(45.0, 61.0)	(46.0, 62.0)	(46.0, 63.0)	(56.0, 70.0)	(54.0, 69.0)	(57.0, 71.0)	(55.0, 70.0)	(56.0, 70.0)	(56.0, 70.0)
Area-Level SES index value												
Median	−0.16	−0.18	−0.14	−0.50	−0.49	0.59	−0.45	−0.41	−0.50	−0.70	−0.63	0.39
(IQR)	(-0.76, 0.67)	(-0.77, 0.66)	(-0.74, 0.69)	(-1.06, 0.44)	(-0.94, 0.19)	(-0.21, 0.82)	(-1.00, 0.38)	(-0.97, 0.44)	(-1.02, 0.30)	(-1.23, −0.09)	(-1.04, −0.10)	(-0.36, 0.75)
Population Density												
Median	1340	1350	1340	1420	1380	1270	1300	1310	1270	1310	1320	1250
(IQR)	(1080, 1730)	(1080, 1730)	(1080, 1720)	(1110, 1900)	(1090, 1800)	(1050, 1560)	(1040, 1630)	(1060, 1650)	(1030, 1600)	(1030, 1670)	(1060, 1680)	(1040, 1540)
Exercise Facilities												
Median	6.19	6.09	6.33	2.19	6.18	13.5	5.89	5.89	5.89	2.29	6.2	13
(IQR)	(3.13, 10.9)	(3.06, 10.7)	(3.31, 11.0)	(1.29, 3.12)	(5.07, 7.43)	(10.9, 17.6)	(3.00, 9.72)	(3.00, 9.75)	(3.00, 9.64)	(1.42, 3.27)	(5.10, 7.45)	(10.5, 16.5)
Type 2 diabetes	17,938 (1.6%)	10,558 (2.1%)	7380 (1.2%)	6202 (1.7%)	6371 (1.7%)	5365 (1.4%)						
Macrovascular complications							2878 (3.9%)	1954 (4.8%)	924 (2.8%)	1050 (4.0%)	1011 (3.9%)	817 (3.8%)
Microvascular complications							3297 (4.5%)	2135 (5.2%)	1162 (3.6%)	1219 (4.7%)	1137 (4.4%)	941 (4.4%)

Data displayed are n (%), median (IQR), population density is habitants per square kilometre, availability of exercise facilities are count in 1000 m buffer. Exercise facility availability categories are tertiles. Key: SES= Area-Level Socioeconomic Status. IQR= Interquartile Range.

Table 2
Association (relative risks and 95% confidence intervals) between exercise facility availability and incidence of type 2 diabetes, macrovascular and microvascular complications in Madrid.

Exercise facility availability	Model 0 Crude	Model 1 Adjusted by age, sex and population density	Model 2 Adjusted by age, sex, population density and SES
Type 2 Diabetes			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.20** (1.16–1.25)	**1.23** (1.19–1.28)	**0.99** (0.95–1.03)
Low density	**1.17** (1.13–1.21)	**1.25** (1.21–1.30)	**0.99** (0.95–1.03)
Macrovascular complications			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.03** (0.94–1.13)	**1.04** (0.95–1.14)	**1.00** (0.91–1.10)
Low density	**1.06** (0.97–1.17)	**1.09** (1.00–1.19)	**1.04** (0.94–1.15)
Microvascular complications			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.01** (0.93–1.10)	**1.02** (0.93–1.11)	**0.95** (0.87–1.04)
Low density	**1.07** (0.99–1.17)	**1.10** (1.01–1.19)	**1.02** (0.93–1.11)

Results are Relative Risk (Confidence Interval at 95%). Key: Ref = Tertile of Reference. SES= Area-Level Socioeconomic Status.

facilities had a 25% increased risk for type 2 diabetes. These results are consistent with a previous study that have shown a higher risk of type 2 diabetes for people living in areas with lower availability of exercise facilities (Christine et al., 2015) as well as other studies with green and open spaces (Dalton et al., 2016; Paquet et al., 2014). The present study also found a negative association between exercise facility availability and the incidence of macrovascular and microvascular complications associated with poor diabetes control. Previous research has shown similar associations between access to physical activity resources and diabetes and cardiometabolic risk (Chandrabose et al., 2019; Dalton et al., 2016; Paquet et al., 2014). Moreover, there is a body of evidence showing associations between exercise facility availability around home and physical activity levels (Hanibuchi et al., 2011; Pascual et al., 2013; Van Cauwenberg et al., 2018; Wylie et al., 2015). Given the existing direct relationship between physical activity levels and diabetes risk (Gillies et al., 2007; Kriska et al., 2021) and management (Colberg et al., 2016; Colberg and Swain, 2000; Sigal et al., 2004), this causal pathway may explain our results.

Our analysis showed that the association between exercise facility availability and diabetes and its complications was largely attenuated after adjusting for area-level SES. This attenuation implies that part of the effect of SES on the incidence of type 2 diabetes and its complications occurs through the differential distribution of exercise facilities throughout the city. Indeed, previous research with older adults in Madrid has found a mediation effect of exercise facility availability between neighbourhood economic context and physical inactivity (Pascual et al., 2013). Therefore, we suggest that exercise facility availability may be a partial mediator of the influence exerted by the area-level SES on the incidence of diabetes and its micro and macrovascular complications.

Although area-level SES largely attenuated the exercise facility-diabetes association, this may be masking heterogeneity. Therefore, we observed not only the effect on the population but also possible effect differences by socioeconomic status. Our findings showed that the association between exercise facility availability and diabetes burden was highest for people living in low SES areas. This has health equity implications, whereby those living in more deprived areas have a higher vulnerability to a lack of exercise facilities available. Previous research has shown that exercise facility distribution in Madrid follows a social gradient (Cereijo et al., 2019), and other studies found a similar effect modification by area-level SES when observing the association between exercise facilities and the prevalence of diabetes and obesity (Angraal et al., 2019; Cereijo et al., 2022; Mason et al., 2018). Our results also showed an inverse association for those living in high SES areas, consistent with previous studies (Schüle and Bolte, 2015). These results may suggest that residents from high SES areas may have more resources and alternatives to enable them to participate in activities located outside of their local neighbourhood (e.g. golf, tennis, personal trainers …); so they are not as reliant on facilities available to them in their immediate neighbourhood compared with people of lower SES.

Finally, these results showed some differences by sex on the association between exercise facility availability and diabetes burden. Overall, men living in low SES areas showed a stronger association between exercise facility availability and incidence of type 2 diabetes and microvascular complications than women living in low SES areas. This association could be influenced by the higher type 2 diabetes incidence in men than previously reported (Vega et al., 2015). However, in our study, in medium SES areas, women showed stronger associations

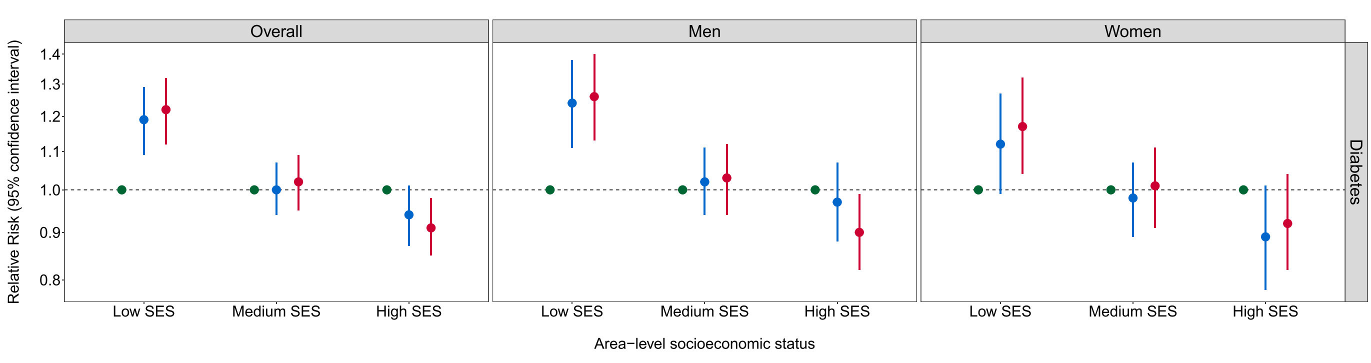

Fig. 2. Association between exercise facility availability and incidence of type 2 diabetes, with interactions by area-level SES, stratified by sex, and adjusted by age and population density.
Key: Dashed lines at zero represent the reference group (highest availability of exercise facilities).

