Universidad de Alcalá
COMISIÓN DE ESTUDIOS OFICIALES
DE POSGRADO Y DOCTORADO

ACTA DE EVALUACIÓN DE LA TESIS DOCTORAL

(FOR EVALUATION OF THE ACT DOCTORAL THESIS)

Año académico (*academic year*): 2017/18

DOCTORANDO (*candidate PHD*): **GULLÓN TOSIO, PEDRO**
D.N.I./PASAPORTE (*Id.Passport*): ******8156G**
PROGRAMA DE DOCTORADO (*Academic Committee of the Programme*): **D422-EPIDEMIOLOGÍA Y SALUD PÚBLICA**
DPTO. COORDINADOR DEL PROGRAMA (*Department*): **CIRUGÍA, CIENCIAS MÉDICAS Y SOCIALES**
TITULACIÓN DE DOCTOR EN (*Phd title*): **DOCTOR/A POR LA UNIVERSIDAD DE ALCALÁ**

En el día de hoy 22/01/18, reunido el tribunal de evaluación, constituido por los miembros que suscriben el presente Acta, el aspirante defendió su Tesis Doctoral **con Mención Internacional** (*In today assessment met the court, consisting of the members who signed this Act, the candidate defended his doctoral thesis with mention as International Doctorate*), elaborada bajo la dirección de (*prepared under the direction of)* MANUEL FRANCO TEJERO.

Sobre el siguiente tema (*Title of the doctoral thesis*): *WALKABILITY IN THE CITY OF MADRID: INTEGRATION OF DIFFERENT TOOLS AND METHODS*

Finalizada la defensa y discusión de la tesis, el tribunal acordó otorgar la CALIFICACIÓN GLOBAL[1] de (**no apto, aprobado, notable** y **sobresaliente)** (*After the defense and defense of the thesis, the court agreed to grant the GLOBAL RATING (fail, pass, good and excellent)*): SOBRESALIENTE

Alcalá de Henares, a 22 de Enero de 2018

Fdo. (*Signed*): Fco Bolumar
Fdo. (*Signed*): Fatima Pina
Fdo. (*Signed*): Carmen Vives

FIRMA DEL ALUMNO (candidate's signature),

Pedro Gullón Tosio

Fdo. (*Signed*):

Con fecha 1 de marzo de 2018 la Comisión Delegada de la Comisión de Estudios Oficiales de Posgrado, a la vista de los votos emitidos de manera anónima por el tribunal que ha juzgado la tesis, resuelve:

☒ Conceder la Mención de "Cum Laude"
☐ No conceder la Mención de "Cum Laude"

La Secretaria de la Comisión Delegada

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[1] La calificación podrá ser **"no apto" "aprobado" "notable"** y **"sobresaliente"**. El tribunal podrá otorgar la mención de "cum laude" si la calificación global es de sobresaliente y se emite en tal sentido el voto secreto positivo por unanimidad. (*The grade may be "**fail**" "**pass**" "**good**" or "**excellent**". The panel may confer the distinction of "cum laude" if the overall grade is "Excellent" and has been awarded unanimously as such after secret voting.*).

Universidad
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En aplicación del art. 14.7 del RD. 99/2011 y el art. 14 del Reglamento de Elaboración, Autorización y Defensa de la Tesis Doctoral, la Comisión Delegada de la Comisión de Estudios Oficiales de Posgrado y Doctorado, en sesión pública de fecha 1 de marzo, procedió al escrutinio de los votos emitidos por los miembros del tribunal de la tesis defendida por *GULLÓN TOSIO, PEDRO*, el día 22/01/18, titulada *WALKABILITY IN THE CITY OF MADRID: INTEGRATION OF DIFFERENT TOOLS AND METHODS*, para determinar, si a la misma, se le concede la mención "cum laude", arrojando como resultado el voto favorable de todos los miembros del tribunal.