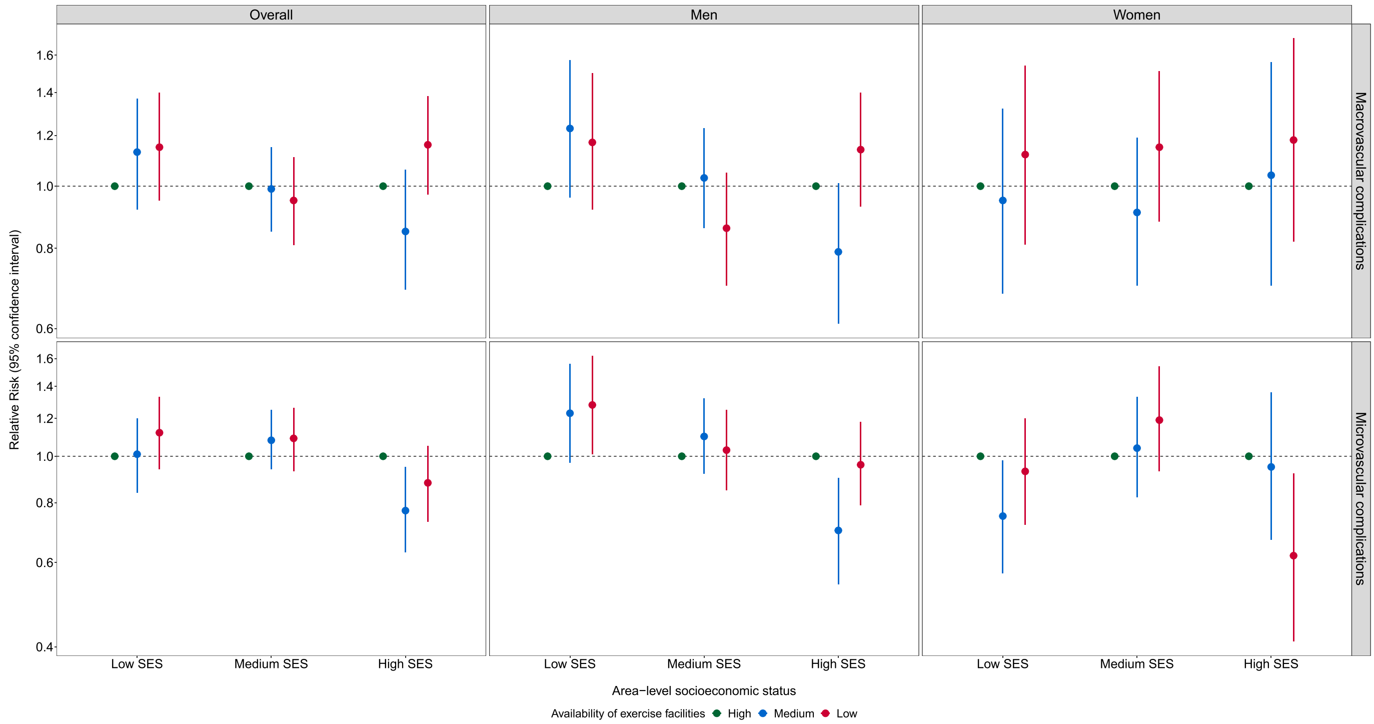

Fig. 3. Association between exercise facility availability and incidence of macrovascular and microvascular complications, with interactions by area-level SES, stratified by sex, and adjusted by age and population density.
Key: Dashed lines at zero represent the reference group (highest availability of exercise facilities).

compared with men for macrovascular and microvascular complications. This denotes the need to undertake longitudinal studies on this topic over a longer period to achieve a more robust understanding of sex differences, SES, and diabetes burden.

Recently, research on social stratification and health has been recommended in social epidemiology (Diez Roux, 2022). Stratified analysis introducing an interaction term by possible variables of interest allows us to identify whether they are confounding the association or, as in the case of this study, they are effect modifiers. This methodological alternative allows us to know the variations that exist between the different social strata, providing a deeper vision to identify how inequalities are associated with the burden of diabetes. Indeed, our results provide important information for the translation of scientific results into practice, showing which areas potentially require interventions to improve access to physical exercise.

Our study presents several strengths. First, this work analyses the whole population aged 40–75 years (N = 1,214,281) of a major European city (Madrid). Utilising such a large sample size allowed us to explore both geographic and demographic differences across the city, while minimising selection bias, unlike surveys or regular cohort studies (Weisskopf et al., 2015). Second, the database of exercise facilities was collected following specific criteria associated with exercise practice, compared with other studies that relied on secondary databases, such as industry classifications or business registers. Third, exercise facilities availability was assess using GIS constructing unique neighbourhood exposures for all participants. Finally, type 2 diabetes diagnosis have been validated previously and other diseases were clinically assessed.

The study also has some limitations. First, we did not measure the physical activity levels of participants or whether they were active at their local exercise facilities; this prevents us confirming the association between exercise facility availability and their use by participants. However, studies have shown positive associations between exercise facility availability and physical activity levels (Hanibuchi et al., 2011; Pascual et al., 2013; Van Cauwenberg et al., 2018; Wylie et al., 2015). Second, the use of administrative boundaries artificially restricts the exercise environment profile if residents live close to neighbourhood boundaries. Third, those participants who moved to another census tract within the study area were excluded due to a lack of information about where they moved to; analyzes are based on exposures collected in 2014, and changing residence to another census tract will change exposure, but what changes is unknown. Fourth, we have no information about validity of diabetes complications. However, all health outcomes were clinically assessed in the EMRs. Finally, there were minor temporal differences across the datasets (2014–2018 for EMRs; 2015 for exercise facilities database, and 2017 for area-level SES). However, it is unlikely that exercise facility availability or area-level SES changed substantially during this period.

5. Conclusions

People living in areas with lower availability of exercise facilities have a higher risk of type 2 diabetes and related macrovascular and microvascular complications. These associations were stronger for people living in low SES areas. Our findings reinforce the role of exercise facility availability as a contributor to the social gradient and as a mechanism for improving population health. This study highlights the relevance of investigating how health outcomes interact with the built environment to improve our knowledge about strategies to reduce health inequities in cities.

Ethics approval

The HHH study was conducted according to the guidelines laid down in the Declaration of Helsinki and received IRB approval from the Ethics Research Committee of the Madrid Health Care System on May 12, 2015.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated during and/or analysed during the current study are not publicly available due to ethical restrictions but are available from the researchers of the HHH Project Manuel Franco, manuel.franco@uah.es, and Isabel del Cura, isabel.cura@salud.madrid.org, on reasonable request.

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Authors contributions

LC and PG conceived the idea. UB developed the area-level socioeconomic status index. LC developed and cleaned the exercise facility database. LC carried out the spatial analysis. LC carried out the statistical analysis, with the collaboration of UB and PG. LC drafted the manuscript. All authors contributed to discussion, data interpretation, and edited and reviewed the manuscript. MF acquired the funds for the development of the study. MF LC, PG and MF are the guarantors of this work and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Declaration of competing interest

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2023.103027.

List of abbreviations

SES	Socioeconomic Status
RR	Risk Ratio
CI	Confidence Interval
EMR	Electronic Medical Record
ICPC	International Classification of Primary Care

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CHAPTER 8.
Discussion

8.1 Summary of thesis findings

In this research thesis, the entire city of Madrid, Spain (with a sample size of ~1.4M inhabitants) was studied, revealing that exercise facilities play a significant role in the residential environment for preventing and controlling T2DM and its associated diseases. This research focused on the study of the availability of exercise facilities has provided a series of novel valuable findings: (1) the availability of exercise facilities decreases with the area-level SES; (2) greater exercise facility availability was associated with a lower prevalence of obesity and T2DM, and with a lower incidence of T2DM and its microvascular and macrovascular complications; (3) these associations were stronger when low exercise facility availability and low socioeconomic status were combined; (4) in addition, there were gender differences in the associations found. To our knowledge, this is the first investigation exploring exercise facility availability, and its association with prevalence and/or incidence through area-level SES and sex effect modification.

The literature review (Chapter 2) described the main determinants of T2DM burden, such as obesity (main predictor of T2DM), T2DM, and macrovascular and microvascular complications of T2DM. Physical activity was described as one of the best ways to prevent the pathologies associated with the burden of T2DM, and exercise, when performed in locations with programmed and supervised programs, generated significant health gains.

Based on this conceptualisation, the chapter continues evaluating and analysing the different physical activity resources in the urban environment and what type of physical activity practice is most associated with each of them. Thus, based on the literature review, I described a type of physical activity facility that have a mode of use and subscription that allows it to be associated with periodic and repetitive practice, high-quality sports resources that encourage high-intensity activities, and qualified personnel that allow advice and programming of activities, defined as "exercise facilities". Using a social determinants of health framework, I identified a set of potential sources of exercise facility inequity that may require actions to improve population health.

The first empirical study (Chapter 5) provided evidence showing that, although residents from low SES areas in Madrid have better accessibility (i.e. decile 2 showed a -20% change in distance to nearest facility than decile 1) to exercise facilities, they showed worse availability (i.e. decile 8 showed a 4.0 relative change in density of exercise facilities than decile 1) compared with residents from high SES areas. The association between access and area-level SES varied depending on the type of exercise facilities examined, yet public, private and low-cost exercise facilities generally tended to be more proximal in low SES areas. However, availability measures showed an increased likelihood of having more than one exercise facility available as area-level SES increased, with stronger patterning for private and sessional exercise facilities.

The second study (Chapter 6) was a cross-sectional study investigating whether exercise facility availability was related to prevalence of obesity and T2DM. Findings showed an association between exercise facility availability and prevalence of obesity and T2DM. Those people living in areas with fewer exercise facilities have a 22% higher prevalence of obesity and 38% of T2DM compared with those who reside in neighbourhoods with more exercise facilities. Likewise, this study showed that these associations were modified by area-level SES and sex, whereby residents from more deprived areas tended to have lower exercise facility availability and higher prevalence of both diseases, which was more pronounced in women for T2DM.