Por lo tanto, la Comisión de Estudios Oficiales de Posgrado **resuelve otorgar** a dicha tesis la

MENCIÓN "CUM LAUDE"

Alcalá de Henares, 2 de marzo de 2018
EL PRESIDENTE DE LA COMISIÓN DE ESTUDIOS
OFICIALES DE POSGRADO Y DOCTORADO
(en funciones)

Juan Ramón Velasco Pérez

UNIVERSIDAD DE ALCALÁ, PATRIMONIO DE LA HUMANIDAD

Copia por e-mail a:
Doctorando: GULLÓN TOSIO, PEDRO
Secretario del Tribunal: MARÍA DEL CARMEN VIVES CASES.
Director de Tesis: MANUEL FRANCO TEJERO

Universidad de Alcalá

ESCUELA DE DOCTORADO
Servicio de Estudios Oficiales de Posgrado

DILIGENCIA DE DEPÓSITO DE TESIS.

Comprobado que el expediente académico de D./Dª PEDRO GULLÓN TOSIO reúne los requisitos exigidos para la presentación de la Tesis, de acuerdo a la normativa vigente, y habiendo presentado la misma en formato: ☒ soporte electrónico ☐ impreso en papel, para el depósito de la misma, en el Servicio de Estudios Oficiales de Posgrado, con el nº de páginas: 182 se procede, con fecha de hoy a registrar el depósito de la tesis.

Alcalá de Henares a 25 de SEPTIEMBRE de 2017

Aurora Juárez Abril

Fdo. El Funcionario

HEART HEALTHY HOODS

erc

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A/A Comisión académica del programa de doctorado en Epidemiología y Salud Pública

RE: depósito tesis doctoral Pedro Gullón

Yo, Manuel Franco Tejero, profesor titular del Departamento de Cirugía, Ciencias médicas y sociales y director del grupo de Epidemiología Social y Cardiovascular de la Universidad de Alcalá, confirmo que el doctorando **Pedro Gullón Tosio** ha completado con éxito la redacción de la tesis doctoral con mención internacional titulada *"Walkability in the city of Madrid: integration of different tools and methods"* bajo mi dirección. Pedro ha sido evaluado positivamente en todas las evaluaciones correspondientes y considero que ha cumplido los requisitos del programa. Por ello, solicito a la comisión académica que emita un informe favorable para proceder a su depósito en la Escuela de Doctorado.

Agradeciendo su atención,

Madrid a 11 de septiembre de 2017

Fdo: Dr. Manuel Franco.

Universidad
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Francisco Bolúmar Montrull, Coordinador de la Comisión Académica del Programa de Doctorado en _Epidemiología y Salud Pública__

INFORMA que la Tesis Doctoral titulada __ Walkability in the city of Madrid: integration of different tools and methods _, presentada por **D/_Pedro Gullón Tossío_,** bajo la dirección del / de la Dr. _Manuel Franco Tejero, reúne los requisitos científicos de originalidad y rigor metodológicos para ser defendida ante un tribunal. Esta Comisión ha tenido también en cuenta la evaluación positiva anual del doctorando, habiendo obtenido las correspondientes competencias establecidas en el Programa.

Para que así conste y surta los efectos oportunos, se firma el presente informe en Alcalá de Henares a _18_ de_Septiembre_ de _2017_

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WALKABILITY IN THE CITY OF MADRID: INTEGRATION OF DIFFERENT TOOLS AND METHODS

Pedro Gullón Tosio
Tesis doctoral
Alcalá de Henares, 2017

Director: Manuel Franco

Universidad de Alcalá

Programa de Doctorado en Epidemiología y Salud Pública

WALKABILITY IN THE CITY OF MADRID: INTEGRATION OF DIFFERENT TOOLS AND METHODS

Tesis doctoral con mención internacional presentada por

PEDRO GULLÓN TOSIO

Director:
Dr. D. Manuel Franco

Alcalá de Henares, 2017

"Disease is not something personal and special,
but only a manifestation of life under modified conditions,
operating according to the same laws
as apply to the living body at all times,
from the first moment until death"
Rudolf Virchow

"The primary determinants of disease are mainly
economic and social, and therefore its remedies
must also be economic and social. Medicine and
politics cannot and should not be kept apart"
Geoffrey Rose

"This city is afraid of me"
Roscharch. Watchmen

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El día que comencé a escribir el texto de la tesis doctoral, mi amigo Usama Bilal me dijo que lo más difícil de todo es escribir los agradecimientos, y que empezara lo antes posible. ¡Ojalá lo hubiese escuchado! Ahora escribo sabiendo que es imposible reflejar en un pequeño texto (y en spanglish) todas las personas a las que tengo que agradecer su apoyo en este trabajo.

Primero, agradecer a Manuel Franco, mi director y mentor, la oportunidad que me ha dado de trabajar con él y acogerme bajo el mejor equipo posible. Con él he aprendido muchas cosas que van mucho más allá de la propia metodología; me ha transmitido su pasión por la investigación y porque ésta sea una herramienta en la lucha por un mundo más justo. Los buenos y divertidos momentos (a veces no tan buenos y muy estresantes) que hemos pasado juntos, se seguirán repitiendo en el futuro.

Second, I would like to thank my thesis committee: Hannah Badland, Iñaki Galán and Francisco Escobar (better called Patxi). They have been the head and the path to follow in the last 3 years. Hannah, even in the distance, has become one of the researchers that I most admire; her ideas, her patience and her determination make me jealous. I am sure next year it will be possible to spend some months in Melbourne with Hannah and her team. Iñaki has been the "epi head" in this committee; I am really pleased to collaborate with different researchers and disciplines, but in the end, Epidemiology has to be there in an Epi thesis; hope in the future we will have more opportunities to work together. Patxi and his passion for geography and GIS has transformed me into an (amateur) form of geographer; now I cannot see cities in the same way as before. Thank you.

Para el resto del equipo del Heart Healthy Hoods, es muy difícil encontrar palabras. Gracias por enseñarme, gracias por aguantarme, y gracias por cuidarme. Usama, esta tesis no sería nada sin ti, mi gran compañero y amigo durante esta aventura, eres una de las personas a las que más admiro y respeto tengo en el mundo, y con la que más ideas por segundo puedo generar, en una conversación constante que nunca cesa; Madrid-Baltimore-Philadelphia via Hangouts. Julia, mi confidente y apoyo, has mantenido mi cordura durante tantos momentos que no soy capaz de contarlos. Los momentos contigo hacen que todo merezca la pena. Nunca os vayáis de mi vida. Xisca, tu experiencia siempre me ha allanado el camino; Alba, la geógrafa que se convierte en epidemióloga mientras enseña al epidemiólogo a entender la geografía; Angelica,

María, Andrea, Rober, Paloma y Rocío, seguid manteniendo este equipo así. Además, no puedo olvidarme aquellas compañeras que ya no están en el grupo, pero que han sido vitales en el desarrollo de esta tesis, especialmente Silvia, que me acompañó a patear las calles de Madrid allá por 2014.

Siguiendo en Alcalá, quiero agradecer a Ángel Asúnsolo siempre estar ahí. Ángel es uno de los grandes culpables de picarme el gusanillo con la epidemiología y la salud pública. Es un apoyo, y espero serlo también para él. María Sandín y Paco Bolúmar siempre han estado ahí también, Paco incluso fue culpable de hacerme creer en segundo de medicina que esto de la epi era lo mío, cuando me insistió que no me olvidara de esto de las odds ratio que volvería a ello.

Las gracias institucionales se las lleva la Sociedad Española de Epidemiología, por financiar parte de esta tesis gracias a las ayudas a la investigación Enrique Nájera, y por ser el foro en el que los epidemiólogos de España podemos debatir e intentar mejorar la forma en la que se hace investigación.

Durante los últimos 4 años mi casa ha sido la Escuela Nacional de Sanidad y la Unidad Docente de Medicina Preventiva y Salud Pública del ISCIII. Beatriz Pérez siempre se quejó de la "opa hostil" que Manuel hizo sobre mí, pero sabe que mi aprecio y respecto por lo que me ha aportado son enormes; con ella he aprendido a desenvolverme en la salud pública, y me ha dado cabeza y realidad a partes iguales, en unos consejos y una formación que creo que según pasen los años valoraré todavía más. José Manuel Freire siempre ha confiado en mí, me ha empujado a seguir adelante, y a intentar usar la política para que todo lo que se haga en salud pública sea relevante para mejorar la vida de la población.