The third study (Chapter 7) was a longitudinal study between 2015 and 2018 exploring associations between exercise facility availability and 4-year incidence of T2DM and macrovascular and microvascular complications of diabetes. Those residing in areas with lower exercise facility availability showed a 25% higher risk of T2DM, an 8% higher risk of macrovascular complications and a 9% higher risk of microvascular complications of diabetes, when compared with those living in areas with a higher availability of exercise facilities. These associations were stronger for those living in lower SES neighbourhoods.

The above-mentioned findings were discussed in depth earlier in each of the chapters dedicated to each study. The present chapter is devoted to presenting the main contributions of the thesis (section 8.2), possible new avenues of research that opened from this research (section 8.3), strengths and limitations of the research (section 8.4), and a set of policy implications and practical recommendations based on the findings (section 8.5).

8.2 Implications of the findings

8.2.1 Exercise facilities is a relevant urban resource to health improvement

In this thesis, I conducted an extensive analysis of physical activity in relation to enabling physical activity and health improvement. Drawing from the domains and dimensions of physical activity (Sallis et al., 2012; Strath et al., 2013), I identified specific types of physical activities characterised by the following attributes: (1) practiced in leisure time, (2) based on high metabolic cost, (3) planned and supervised by qualified professionals, and (4) aimed at maintaining and/or improving one or more components of fitness. These attributes contribute to better health outcomes than other types of physical activity carried out in urban environments, such as light and/or unsupervised physical activity (Blair et al., 2001; Caspersen et al., 1985; Gajanand et al., 2020; Lee et al., 2011).

Based on this information, I conducted an analysis of the physical activity opportunities of the cities, delving on the characteristics of their physical activities. Through this assessment, I put the focus of this research on exercise facilities due to its provision of physical activities more related with the definition of exercise (Caspersen et al., 1985), and its special contribution to improve health, preventing and controlling many health conditions (Colberg et al., 2016; Gajanand et al., 2020; Garber et al., 2011; Hunter et al., 2020; Innes et al., 2019; Umpierre, 2011), especially considering the effectiveness of exercise programs in reducing the incidence of cardiovascular disease in patients with T2DM (Shinji et al., 2007).

By focusing the research specifically on these types of sports facilities and not grouping them with other physical activity resources, I was able to gain insights into the impact that exercise facilities can have on population health, particularly in populations with diabetes or those at risk of developing it. This provides a relevant knowledge improvement for urban health research, leading to a more comprehensive classification of the built environment. Moreover, this contribution facilitates practical interventions aimed at improving access to exercise facilities for different populations to support the prevention and control of T2DM-related diseases.

8.2.2 Double-disadvantaged scenario: the poorer the neighbourhood, the poorer the exercise facility availability

A contribution of this thesis research was the identification of the social patterning of exercise facilities, whereby lower SES areas have lower availability of exercise facilities. This translates not only into fewer exercise facilities in proximity to residential areas but also a lower competitiveness in the exercise offering, which could influence on the affordability and diversity of the exercise opportunities due to the cumulative supply of exercise in the neighbourhood (e.g. fewer visual stimuli and role models that may encourage physical activity in the environment (Sallis et al., 1990).

Furthermore, the findings show that certain types of exercise facilities with higher quality, which is associated with higher levels of LTPA (Heinrich et al., 2017), programs show even greater inequity in availability. For example, sessional facilities with individualised physical activity programs exhibit the most distinct social pattern. Such tailored programs not only have a better impact on health (Colberg et al., 2016; Gajanand et al., 2020; Garber et al., 2011; Hunter et al., 2020; Innes et al., 2019; Umpierre, 2011), but also lead to greater adherence to exercise than other programs without personalized supervision (Picorelli et al., 2014). Moreover, the social gradient persists in other types of exercise facilities, with private exercise facilities exhibiting the second-most unequal patterning, and low-cost and public exercise facilities showing a more equitable distribution.

Although the social pattern in access to exercise facilities by type of facility has never been studied before, previous studies have analysed association between SES and access to different physical activity resources. Several studies have also found negatives associations between area-level SES and accessibility (i.e. proximity to nearest physical activity resource from home) to green spaces (Hobbs, Green, et al., 2017; Kessel et al., 2009; Mavoa et al., 2015), recreational facilities (Giles-Corti & Donovan, 2002; Mavoa et al., 2015; Pearce et al., 2007) and playgrounds (Cradock et al., 2005; Smoyer-Tomic et al., 2004). Nevertheless, some studies have found inverse associations with better proximity results in high SES areas, but not for other resources (Harris et al., 2015; Rigolon & Flohr, 2014; Wen et al., 2013a).

Regarding availability of exercise facilities (i.e. density of physical activity resources around home), other previous studies have shown results consistent with ours, showing higher availability of exercise facilities in higher SES areas (Estabrooks et al., 2003; Hillsdon et al., 2007; Macintyre, 2000; Powell et al., 2006). However, other studies have reported inverse associations (Ogilvie et al., 2011; Schneider et al., 2015), as well as mixed or null results (Jacobs et al., 2019).

8.2.3 Exercise facility availability is associated with obesity, T2DM and cardio-metabolic diseases risk

This research showed that living with a lower availability of exercise facility was associated with higher rates of prevalence of obesity and T2DM, and a higher risk of T2DM, microvascular and macrovascular complications. Considering the body of evidence finding and association between living with higher exercise opportunities and higher physical activity levels (Duncan et al., 2005; Hanibuchi et al., 2011; Kaufman et al., 2019a; Pascual, Regidor, Álvarez-del Arco, et al., 2013; Sallis et al., 1990; Van Cauwenberg et al., 2018; Wylie et al., 2015), and the influence of physical activity on T2DM prevention (Gillies et al., 2007; Kriska et al., 2021) and control (Colberg et al., 2016; Colberg & Swain, 2000; Sigal et al., 2004), this may be the causal pathway that explaining our results. This hypothesis is consistent with previous research conducted in Madrid with older adults, which found that exercise facility availability mediated the relationship between neighbourhood economic context and physical inactivity (Pascual, Regidor, Arco, et al., 2013).

These findings are consistent with previous studies that have found associations between exercise facilities and prevalence of obesity (Ellaway et al., 2016; Mason et al., 2018), as well as other physical activity facilities (Devarajan et al., 2020; Hobbs, Griffiths, et al., 2017). These T2DM prevalence results are also consistent with other studies showing the same direction in associations for the availability of exercise facilities (Angraal et al., 2019), and other physical activity resources (Astell-Burt et al., 2014; Bilal et al., 2018; Bodicoat et al., 2014).

The extant body of research examining longitudinal relationships between access to exercise facilities and the incidence of T2DM and cardiovascular diseases is notably scarce (Chandrabose et al., 2019). Our T2DM risk results are consistent with previous studies on physical activity facilities (including exercise facilities) (Christine et al., 2015), and green and open spaces (Dalton et al., 2016; Paquet et al., 2014). To our knowledge, the second study carried out in this thesis (Chapter 7) is the first investigating associations between exercise facilities and macrovascular and microvascular complications. The evidence published show associations between lower availability of physical activity resources and higher rates of cardiometabolic diseases (Chandrabose et al., 2019), cardiovascular diseases prevalence (Chum & O'Campo, 2015), cardiovascular risk (Garg et al., 2021; Kaiser et al., 2016) and cardiovascular mortality (Angraal et al., 2019).

Collectively, these results support the hypothesis of this PhD research, which posited that residing in areas with greater exercise facility availability would be associated with improved health outcomes related to T2DM. While there are still some gaps in our understanding, such as describing the potential mediating effect of physical activity practice in the exercise facilities around home, these findings highlight the importance of ensuring equitable distribution of exercise facilities in urban environments as a means of reducing the prevalence and incidence of T2DM-related diseases, as well as improving their management to prevent complications.

8.2.4 Social stratification identified the populations that require priority action

Urban health research has investigated how the built and social environment affect the health outcomes of residents. However, as discussed in Chapter 2, the health status in general, and physical activity levels of the population in particular, is strongly influenced by both structural and individual socioeconomic variables, such as SES, age, and gender (Beenackers et al., 2012; M. L. Booth et al., 1993; Crespo, 2000; Cusatis & Garbarski, 2019; Duffy & MacDonald, 1990; Kruger et al., 2007). These determinants shape the position of individuals in the social structure and affect the distribution of resources and opportunities in society (Ministerio de Sanidad Servicios Sociales e Igualdad, 2015a). As a result, the ability of populations to benefit from the resources of urban environments may be affected by inequities in resource distribution and sociodemographic characteristics.

Few studies have gone beyond adjustment for confounders investigating the potential effect modification by socioeconomic determinants to understand the associations between physical activity-built environment and T2DM (DenBraver et al., 2018). As I have described before, the findings uncovered in this thesis have shown that those populations living in low SES areas have a stronger association between lower exercise facility availability and higher rates of obesity and T2DM prevalence, as well as higher rates of T2DM and macrovascular complications risks. These findings are consistent with previous studies showing higher associations between lower availability of physical activity resources and obesity and T2DM prevalence for more deprived populations (Angraal et al., 2019; Mason et al., 2018).

In this PhD thesis, I applied social determinants of health approach to explore potential differences in the associations between exercise facility availability and T2DM-related diseases based on sociodemographic variables. This approach revealed important practical implications: populations living in areas with lower socioeconomic status were more likely to experience a lack of exercise facilities in their environment, leading to higher prevalence and risks of the diseases studied.