Pero lo más importante de este tiempo en la Escuela han sido mis compañeras y compañeros residentes: Raquel, gracias por creer siempre en mí; Marta, mi para siempre eterna compañera de fatigas, que me da los puntos de realidad siempre necesarios; mis resis mayores Laura, Leandro, Carmen y Marcela, que me allanaron el camino; mis resis pequeños Ana, Quique, Álex, Fran, Jorge, Carlos y Belén, con los que un futuro mejor está asegurado. Hablando de residentes, la especialidad de MPySP no es lo mismo sin la gente del máster. Gracias a todas y todos por un año maravilloso: Irene(s), Carlos, Elena (siempre constante desde 2006), Sebas, Antonio… se echan de menos esos momentos. Igualmente, el resto de resis que me han ido acompañando la aventura de ARES para intentar hacer las cosas de una forma diferente. Mi fe en el futuro en los especialistas en salud pública con integridad, apertura de vista, y luchadores se deposita en vosotras y vosotros.

Durante estos últimos años he tenido la oportunidad de conocer a gente maravillosa que han colaborado en mi formación y a las que quería hacer una pequeña mención. La gente del Centro Nacional de Epidemiología (especialmente Elena y Diana) me enseñaron a lidiar con la institución y las dificultades. Jonay me hizo creer en la calidad y la salud pública en el hospital. Paco Sevilla buceaba en las profundidades de Bruselas para enseñarme cómo ocurre la política. Isabel, Esperanza y el resto de compañeras de la Unidad de Apoyo a la Investigación de Atención Primaria han sido otra constante, desde que era estudiante de medicina sin saber que hacer con su vida, hasta ahora acabando la tesis siempre ofreciéndome apoyo y sabiduría. La gente del CMS de Puente de Vallecas y Madrid-Salud por hacerme conocer de verdad la salud comunitaria y la salud en los barrios; los barrios no son nada sin su gente.

A special thank you to the people in the Urban Health Collaborative at Drexel, specially Gina Lovasi, for the amazing 3 months in Philadelphia. Gina is one of the best thinking heads in urban health, I think I am not really aware of the opportunity that I've had. Also, working in the same group as Anna Diez Roux is unique. Thanks to the PhD students (specially Kim and Anita) for showing me Philly.

Fuera de mi vida académica y profesional (sí, de verdad la hay) hay muchas personas a las que agradecer este trabajo, y es la parte que nunca podría llegar a completar. Quiero agradecer a mis amigos de medicina todo su apoyo, su amistad, y todas las aventuras que hemos tenido y tendremos. A mi amigo Luis Cereijo, que ha pasado por tantas fases en mi vida que no sabría donde etiquetarle: compañero de facultad, de aventuras políticas, compañero de piso, y ahora de investigación; diferentes pero juntos, como palitos de pescado con natillas.

Combinando facetas activistas, personales y académicas, quiero agradecer a mis compañeros de militancia del Colectivo Silesia; con V de Virchow. A mi grupo distópico-político "Watchmen", gracias por cada momento inolvidable con el que reflexionar y reír a partes iguales, pero con el que siempre disfrutar.

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Por último, a Dafne, mi compañera de vida. Tu amor es el elemento que me sujeta. Gracias por tu comprensión y paciencia cuando en estos últimos años me frustraba. En los peores y en los mejores momentos, lo único que tenía claro era que, a tu lado, las cosas siempre estarán bien. A Honey y Udai, ya no presentes, pero nunca olvidadas.

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RESUMEN

Introducción

En los últimos años han proliferado los estudios sobre la relación entre el entorno en el que vivimos y la salud. Particularmente, existen numerosos estudios en EEUU y Australia que relacionan la presencia de barrios más con mayor actividad física de sus residentes. No obstante, existe una falta de homogeneidad en la medición de la caminabilidad a diferentes escalas, especialmente para ciudades europeas, con un diseño diferente a los lugares donde fueron desarrolladas estas medidas. Además, estas medidas no suelen estar integrada con el resto de elementos de la ciudad que pueden influir en la salud (p ej. el entorno alimentario), ni con los elementos de la dinámica de las ciudades.

Objetivos

El objetivo general de esta tesis doctoral es el desarrollo e integración de diferentes métodos y herramientas para medir la caminabilidad, así como explorar el patrón socio-espacial de estas medidas. Los objetivos específicos son:

1. Desarrollar y validar una herramienta (Madrid Systematic Pedestrian and Cycling Scan – M-SPACES) para medir la caminabilidad y la ciclabilidad de las calles de Madrid.

2. Explorar la integración de los datos de caminabilidad recogidos por el M-SPACES con otras medidas cuantitativas, cualitativas e indicadores de salud del entorno físico y social de un área mediana en términos sociodemográficos de Madrid.

3. Estudiar la distribución socio-espacial de la caminabilidad medida con bases de datos secundarias para todas las secciones censales de Madrid.

Métodos

Para el objetivo 1, se seleccionaron en Madrid tres zonas (agrupaciones de 12 secciones censales cada una) de diversa densidad de población (baja, media, alta). Estas 36 secciones censales estaban compuestas de 500 segmentos de calle, definidos como la calle de una intersección a otra. M-SPACES fue utilizado por dos investigadores en 2013-2014 para medir segmentos de la calle de forma directa y de forma virtual (con Google Street View). La herramienta evaluó cuatro factores: función, seguridad, estética y destinos. Los resultados de las medidas se compararon por área y por método de medición; también se evaluó el acuerdo intra e inter-observador.

Para el objetivo 2, se realizó un estudio en un área de 16.000 residentes en Madrid. Se obtuvieron datos de salud cardiovascular y de factores de riesgo de todos los residentes de 45 años o más utilizando datos de la Historia Clínica Digital del Sistema de Atención Primaria de Madrid. Se utilizaron varias herramientas de medida cuantitativas para evaluar: el tipo y ubicación de los establecimientos de alimentación y la disponibilidad de alimentos saludables; puntos de venta de tabaco y alcohol; caminabilidad de todas las calles y uso de parques y espacios públicos. También se realizaron 11 entrevistas cualitativas con informantes clave para ayudar a entender las relaciones entre el entorno urbano y los comportamientos en salud cardiovascular. Los datos cuantitativos y cualitativos se han analizado siguiendo un enfoque de métodos mixtos.

Para el objetivo 3, se incluyeron todas las secciones censales de la ciudad de Madrid (n = 2415). El nivel socioeconómico a nivel de área se midió utilizando un índice compuesto de 7 indicadores en 4 dominios (educación, riqueza, ocupación y condiciones de vida). Se calcularon dos indicadores de la dinámica urbana: gentrificación, medida por el cambio en los niveles de educación en los 10 años anteriores, y la edad de construcción, medida por el año mediano de construcción de unidades de vivienda en el área. La caminabilidad se midió utilizando un índice compuesto de 4 indicadores (Densidad Residencial, Densidad de Población, Destinos y Conectividad). Se modeló la asociación utilizando modelos lineales de efectos mixtos.

Resultados

En el primer estudio, tanto para las medidas directas como las virtuales, se encontraron diferencias significativas por área ($p<0.05$) para los 4 factores. La mayoría de las características mostraron un acuerdo sustancial (ICC= 0,6-0,8) o casi perfecto (ICC$\geq$0,8) entre las medidas virtuales y directas, especialmente la infraestructura de las calles de permeabilidad del barrio, la seguridad del tráfico, la estética y la presencia de destinos. El acuerdo intra-observador fue generalmente aceptable (ICC<0.6). El acuerdo entre observadores fue generalmente bajo (ICC<0.4).

En el segundo estudio, los registros electrónicos de salud de toda la población del área mostraron una prevalencia similar de factores de riesgo en comparación con el resto de Madrid / España (prevalencia de diabetes: 12%, hipertensión 34%, dislipidemia 32%, fumar: 10 %, obesidad: 20%). El entorno alimentario era muy denso, con muchas tiendas pequeñas (n = 44) y un gran mercado de alimentos con 112 puestos. Los residentes destacaron la importancia de estas pequeñas tiendas para comprar alimentos saludables. Los entornos de alcohol y tabaco también eran muy densos (n = 91 y 64, respectivamente), dominados por bares y restaurantes (n = 53) que también actuaban como servicios de alimentación. Los vecinos enfatizaron la importancia del consumo de alcohol como un mecanismo de socialización. Los espacios públicos abiertos fueron utilizados principalmente por personas de la tercera edad que remarcaron la importancia de la accesibilidad a estos espacios y la disponibilidad de destinos para caminar.