The analysis stratified by socioeconomic determinants highlights that a simple adjustment for socioeconomic variables was not enough, since it prevents both identifying the possible variations caused by certain social determinants, as well as knowing the magnitude of these social differences. Exploring potential stratifications through the introduction of an interaction term provided valuable information for identifying which populations require priority political action over others (Diez Roux, 2022; Gullón et al., 2021).

8.2.5 The case of gender inequities

By stratifying the analyses by sex, it was observed that the associations between exercise facility availability and the prevalence and incidence of the diseases studied differed depending on the sex of the individuals. Distinct trends in gender inequities for the impact of exercise facility availability on T2DM burden were revealed (Chapters 6 and 7). While the cross-sectional analysis indicated a stronger association for women, rather than men, between lower exercise facility availability and prevalence of obesity and T2DM in low SES areas, the longitudinal study findings (Chapter 7) demonstrated a stronger association for men compared with women, although women exhibited a greater association for T2DM risk in medium SES areas. These findings highlight the presence of sex differences and emphasise the importance of conducting longitudinal studies over an extended period to gain a more comprehensive understanding of the relationship between exercise facilities, sex, SES, and the T2DM burden.

The study findings align with previous research on gender differences in access to green spaces (Plans et al., 2019) and exercise facilities (Mason et al., 2018). Other studies have shown that cost and lack of transportation were barriers significantly higher for women than men to access to exercise facilities (Kruger et al., 2007). Likewise, there is a strongly gender inequity on physical activity levels caused by difference in responsibilities assumed by men and women in the household: while men showed higher levels on LTPA, women showed higher levels of physical activity related with house and care work (Cusatis & Garbarski, 2019).

8.3 Limitations and strengths

As with all research, this thesis has several limitations that should be considered when interpreting the findings.

First is the absence of individual behavioural data of the population, such as physical activity levels and exercise facility use. This lack of information has prevented fully confirming the causal pathway between exercise facility availability and T2DM-related diseases studied through the engagement of exercise. However, evidence has shown that a greater availability of exercise facilities is linked to higher facility membership (Kaufman et al., 2019a), as well as with overall higher physical activity (Duncan et al., 2005; Pascual, Regidor, Álvarez-del Arco, et al., 2013; Sallis et al., 1990) and MVPA (Kaufman et al., 2019a). Moreover, the data used in the analysis allows us to understand the overall impact of exercise facility availability on the health outcomes of residents. This includes not only access to exercise equipment and programs within the facility, but also related factors like the visual stimuli provided by a facility-rich environment and the variety of exercise models offered, which can encourage physical activity (Sallis et al., 1990).

Second, due to the absence of individual-level information, I used area-level SES as a measure of disadvantage. Area-level measures of SES may not be suitable proxies for individual-level SES due to potential disagreement between contextual and compositional effects (Pardo-Crespo et al., 2013). Similarly, due to a lack of participants' employment or study address information, availability of exercise facilities was only calculated from residential portals in Madrid. Exercise facilities around workplaces and/or study centres may also be important but were not investigated.

Third, since the research focus was exercise facilities, other physical activity resources were not examined. Therefore, the analyses may not fully capture the potential impact that these resources could have on the associations studied. However, as described in the theoretical framework of this thesis (Chapter 2), the research was restricted to exercise facilities as they provide structured activities at MVPA intensities (Ainsworth et al., 2011), which yields greater health benefits (Blair et al., 2001; Lear et al., 2017; Mason et al., 2018; Umpierre, 2011). Fourth, there were some minor temporal differences across the datasets (2014-2018 for EMRs; 2015 for exercise facilities database; 2017 for area-level SES). While it is unlikely that exercise facility availability or area-level SES changed substantially during this period, this cannot be ruled out. Finally, the health data used in the studies were obtained from EMR data, which may be subject to bias. Nevertheless, a validation study that utilised the same datasets demonstrated accurate diagnoses of T2DM ($\kappa = 0.99$), and all health outcomes were clinically assessed in the EMR.

Likewise, the research has certain strengths that are worth mentioning. First, the studies comprising this thesis have been conducted throughout the city of Madrid, the fifth largest European city. Furthermore, the study has analysed the entire population of residents in Madrid aged 40-75 years (~1.4M adults). This large area of study and sample size allowed us to capture the geographic and demographic variation across the city, while minimising selection bias compared to surveys or regular cohort studies (Weisskopf et al., 2015). Second, while several studies have operationalized access as the number of facilities available per 1,000 population (Pascual, Regidor, Arco, et al., 2013), the number of facilities available at a range of distances around zip code (Powell et al., 2006) or whether facilities were pay- or free-for-use (Estabrooks et al., 2003), I evaluated exercise facilities objectively using GIS from each residence entrance of the entire city of Madrid to create unique neighbourhood exposures for each participant. Thirdly, the exercise facility database was compiled based on specific criteria related to exercise practice and ground-truthed accordingly, in contrast to other studies which utilised secondary databases, such as the national census of sports facilities (Pascual, Regidor, Arco, et al., 2013), or industry and business registers (Powell et al., 2006), which may lead to errors on identification, misclassification and localisation (Boone et al., 2008). Furthermore, secondary databases do not have information about the specific physical activities provided by the facilities, which would prevent us to identify correctly exercise facilities. This limitation has a relevant implication considering the differences in the effect on health based on the type of physical activity.

8.4 Future research directions

This thesis has answered several questions and responded to some gaps existing in the literature. However, some knowledge gaps remain, opening new avenues of research.

8.4.1 Physical activity behaviour measured objectively for a better understanding of the role of exercise facilities in population health

Evidence supports an association between the availability of exercise facilities and higher levels of physical activity (Kaufman et al., 2019a), potentially through use of the facilities available, the visual stimuli provided by the facilities, and/or role-modelling of behaviours (Sallis et al., 1990). Future studies should seek to measure how much physical activity is accumulated at exercise facilities. Preferably these data should be collected objectively (e.g. via accelerometers) so as a time and date stamp can be matched with physical activity intensity to better understand both the physical activity performed by the participants while attending exercise facilities. This will allow us to achieve a better understanding for how exercise facilities support population health.

8.4.2 Qualitative studies to identify barriers and enablers of physical activity access in exercise facilities

The quantitative analysis was valuable for investigating large population sample sizes to draw important conclusions. However, quantitative approaches are limited when trying to identify unknown social perceptions of the population. Integrating qualitative methods to evaluate how exercise facilities are perceived by the population will be helpful in future for gaining a better understanding of the barriers and enablers for using exercise facilities by different population groups (e.g. women, those living in disadvantaged neighbourhoods). Moreover, a wider range of exercise facility characteristics could be assessed to better understand preferences (e.g. service quality, cultural appropriateness, timetabling).

Previous studies have studied barriers and enablers to access exercise facilities (Coen et al., 2018; Heinrich et al., 2017; Kruger et al., 2007; Rivera-Navarro et al., 2022; Sallis et al., 2006; Van Cauwenberg et al., 2018). The most common barrier on access to exercise facilities is the economic cost of the facilities. Geographical reasons have been also identified, such as proximity to residence or convenient to other places where they often go. Quality of exercise facilities, age-appropriate group activities or large assortment of physical activity options are other important determinants conditioning access to exercise facilities for adult population. However, relatively little research has been conducted in Spain at this microscale level, and there is opportunity to further investigate specific barriers and enablers accessing to exercise facilities in adult population in Spain using qualitative approaches.

8.4.3 Better understanding of exercise facility-related gender inequities

Differences shown by gender suggest that future studies should seek to combine quantitative and qualitative approaches to identify, not only gender differences in the use of exercise facilities, but also specific barriers and enablers associated with gender.

The findings revealed on this thesis research add to the vast existing evidence on gender inequalities in access to physical activity. Differences on physical activity domains between men and women showed an unfair distribution of household chores that has harmful consequences to women's levels of LTPA (Cusatis & Garbarski, 2019). Other researches have showed that economic cost and lack of transport were significantly higher for women compared to men (Kruger et al., 2007). Specifically, the findings of this thesis research showed that gender inequalities in access to facilities translate into health inequities in the burden of diabetes.

Previous exercise facility research has shown strong gender associations (Coen et al., 2018). Coen established that gyms' internal processes can reinforce the normalisation of gender differences in exercise type participation, and possibly beyond in daily life. For example, high intensity activities, such as weightlifting, have been reported as replicating aspects of masculinity in ways that reinforce harmful stereotypes (Coen et al., 2018). These gendered constructs need to be understood better to inform the development of exercise-related programs that reduce gender inequities.

Exercise facilities offer a variety of activities, ranging from individual strength training to collective activities with musical support. This variety of activities requires a detailed analysis that allows us to acquire a better understanding of the sexualising inertias that occur within them to inform gender-transformative place-based interventions (Coen et al., 2018; Crossley, 2004, 2006). Examining what happened inside the exercise facilities is crucial for promoting gender equity and addressing inequalities in obesogenic environments. This approach challenges the "fallacy of enclosure" and is essential for achieving significant progress in this area (Biehler & Simon, 2011).

8.4.4 The city as a provider of physical activity: improving the understanding of physical activity environment

This thesis has shown that exercise facilities have inequitable spatial distributions across Madrid, and these distributions have been associated with different health outcomes for different groups. Potentially, other physical activity resources may be distributed differentially across cities, such as recreational facilities (Mavoa et al., 2015; Pearce et al., 2007) and green and open spaces (Kessel et al., 2009; Wen et al., 2013b). These disparities might also contribute to different population-level physical activity outcomes (Guo et al., 2015; James et al., 2015; Kajosaari & Laatikainen, 2020; Karusisi et al., 2013; Pyky et al., 2019; Wendel-Vos et al., 2007). Accordingly, there is an opportunity to undertake a comprehensive analysis of the physical activity environment in the cities. Such a holistic analysis of entire city environments would generate a high-value dataset that quantifies and/or characterises the physical activity provided by a city to its population, but perhaps more importantly, would allow ‘deserts’ of physical activity resources to be identified and targeted.

8.5 Practical implications of the research: policy recommendations

8.5.1 Opportunity to shape exercise facility policy

There is a substantial body of evidence pointing out structural inequities as in part being responsible for physical activity disparities at the individual (Beenackers et al., 2012; M. L. Booth et al., 1993; Crespo, 2000; Cusatis & Garbarski, 2019; Duffy & MacDonald, 1990; Kruger et al., 2007) and neighbourhood level (Atkinson et al., 2005; Giles-Corti, 2006; Sallis et al., 2006; Thornton et al., 2017).

Previous studies have shown that local policies have the potential to encourage physical activity participation of resident populations (Giles-Corti, 2006; Pilkington et al., 2016). A study carried out in England showed that providing universal free access to leisure facilities was associated with a 64% increase in attendances at exercise facilities sessions with significantly greater effect for the more disadvantaged socioeconomic group (Higgerson et al., 2018). This evidence is particularly relevant considering that economic cost is one of the main barrier pointed out by disadvantaged populations in Madrid (Rivera-Navarro et al., 2022).

The framework of social determinants of health (Ministerio de Sanidad Servicios Sociales e Igualdad, 2015a; Solar & Irwin, 2010) showed us that these determinants are beyond the individual control of people and their decisions, highlighting the central role of government action and policies to addressing them. For instance, have been shown that structural changes, such as increasing investment in sport and recreation policies, had greater effects than individual physical activity prescription, leading to higher reductions on incidence of T2DM (Goryakin et al., 2019).

In conclusion, having equitable access to exercise facilities should be considered by countries and cities as a public health strategy cornerstone. Strategies to equitably improve access and public offering of exercise facilities that support moderate-to-vigorous physical activity should be a priority.

8.5.2 Low socioeconomic areas must be the priority

Areas and populations with lower socioeconomic status suffer the most from the lack of exercise facilities near the place of residence, and this is especially detrimental for those who live in disadvantaged neighbourhoods and are poor themselves (i.e. are doubly-disadvantaged).

Our findings showed that low SES areas have a lower exercise facility availability (Cereijo et al., 2019), which is consistent with the barriers reported by Madrid's disadvantaged population highlighting a lack of exercise facilities in their neighbourhoods (Rivera-Navarro et al., 2022). Although the creation or improvement of access to physical activity opportunities entail a high economic investment, previous studies have shown them to be cost-effective and offered gains in both survival and health-related quality of life, and with reasonable cost-per- quality-adjusted life year (Roux et al., 2008).

It is also important to develop targeted interventions to respond to the specific needs of disadvantaged populations. Indeed, disadvantaged populations may respond differently to various features of the built environment, such as concerns around safety, availability of time for physical activity, or challenging working conditions, among other factors (Adkins et al., 2017). Giles-Corti (2006) provides several ideas to shape physical activity inequities in deprived areas. Her study highlighted the importance of design specific programs responding the interests of diverse population groups across the lifespan; likewise, developing individually-oriented programs to facilitate social support for physical activity practices among populations.

In summary, increasing access to exercise opportunities is an efficient intervention to reduce physical inactivity shaping health inequities and improving quality of life of populations. However, it is just as important to develop exercise opportunities tailored to the needs and interests of populations residing in the most deprived areas. For this, it is essential to consider the structural conditions that these populations have to maintain themselves in an exercise program.

8.5.3 Exercise programs should overcome gender differences

Physical activity strategies that seek to reduce health inequalities, as a priority, need to reduce real and/or perceived gender barriers in the design of their activities. Evidence has shown that some physical exercise facilities are inaccessible to women due to gender inequities present in our societies (Coen et al., 2018). For example, some high-intensity activities, such as weightlifting, replicate aspects of masculinities and femininities in ways that reinforce harmful stereotypes. Current evidence recommends reshaping the elements of gendered sport stereo-typing, including interspersing traditionally-gendered activities throughout a more holistic exercise program or de-hierarchizing the masculinities and femininities traditionally perceived through sports.

Addressing strategies that tackle the unfair inequities present in the structures of our societies can be highly beneficial for the social environment, beyond the practice of sports itself. The transformations that take place in these spaces have the potential to transform relationships outside of them on a day-to-day basis (Biehler & Simon, 2011).

In conclusion, the persistence of physical inactivity and its consequences urge public administrations to rely less on the "leisure and free time" approach of public sports policies and assume sports policies as a key public health strategy. This urgency becomes even more relevant considering the prominent inequities associated with access to exercise facilities and their promise for reducing the risk of some of the most prevalent diseases in our societies. Urban areas that are more disadvantaged should be prioritised for delivering free or more affordable exercise programs and facilities to reduce health inequities. Similarly, the design of exercise programs must attend cultural interests of the target populations, as well as develop inclusive activity spaces to reduce gender inequalities.

CHAPTER 9.
Conclusions

This thesis has investigated four research questions focused on the city of Madrid and its adult population. These are: (1) How is the socio-spatial distribution of exercise facilities in Madrid? (2) How disparities in exercise facility availability are associated with differences on prevalence of obesity and/or T2DM? (3) Is the availability of exercise facility associated with the incidence of T2DM and its macrovascular and microvascular complications? and (4) Does SES and/or sex effect modifiers in the associations between exercise facility availability and T2DM, obesity and macrovascular and microvascular complications of T2DM?

This thesis has investigated the impact of the physical activity environment on health outcomes, considering the varying levels of physical activity provided by different urban built environments. During this research, I have found that exercise facilities can play a significant role in preventing and managing T2DM and related diseases in urban areas, due to their structured programs tend to occur at moderate to vigorous intensity, which elicit better health improvement. Following this evidence, I have defined exercise facilities “as facilities, both public and private, which offered physical activity programs, both with monthly subscription or pay per session”.

This research has found that area-level SES have different associations with accessibility and availability of exercise facilities varied depending on facility type. Whereas lower SES areas have a better accessibility to exercise facilities, the high SES areas have a greater number of exercise facilities in the area (availability). Furthermore, associations showed differences depending on the type of exercise facilities. Public exercise facilities have a greater availability in low SES areas than in the higher ones, whereas private and sessional exercise facilities (the most common types) increase their availability as the socioeconomic level of the area increases. These findings showed that the unfair socio-spatial distribution of exercise facilities brings a double disadvantaged scenario for those populations.

The cross-sectional study analysed EMR of 1,270,512 residents of Madrid aged 40-75 years, revealing that populations living in areas with limited access to exercise facilities had higher rates of obesity and T2DM than those with greater availability. The study also identified effect modification by socioeconomic status (SES) and sex, with the combined effect of low SES and limited access to exercise facilities showing higher rates of obesity and T2DM than those areas with lower exercise facility availability and high SES. Likewise, this association was found to be stronger in women than in men.

Finally, a longitudinal analysis of real-world data including information from ~1.4M residents evidenced that exercise facility availability is associated with a higher risk of T2DM and related macrovascular and microvascular complications. Likewise, effect modification by SES were identified with higher associations between exercise facility availability and incidence of T2DM and its microvascular and macrovascular complications.

My thesis research findings yield crucial several health equity implications. Overall, living with a lower availability of exercise facilities is associated with a prevalence and/or incidence of T2DM related diseases, and those living in more deprived areas have a higher vulnerability to a lack of exercise facilities available. This evidence reinforces the role of exercise facility availability as a contributor to the social gradient and as a mechanism for improving population health, underscoring the need for an increase in high-intensity supervised exercise opportunities in lower socioeconomic areas to enhance the prevention and management of T2DM burden in the adult population. The findings highlight the significance of conducting social stratification studies to enhance our comprehension of the varying impact of the urban environment on population health helping in the development of targeted equity interventions to promote better health outcomes for all individuals.

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APPENDIX

ANNEX 1. Supplementary material of study 2

Exercise facilities and prevalence of obesity and type 2 diabetes mellitus: A population study of 1,270,512 adults from an equity perspective in the city of Madrid

Luis Cereijo, Pedro Gullón, Isabel del Cura, David Valadés, Usama Bilal, Hannah Badland, Manuel Franco.

Supplementary Material

ESM Table 1. Characteristics by January 1st, 2017 of administrative units in the City of Madrid and whole Spain.

ESM Table 2. Description of the classification of the exercise facilities based on its characteristics.

ESM Table 3. Area Level Socioeconomic status indicators.

ESM Table 4. Sensitivity analysis by deciles of exercise facilities availability.