El tercer estudio mostró que el nivel socioeconómico de área y la caminabilidad tienen una relación inversa y estadísticamente significativa en Madrid. Las áreas con nivel socioeconómico más bajo mostraron la caminabilidad más alta. Este patrón no se aplica a las áreas con un aumento en el nivel de educación, donde la asociación era plana (no hay disminución en caminabilidad a mayor nivel socioeconómico). Por otra parte, la asociación se atenuó en las zonas de nueva construcción: la asociación fue más fuerte en las zonas construidas antes de 1975, más débil en las zonas construidas entre 1975 y 1990 y plana en las zonas construidas a partir de 1990.

Conclusiones

Este estudio implica el uso de diferentes medidas de caminabilidad a diferentes escalas. Las medidas directas permiten medir elementos de pequeña escala presentes en las calles, tales como el estado de la acera o la estética, mientras que las medidas mediante bases de datos secundarias permiten la extensión a gran escala. Asimismo, la integración de diferentes medidas y el uso de análisis por métodos mixtos son herramientas esenciales para medir fenómenos complejos como la relación entre el diseño de los barrios y la actividad física de los residentes. Por último, una mejor comprensión de la relación entre la forma urbana y la composición social de los barrios puede proporcionar elementos clave para la salud y para prevenir que la planificación urbana aumente las desigualdades en salud.

ABSTRACT

Introduction

In the last years there has been an increasing interest in showing the relationship between the urban environment in which we live and health. In particular, many studies, mostly in the US and Australia, have analyzed the relationship between walkable neighborhoods and physical activity of its residents. Nevertheless, there is a lack of homogeneity between different-scale measures, especially for European cities, with different urban shape as the cities where these measures where developed. Moreover, these measures are not commonly integrated with the other "healthy neighborhood" elements (e.g. healthy food availability), neither with neighborhood dynamic characteristics.

Objectives

The general objective of this PhD dissertation is the development and integration of different tools and methods to measure walkability, and to explore the socio-spatial distribution of these measures. The specific aims are:

1. To develop and validate an audit tool (Madrid Systematic Pedestrian and Cycling Environment Scan – M-SPACES) to measure walkability and bikeability in the streets of Madrid

2. To explore the integration of the M-SPACES walkability with other quantitative, qualitative and health indicators of the physical and social environment in a median sociodemographic area in Madrid

3. To study the socio-spatial distribution of small area-level walkability measured with secondary datasets for all the census sections of the city of Madrid in 2014

Methods

For the aim 1, three areas (clusters of 12 census section each) of diverse population density (low, medium, high) were selected in Madrid. These 36 census sections were composed of 500 street segments, defined as the street from one intersection to another. M-SPACES was used to audit street segments physically and virtually (Google Street View) by two researchers in 2013-2014. The tool assessed four factors: function, safety, aesthetics and destinations. Audit scores were compared by area and by measurement method; also, intra- and inter-rater agreement was assessed.

For the aim 2, we conducted this study in an area of 16,000 residents in Madrid (Spain). We obtained cardiovascular health and risk factors data from all residents aged 45 and above using Electronic Health Records from the Madrid Primary Health Care System. We used several quantitative audit tools to assess: the type and location of food outlets and healthy food availability; tobacco and alcohol points of sale; walkability of all streets and use of parks and public spaces. We also conducted 11 qualitative interviews with key informants to help understanding the relationships between urban environment and cardiovascular behaviors. We integrated quantitative and qualitative data following a mixed-methods merging approach.

For aim 3, all census sections of the city of Madrid (n = 2415) were included. Area-level SES was measured using a composite index of 7 indicators in 4 domains (education, wealth, occupation and living conditions). Two neighborhood dynamics factors were computed: gentrification, proxied by change in education levels in the previous 10 years, and neighborhood age, proxied by median year of construction of housing units in the area. Walkability was measured using a composite index of 4 indicators (Residential Density, Population Density, Retail Destinations and Street Connectivity). We modeled the association using linear mixed models with random intercepts.

Results

In the first study, for both physical and virtual audits, all analyzed features score significantly different by area ($p<0.05$). Most of the features showed substantial ($ICC=0.6–0.8$) or almost perfect ($ICC\geq 0.8$) agreement between virtual and physical audits, especially neighborhood permeability walking infrastructure, traffic safety, streetscape aesthetics, and destinations. Intra-rater agreement was generally acceptable ($ICC>0.6$). Inter-rater agreement was generally poor ($ICC<0.4$).

In the second study, Electronic Health Records of the entire population of the area showed similar prevalence of risk factors compared to the rest of Madrid/Spain (prevalence of diabetes: 12 %, hypertension: 34 %, dyslipidemia: 32 %, smoking: 10 %, obesity: 20 %). The food environment was very dense, with many small stores (n = 44) and a large food market with 112 stalls. Residents highlighted the importance of these small stores for buying healthy foods. Alcohol and tobacco environments were also very dense (n = 91 and 64, respectively), dominated by bars and restaurants (n = 53) that also

acted as food services. Neighbors emphasized the importance of drinking as a socialization mechanism. Public open spaces were mostly used by seniors that remarked the importance of accessibility to these spaces and the availability of destinations to walk to.

The third study showed that area-level SES and walkability were inversely and significantly associated. Areas with lower SES showed the highest walkability. This pattern did not hold for areas with an increase in education level, where the association was flat (no decrease in walkability with higher SES). Moreover, the association was attenuated in newly built areas: the association was stronger in areas built before 1975, weaker in areas built between 1975 and 1990 and flat in areas built from 1990 on

Conclusions

This study involves the use of different measures of walkability at different scales. Direct audits allow the measurement of small scale elements present on the streets, such as the sidewalk characteristics or aesthetics, while measurements using secondary databases allow large-scale extension. Also, the integration of different measures and the use of analysis by mixed methods are key elements to measure complex phenomena such as the relationship between neighborhood design and physical activity of its residents. Lastly, a deeper understanding of the dynamic relationship between urban form and neighborhood composition would provide further insights into mobility and health behaviors and outcomes, and inform urban planning policy to preserve health equity.

1. INTRODUCTION

1.1. Physical activity and health

1.1.1. Health effects of physical activity

Physical inactivity is recognized as a global pandemic that requires global action (Kohl et al., 2012). Insufficient physical activity is one of the 10 leading risk factors of deaths worldwide, causing an estimated 3.2 million deaths each year (Lim et al., 2012). For instance, in 2010, lack of sufficient physical activity was estimated to cause 2.8 % loss of total – globally DALYs (69.3 million) (Lim et al., 2012).

The WHO Regional Office for Europe summarizes the published evidence of the individual health benefits of physical activity as: reduce risk of heart disease and mortality, stroke, overweight and obesity, type II diabetes, colon and breast cancer, falls in older people and depression; also, improvement of musculoskeletal health, cognitive function and psychological well-being (Cavill, Kahlmeier, & Racioppi, 2006; Lee et al., 2012). It is estimated that the failure to spend 15-30 minutes a day briskly walking (following WHO recommendations (WHO, 2010b)) is responsible for 6-10% of the burden of major non-communicable diseases (Lee et al., 2012); a global burden of disease similar to smoking (Wen & Wu, 2012). In particular, physical inactivity has a population attributable factor (PAF) of 5.8 % for coronary heart disease, 7.2 % for type 2 diabetes, 10.1 % for breast cancer, 10.4 % for colon cancer, and 9.4 % for the overall mortality (Lee et al., 2012). In Spain, PAF are slightly higher; thus, lack of meeting WHO recommendations is responsible for 8.3 % of coronary heart disease, 10.3 % of type 2 diabetes, 13.8 % of breast cancer, 14.9 % of colon cancer, and 13.4 % of overall mortality (Lee et al., 2012). Moreover, meeting WHO recommendations for physical activity would increase life expectancy by 0.68 years worldwide (Lee et al., 2012).

Despite the effort that has been done in identifying the independent effects of physical activity on individual and population's health, using a multi-behaviour – multi-morbidity health framework, physical activity can also improve population health by acting in alternative pathways to promote additional healthy behaviors (e.g. healthier eating, smoking cessation) (Das & Horton, 2012; Loprinzi, 2015).