ESM Table 5. The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

ESM Table 1. Characteristics by January 1st, 2017 of administrative units in the City of Madrid and whole Spain

	Unit	Description	N	Area*	Population*
SPAIN	**Autonomous Communities**	Main Regional division of Spain	17	11073.55 (4995.87-93827.15)	2031.48 (315.38-8379,82)
	Provinces	Main Regional Subdivision	52	9722.31 (1906.09-21792.47)	611764.5 (84.96-6507.18]
	Municipalities	Main Local division of Spain	8124	34.9 (0.03-1753.85)	0.53 (0-3182.98)
CITY OF MADRID	**Census Districts**	Main Local subdivision	21	14.05 (4.68-237.84)	143.42 (46.88-244)
	Neighborhoods	Sub-divisions of districts	131	1.36 (0.25-187.6)	22.40 (1.11-80.3)
	Census Sections	Basic census area	2443	0.04 [0.1-94.7]	1.2 (0.11-2.44)

Key: *Area is in km^2 and shown as the Median (Min-Max); Population is in 1000s of residents, excluding the two Autonomous Cities (Ceuta and Melilla), and shown as the Median (Min-Max).

ESM Table 2. Description of the classification of the exercise facilities based on its characteristics.

Exercise facility type	Definition	*N (%)*
	All the facilities	595
Publicly owned	Monthly payment option. Public ownership	59 (10%)
Privately owned	Monthly payment ≥ 30€/month. Private ownership	222 (37%)
Low cost	Monthly payment < 30€/month. Private ownership	63 (11%)
Sessional	Facilities with Pay-per-session (e.g. Pilates Studios, Dance Schools, electrostimulation centres…). Private ownership.	251 (42%)

ESM Table 3. Area Level Socioeconomic status indicators.

Construct	Domain	Indicator	Operationalization	Source	Level
SES	Education	Low Education	Residents with mandatory studies or below / all residents aged 25 years or above	Padron	Census Section
		High Education	Residents with university education or above / all residents aged 25 years or above	Padron	Census Section
	Occupation	Part time Jobs	Workers in part-time jobs / all workers	Social Security	Neighbourhood
		Temporary Jobs	Workers in temporal jobs / all workers		
		Manual Occupation Class	Workers in manual or unskilled occupations / all workers		
	Wealth	Housing Prices	Average sale price of housing per m^2	Idealista Report	Census Section
	Living Conditions	Unemployment Rate	Residents registered as unemployed / all residents aged 16–64 years	Employment Service	Neighbourhood

Key: SES = Socio-Economic Status

ESM Table 4. Sensitivity analysis: Association between exercise facility availability (by deciles) and prevalence of obesity and type 2 diabetes in Madrid, adjusted by gender, age and population density

Exercise facilities availability	**Decil 1** High	**Decil 2**	**Decil 3**	**Decil 4**	**Decil 5**	**Decil 6**	**Decil 7**	**Decil 8**	**Decil 9**	**Decil 10** Low
Prevalence Ratio of Obesity	1 (Ref.)	1.08 (1.05 - 1.11)	1.09 (1.06 - 1.12)	1.19 (1.16 - 1.22)	1.22 (1.19 - 1.26)	1.26 (1.23 - 1.30)	1.30 (1.26 - 1.33)	1.30 (1.26 - 1.33)	1.36 (1.33 - 1.40)	1.26 (1.22 - 1.29)
Prevalence Ratio of Type 2 Diabetes	1 (Ref.)	1.13 (1.09 - 1.16)	1.22 (1.18 - 1.26)	1.43 (1.39 - 1.47)	1.41 (1.37 - 1.45)	1.54 (1.49 - 1.58)	1.55 (1.51 - 1.60)	1.57 (1.52 - 1.61)	1.69 (1.64 - 1.74)	1.49 (1.44 - 1.54)

Results are Prevalence Ratio (Confidence Interval at 95%). All coefficients are statistically significant (p<0.000). Ref= Decile of reference.

ESM Table 5. The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.

	Item No.	STROBE items	Location in manuscript where items are reported	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place	Abstract (L.37) Title and L.38

				should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	L. 37 and 38.
Introduction					
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			
Objectives	3	State specific objectives, including any prespecified hypotheses			
Methods					

Study Design	4	Present key elements of study design early in the paper			
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			
Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control		RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If	L. 158 L. 160

		selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case		validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	✗
Variables	7	Clearly define all outcomes, exposures, predictors, potential		RECORD 7.1: A complete list of codes and algorithms used to classify	L. 158

		confounders, and effect modifiers. Give diagnostic criteria, if applicable.		exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group			
Bias	9	Describe any efforts to address potential sources of bias			
Study size	10	Explain how the study size was arrived at			
Quantitative variables	11	Explain how quantitative variables were handled in the			

		analyses. If applicable, describe which groupings were chosen, and why			
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed			

		Cross-sectional study - If applicable, describe analytical methods taking account of sampling strategy (e) Describe any sensitivity analyses			
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	L. 155 ✗

Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	L. 149. 175-177 and 191.
Results					
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage.		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	L. 151-157

		(c) Consider use of a flow diagram			
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time			

		Case-control study - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized			

		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses			
Discussion					
Key results	18	Summarise key results with reference to study objectives			
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing	L. 290-316

				data, and changing eligibility over time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			
Generalisability	21	Discuss the generalisability (external validity) of the study results			
Other Information					
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable,			

		for the original study on which the present article is based			
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Supplementary Material.

*Reference: Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I, Sørensen HT, von Elm E, Langan SM, the RECORD Working Committee. The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) Statement. *PLoS Medicine* 2015; in press.

ANNEX 2. Supplementary material of study 3

Exercise facility availability and incidence of type 2 diabetes and complications in Spain: a population-based retrospective cohort 2015-2018

Luis Cereijo, Pedro Gullón, Isabel del Cura, Usama Bilal, David Valadés, Manuel Franco, Hannah Badland.

Supplementary Material

Supplementary Table 1.	The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data.
Supplementary Table 2.	Characteristics by January 1st, 2015 of administrative units in the City of Madrid and whole Spain.
Supplementary Table 3.	Characteristics of the sample excluded, and characteristics of the sample used in the analysis.
Supplementary Table 4.	Sensitivity analysis for each diabetes complication separately.
Supplementary Table 5.	Description of the classification of the exercise facilities based on its characteristics.
Supplementary Table 6.	Area Level Socioeconomic status indicators.

Supplementary Table 7. Sensitivity analysis: Association between exercise facility availability (by deciles) and incidence of type 2 diabetes, and macrovascular and microvascular complications in Madrid, adjusted by gender, age and population density.

Supplementary Table 8. Sensitivity analysis: Association between exercise facility availability and incidence of type 2 diabetes, and macrovascular and microvascular complications in Madrid, adjusted by gender, age and population density, excluding those participants who did not develop any of the health outcomes investigated during follow-up and died during the study period (n=12,682; >1%).

Supplementary Table 1. The RECORD statement – checklist of items, extended from the STROBE statement, that should be reported in observational studies using routinely collected health data

	Item No.	STROBE items	RECORD items	Location in manuscript where items are reported
Title and abstract				
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found	RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included.	Abstract (L.41)
			RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract.	Title and L.42
			RECORD 1.3: If linkage between databases was conducted for the study,	L. 41

			this should be clearly stated in the title or abstract.	
Introduction				
Background rationale	2	Explain the scientific background and rationale for the investigation being reported		
Objectives	3	State specific objectives, including any prespecified hypotheses		
Methods				
Study Design	4	Present key elements of study design early in the paper		
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection		
Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of	RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not	L. 191

		participants. Describe methods of follow-up.	possible, an explanation should be provided.	
		Case-control study - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls.	RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided.	L. 195
		Cross-sectional study - Give the eligibility criteria, and the sources and methods of selection of participants	RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstrate the data linkage process, including the number of individuals with linked data at each stage.	✗
		(b) Cohort study - For matched studies, give matching criteria and number of exposed and unexposed		

		Case-control study - For matched studies, give matching criteria and the number of controls per case		
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	L. 191, L.205, L.227, L.236
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group.		
Bias	9	Describe any efforts to address potential sources of bias		

Study size	10	Explain how the study size was arrived at		
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why		
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding. (b) Describe any methods used to examine subgroups and interactions. (c) Explain how missing data were addressed.		

		(d) *Cohort study* - If applicable, explain how loss to follow-up was addressed. *Case-control study* - If applicable, explain how matching of cases and controls was addressed. *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling strategy. (e) Describe any sensitivity analyses		
Data access and cleaning methods		..	RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population.	L. 170

			RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	✗
Linkage		..	RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	L. 170, L.205, L.227.
Results				
Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed).	RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	L. 178-184, and figure 1.

		(b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders. (b) Indicate the number of participants with missing data for each variable of interest. (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)		

Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time. *Case-control study* - Report numbers in each exposure category, or summary measures of exposure. *Cross-sectional study* - Report numbers of outcome events or summary measures		
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included.		

		(b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period		
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses		
Discussion				
Key results	18	Summarise key results with reference to study objectives		
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision.	RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of	L. 343-346.

		Discuss both direction and magnitude of any potential bias	misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence		
Generalisability	21	Discuss the generalisability (external validity) of the study results		
Other Information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the		

		original study on which the present article is based		
Accessibility of protocol, raw data, and programming code		..	RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Data availability statement.

Supplementary Table 2. Characteristics by January 1st, 2015 of administrative units in the City of Madrid and whole Spain

	Unit	Description	N	Area*	Population*
SPAIN	**Autonomous Communities**	Main Regional division of Spain	17	11,073.55 (4995.87-93827.15)	2,732.62 (317.05 – 8,399.04)
	Provinces	Main Regional Subdivision	52	9722.31 (1906.09-21792.47)	612.827 (84.26-6437]
	Municipalities	Main Local division of Spain	8119	34.9 (0.03-1753.85)	0.52 (0-315.43)
CITY OF MADRID	**Census Districts**	Main Local subdivision	21	14.05 (4.68-237.84)	142.039 (45,87 – 241,32)
	Neighborhoods	Sub-divisions of districts	131	1.36 (0.25-187.6)	22.43 (1.10-74.94)
	Census Sections	Basic census area	2420	0.04 [0.1-94.7]	1.2 (0.11-2.44)

Key: *Area is in km^2 and shown as the Median (Min-Max); Population is in 1000s of residents, excluding the two Autonomous Cities (Ceuta and Melilla), and shown as the Median (Min-Max).

Supplementary Table 3. Characteristics of the sample excluded, and characteristics of the sample used in the analysis

	Participants excluded			Analytic sample		
	Overall (N=228,559)	**Men (N=109,809)**	**Women (N=118,750)**	**Overall (N=228,559)**	**Men (N=109,809)**	**Women (N=118,750)**
Age	50 (44, 59)	50 (44, 58)	51 (44, 59)	54 (46, 63)	53 (46, 62)	54 (47, 64)
Exercise Facilities	6 (3, 11)	6 (3, 11)	6 (3, 11)	6 (3, 11)	6 (3, 11)	6 (3, 11)
Type 2 diabetes	3,398 (1.58%)	2,030 (2.00%)	1,368 (1.21%)	17,938 (1.59%)	10,558 (2.06%)	7,380 (1.20%)
Macrovascular complications	501 (4.28%)	348 (5.20%)	153 (3.05%)	2,878 (3.91%)	1,954 (4.77%)	924 (2.83%)
Microvascular complications	485 (4.14%)	330 (4.93%)	155 (3.09%)	3,297 (4.48%)	2,135 (5.21%)	1,162 (3.56%)

Data displayed are median (IQR) and n (%). Data for health outcomes are calculated following study criteria: Type 2 diabetes only among those people without a diagnosis of T2DM at baseline; and macrovascular and microvascular complications only among residents with T2DM at baseline.

Key: SES= Area-Level Socioeconomic Status. IQR= Interquartile Range.

Supplementary Table 4. Sensitivity analysis for each diabetes complication separately

4.1 Association (relative risks and 95% confidence intervals) between exercise facility availability and incidence of cardiac ischemia, stroke, chronic kidney disease, retinopathy, and peripheral vascular disease in Madrid

Exercise facility availability	Model 0 Crude	Model 1 Adjusted by age, sex and population density	Model 2 Adjusted by age, sex, population density and SES
Cardiac Ischemia			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**0.95** (0.85 – 1.01)	**0.96** (0.85 – 1.09)	**0.92** (0.81 – 1.05)
Low density	**1.05** (0.93 – 1.18)	**1.07** (0.95 – 1.20)	**1.02** (0.89 – 1.16)
Brain Ischemia			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.12** (0.98 – 1.28)	**1.13** (0.98 – 1.29)	**1.08** (0.93 – 1.25)
Low density	**1.07** (0.94 – 1.23)	**1.11** (0.96 – 1.27)	**1.05** (0.91 – 1.22)
Chronic Kidney Disease			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**0.99** (0.87 – 1.13)	**1.00** (0.88 – 1.14)	**0.94** (0.82 – 1.08)
Low density	**1.02** (0.90 – 1.16)	**1.06** (0.94 – 1.21)	**0.99** (0.86 – 1.13)
Retinopathy			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**0.97** (0.82 – 1.16)	**0.97** (0.82 – 1.16)	**0.93** (0.77 – 1.13)
Low density	**1.14** (0.96 – 1.35)	**1.14** (0.96 – 1.35)	**1.08** (0.90 – 1.30)
Peripheral Vascular Disease			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.09** (0.94 – 1.26)	**1.10** (0.95 – 1.27)	**1.02** (0.87 – 1.18)
Low density	**1.12** (0.97 – 1.29)	**1.14** (0.99 – 1.32)	**1.05** (0.89 – 1.22)

Results are Relative Risk (Confidence Interval at 95%). Key: Ref= Tercile of Reference. SES= Area-Level Socioeconomic Status.

4.2 Association (relative risks and 95% confidence intervals) between exercise facility availability and incidence of cardiac ischemia, stroke, chronic kidney disease, retinopathy, and peripheral vascular disease in Madrid, stratified by terciles of area-level SES

Exercise facility availability	Low SES	Medium SES	High SES
Cardiac Ischemia			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.00** (0.77 – 1.29)	**0.94** (0.77 – 1.15)	**0.78** (0.58 – 1.05)
Low density	**1.09** (0.85 – 1.40)	**0.92** (0.74 – 1.14)	**1.23** (0.96 – 1.56)
Brain Ischemia			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.19** (0.88 – 1.61)	**1.07** (0.86 – 1.34)	**1.00** (0.72 – 1.39)
Low density	**1.18** (0.87 – 1.59)	**1.00** (0.78 – 1.27)	**1.17** (0.86 – 1.59)
Chronic Kidney Disease			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**0.92** (0.71 – 1.18)	**1.02** (0.82 – 1.28)	**0.94** (0.69 – 1.26)
Low density	**0.94** (0.73 – 1.21)	**1.21** (0.96 – 1.53)	**0.84** (0.63 – 1.14)
Retinopathy			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**0.98** (0.67 – 1.45)	**1.15** (0.85 – 1.56)	**0.92** (0.62 – 1.36)
Low density	**1.31** (0.91 – 1.90)	**1.19** (0.86 – 1.64)	**0.80** (0.52 – 1.22)
Peripheral Vascular Disease			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.18** (0.59 – 1.64)	**1.17** (0.92 – 1.47)	**0.47** (0.30 – 0.74)
Low density	**1.27** (0.93 – 1.75)	**0.95** (0.73 – 1.23)	**1.16** (084 – 1.59)

Results are Relative Risk (Confidence Interval at 95%). Key: Ref= Tertile of Reference. SES= Area-Level Socioeconomic Status.

Supplementary Table 5. Description of the classification of the exercise facilities based on its characteristics

Exercise facility type	Definition	*N (%)*
	All the facilities	595
Publicly owned	Monthly payment option. Public ownership	59 (10%)
Privately owned	Monthly payment ≥ 30€/month. Private ownership	222 (37%)
Low cost	Monthly payment < 30€/month. Private ownership	63 (11%)
Sessional	Facilities with Pay-per-session (e.g. Pilates Studios, Dance Schools, electrostimulation centres…). Private ownership.	251 (42%)

Supplementary Table 6. Area Level Socioeconomic status indicators

Construct	Domain	Indicator	Operationalization	Source	Level
SES	Education	Low Education	Residents with mandatory studies or below / all residents aged 25 years or above	Padron	Census Section
		High Education	Residents with university education or above / all residents aged 25 years or above	Padron	Census Section
	Occupation	Part time Jobs	Workers in part-time jobs / all workers	Social Security	Neighbourhood
		Temporary Jobs	Workers in temporal jobs / all workers		
		Manual Occupation Class	Workers in manual or unskilled occupations / all workers		
	Wealth	Housing Prices	Average sale price of housing per m^2	Idealista Report	Census Section
	Living Conditions	Unemployment Rate	Residents registered as unemployed / all residents aged 16–64 years	Employment Service	Neighbourhood

Key: SES = Socio-Economic Status

Supplementary Table 7. Sensitivity analysis: Association between exercise facility availability (by deciles) and prevalence of obesity and type 2 diabetes in Madrid, adjusted by gender, age and population density

Exercise facilities availability	**Decile 1** High	**Decil 2**	**Decil 3**	**Decil 4**	**Decil 5**	**Decil 6**	**Decil 7**	**Decil 8**	**Decil 9**	**Decil 10** Low
Relative Risk of Type 2 Diabetes	1 (Ref.)	1.18 (1.10 - 1.26)	1.21 (1.13 - 1.30)	1.37 (1.28 - 1.46)	1.42 (1.33 - 1.52)	1.44 (1.34 - 1.54)	1.41 (1.31 - 1.51)	1.44 (1.34 - 1.54)	1.52 (1.42 - 1.63)	1.32 (1.23 - 1.42)
Relative Risk of Macrovascular Complications	1 (Ref.)	1.07 (0.89 - 1.28)	1.03 (0.86 - 1.23)	0.99 (0.83 - 1.18)	0.97 (0.82 - 1.16)	1.12 (0.94 - 1.32)	1.12 (0.94 - 1.33)	1.09 (0.92 - 1.29)	1.11 (0.93 - 1.31)	1.10 (0.92 - 1.31)
Relative Risk of Microvascular Complications	1 (Ref.)	1.01 (0.86 - 1.20)	1.04 (0.88 - 1.22)	1.00 (0.85 - 1.17)	0.97 (0.83 - 1.14)	1.06 (0.90 - 1.24)	1.00 (0.85 - 1.18)	1.17 (1.00 - 1.36)	1.08 (0.92 - 1.27)	1.07 (0.91 - 1.26)

Results are Prevalence Ratio (Confidence Interval at 95%). All coefficients are statistically significant (p<0.000). Ref= Decile of reference.

ESM Table 8. Sensitivity analysis: Association between exercise facility availability and incidence of type 2 diabetes, and macrovascular and microvascular complications in Madrid, adjusted by gender, age and population density, excluding those participants who did not develop any of the health outcomes investigated during follow-up and died during the study period (n=12,682; >1%)

Exercise facility availability	**Model 0** Crude	**Model 1** Adjusted by age, sex and population density	**Model 2** Adjusted by age, sex, population density and SES
Type 2 Diabetes			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.20** (1.16 – 1.25)	**1.23** (1.19 – 1.28)	**0.99** (0.95 – 1.03)
Low density	**1.17** (1.13 – 1.21)	**1.25** (1.21 – 1.30)	**0.99** (0.95 – 1.03)
Macrovascular complications			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.03** (0.94 – 1.12)	**1.03** (0.95 – 1.13)	**0.99** (0.90 – 1.09)
Low density	**1.06** (0.97 – 1.16)	**1.08** (0.99 – 1.18)	**1.03** (0.93 – 1.14)
Microvascular complications			
High density	1 (Ref.)	1 (Ref.)	1 (Ref.)
Medium density	**1.00** (0.92 – 1.09)	**1.01** (0.93 – 1.10)	**0.94** (0.86 – 1.03)
Low density	**1.07** (0.98 – 1.16)	**1.09** (1.00 – 1.19)	**1.01** (0.93 – 1.11)

ANNEX 2. Scientific outcomes of the candidate

Other research outcomes that I have carried out during my pre-doctoral period are detailed below.

Other peer-reviewed publications

(*) denotes corresponding author.

(†) denotes co-first authorship.

- Díez, J., Taulet, G., Fontán-Vela, M., González-Rábago, Y., **Cereijo, L.**, Sandín-Vázquez, M., Rodríguez, E., Franco, M., Borrell, C., Bilal, U., & Gullón, P. (2023). Trends and determinants of social inequities in cardiovascular risk factors in Spain: a mixed-methods study. *Gaceta Sanitaria*, *37*. https://doi.org/10.1016/j.gaceta.2023.102298

- Gonzalo-Encabo, P. †, **Cereijo, L. †***, Remón, Á. L. C., Jiménez-Beatty, J. E., Díaz-Benito, V. J., & Santacruz Lozano, J. A. (2021). Associations between individual and environmental determinants and physical activity levels of an active population during the Spanish lockdown. *Preventive Medicine*, *153*(July), 106719. https://doi.org/10.1016/j.ypmed.2021.106719

- Díez, J., Gullón, P., Valiente, R., **Cereijo, L.**, Fontán-Vela, M., Rapela, A., Blanco, A., Valero, I., Haro, A., Blasco, G., Díaz-Olalla, J. M., & Franco, M. (2022). Influence of home/school environments on children's obesity, diet, and physical activity: the SUECO study protocol. *Gaceta Sanitaria*, *36*(1). https://doi.org/10.1016/j.gaceta.2021.04.005

Book chapters

- **Cereijo, L.**, Jiménez, V., Santacruz, JA., Clemente, C. Capítulo: "Contribuciones a la empleabilidad sostenible desde la supresión de barreras socioeconómicas de acceso al ejercicio físico". En: "Intervención para la mejora de la salud desde una perspectiva integradora y multidisciplinar". 1ª Edición. Ed. ASUNIVEP. ISBN: 978-84-09-23220-8.

- Clemente, C., Santacruz, JA., Jiménez, V., **Cereijo, L.** Capítulo: "Salud percibida y práctica de actividad físico-deportiva según las variables sociolaborales en trabajadores europeos". En: "Intervención para la mejora de la salud desde una perspectiva integradora y multidisciplinar". 1ª Edición. Ed. ASUNIVEP. ISBN: 978-84-09-23220-8.

- **Cereijo, L.**, Gullón, P., Badland, H., Franco, M., Valadés, D. Capítulo: "Diseño de un estudio Delphi para la elaboración de un índice para la evaluación de la accesibilidad a la práctica de actividad física en instalaciones deportivas en entornos urbanos". En: "Séptima Jornada de Jóvenes Investigadores de la Universidad de Alcalá". 1ª Edición. Ed. UAH. ISBN: 978-84-177729-43-1.

Presentations at National and International Scientific Meetings

- **XVIII International Conference on Urban Health, 2022**

  Comunicación oral "Associations between exercise facility availability and incidence of Type-2 Diabetes and macrovascular and microvascular complications among 1,214,281 adults in Madrid between 2015-18".

- **XL Reunión Anual de la Sociedad Española de Epidemiología, 2022**

  Comunicación oral "Asociaciones entre disponibilidad de instalaciones deportivas e incidencia de diabetes tipo 2 y sus complicaciones en una población de 1.214.281 adultos en Madrid entre 2015-2018"

- **World Epidemiology Congress, 2021**

  Comunicación oral "Are Exercise Facilities moderating the effect of socioeconomic inequities on the body mass index of the population?"

- **XVI International Conference on Urban Health, 2021**

  Comunicación oral "Exercise facilities and the prevalence of obesity and type 2 diabetes mellitus: An equity-informed population study of 1,270,512 adults in Madrid"

- **XXXIX Reunión Anual de la Sociedad Española de Epidemiología, 2021**
  Comunicación oral “Instalaciones deportivas y prevalencia de obesidad y diabetes mellitus tipo 2: un estudio poblacional de 1.270.512 adultos desde una perspectiva de equidad”

- **XXXVIII Reunión Anual de la Sociedad Española de Epidemiología. 2020**
  Comunicación oral “Efecto moderador de las instalaciones deportivas en la relación entre el nivel socioeconómico y el índice de masa corporal”

- **III Congreso Internacional de Innovación e Investigación en el ámbito de la salud, 2020**
  Ponencia “Asociación entre la disponibilidad de instalaciones deportivas y prevalencia de diabetes mellitus tipo 2 en Madrid: Proyecto Heart Healthy Hoods”

- **X Congreso Internacional de Ciencias del Deporte de la Asociación Española de las Ciencias del Deporte. 2018**
  Comunicación oral “Relación entre la proximidad de instalaciones deportivas y el nivel socioeconómico de la población en la ciudad de Madrid”

- **XXXVI Reunión Anual de la Sociedad Española de Epidemiología. 2018**
  Póster “Socioeconomic status and availability of physical activity facilities”

- **X Congreso Internacional Asociación Española de Ciencias del Deporte, 2018**
  Coordinación Simposio “Determinantes físicos y sociales del acceso a la actividad física en entornos urbanos y su influencia en el ámbito laboral”.

- **X Congreso Internacional Asociación Española de Ciencias del Deporte, 2018**
  Comunicación oral “¿El nivel socioeconómico determina el acceso de la población a las instalaciones deportivas?”

Participation in research projects

- Title: 'Estudio Pasos: Actividad física, sedentarismo y obesidad en población infantojuvenil española'
  Duration: 2022-2023.
  Funding Agency: Gasol Foundation.
  Role: Researcher

- Title: 'Desigualdades sociales en los factores de riesgo cardiovascular por Comunidad Autónoma en España: evolución temporal y sus determinantes mediante un análisis de métodos mixtos'
  Duration: 2022-2024.
  Funding Agency: Fondo de Investigaciones Sanitarias. Ministerio de Sanidad de España.
  Role: Researcher

- Title: "Alimentación y desigualdad en adolescentes: Un estudio cualitativo en centros educativos de Madrid y Bilbao (ADA).
  Duration: 2021-2024.
  Funding Agency: Plan Estatal de Investigación Científica y Técnica y de Innovación (PEICTI). Ministerio de Ciencia e Innovación.
  Role: Researcher.

- Title: 'Residential and school urban environments in relation to diet, physical activity and obesity in Madrid schoolchildren: the much-needed population approach'.
  Duration: 2020-2021
  Funding Agency: Fundación Mapfre. Programa "Ignacio H. de Larramendi" de ayudas a la investigación en promoción de la salud.
  Role: Researcher.

- Title: ‘Distribución y uso de los parques en Madrid y su relación con la actividad física y la salud cardiovascular: un sub-estudio del proyecto Heart Healthy Hoods’.
  Duration: 2019-2021.
  Funding Agency: Fondo de Investigaciones Sanitarias. Ministerio de Sanidad de España.
  Role: Researcher

- Title: “Social and Physical Urban Environment and Cardiovascular Health: The Much Needed Population Approach (Heart Healthy Hoods)" ERC Starting Grant.
  Duration: 2014-2019.
  Funding Agency: European Research Council (ERC).
  Role: Researcher.

Scientific courses and trainings

- “Comunicación e incidencia política en epidemiología y salud pública. Los documentos ‘policy brief’ como herramienta para la traslación del conocimiento. Lisboa, 2018. Sociedad Española de Epidemiología.

- Programa especializado “Epidemiology for Public Health”.
  Coursera, 2020. Imperial College London.

- “Curso Práctico de Sistema de Información Geográfica sobre Software Libre”.
  EdX, 2020. Universidad Politécnica de Madrid.

- “Investigación cualitativa en salud pública: enfoques para el análisis y aplicación práctica”.
  Menorca, 2022. Escola de Salut Pública de Menorca.

LUIS CEREIJO TEJEDOR

- MAYO 2023 -