In addition to morbidity (Cimarras-Otal et al., 2014) and premature mortality (Evenson, Wen, & Herring, 2016), physical inactivity is responsible for a substantial economic burden (Ding et al., 2016). In the most conservative estimations, in 2013, lack of sufficient physical activity cost \$53·8 billion worldwide, of which \$31·2 billion was paid by the public sector, \$12·9 billion by the private sector, and \$9·7 billion by households. In addition, physical inactivity related deaths contribute to \$13·7 billion in productivity losses (Ding et al., 2016). Just for Spain, it has been estimated that 1.53 % of the health-care direct costs are attributable to physical inactivity (~\$2000 million), one of the highest estimation for the European countries (Ding et al., 2016).

1.1.2. Definition and different types of physical activity

The World Health Organization defines physical activity as "any bodily movement produced by skeletal muscles that requires energy expenditure – including activities undertaken while working, playing, carrying out household chores, travelling, and engaging in recreational pursuits" (WHO, 2010b).

There is some conceptual confusion between different terms that are often used as synonymous for physical activity. For instance, "exercise" refers to a subcategory of physical activity that is planned, structured, repetitive, and aims to improve or maintain one or more components of physical fitness (Caspersen & Christenson, 1985). "Physical fitness", in contrast with physical activity, is a set of attributes that people have or that they have to achieve (Caspersen & Christenson, 1985). "Sport", as defined by the European Sport Charter, includes leisure physical activity that involves an organized participation, aim at expressing or improving physical fitness and mental well-being, forming social relationships or obtaining results in competition at all levels (Berg, Warner, & Das, 2015; Council of Europe, 1992). Therefore, despite the general agreement regarding the significance of physical activity, there is a need for a more precise understanding of the different types of physical activity (Booth, 2000).

One of the most used academic classification for the different types of physical activity comes from the development of the International Physical Activity Questionnaire (IPAQ) (C. L. Craig et al., 2003) after the International Consensus Group, which met in Geneva in 1998. They classified physical activity as: (1) Physical activity at work or occupational physical activity (it can be vigorous, moderate or walking), (2) Transport-related physical activity (walking or cycling by means of transportation), (3) Leisure-time physical activity (vigorous or moderate activities, including walking at leisure time, exercise or sport participation), (4) Physical activity during household and gardening tasks (vigorous or moderate). Despite its academic purpose, this classification goes beyond that, as these different types of physical activity have different impact for the individual physical activity recommendations at different life stages (WHO, 2010b) as well as different policy implications (H. Badland & Schofield, 2005; Berg et al., 2015; Laverty, Palladino, Lee, & Millett, 2015; Samitz, Egger, & Zwahlen, 2011).

1.1.3. Epidemiology of physical activity

According to WHO global health data, the crude prevalence of physical inactivity in adults was high for 2010; it was estimated that 23.3% of adults do insufficient physical activity according to the WHO daily recommendations for physical activity (≥ 30 min of at least moderate physical activity on 5 or more occasions per week) (WHO, 2010a). Overall, older people were estimated to be less active than younger people: 19% of the youngest age group did not meet the recommended level, compared to 55% of the oldest age group. However, young women were slightly less active than middle-aged women. Using the same dataset, the estimation for physical inactivity in Europe was slightly higher (24.5%); in Spain, WHO estimates of physical inactivity prevalence in adults was even higher (30.5%) (WHO, 2010a).

Other estimations reveal slightly different estimations. Gerovasili et al estimated with Eurobameter data in 2013 that 28.6 % of European adults (age 18-64) were physically inactive (Gerovasili, Agaku, Vardavas, & Filippidis, 2015). Other estimations report greater physical inactivity levels for Europeans; for instance, using data from the 2012

European Social Survey, Marques et al estimated that 38.53 % of European adults (>18 years old) did not reach the WHO recommendations of physical activity (Marques, Sarmento, Martins, & Saboga Nunes, 2015). For this estimation, Spain was the third less active country in Europe, only after Israel and Iceland (Marques et al., 2015).

In general, adult women tend to be less active than men (Gerovasili et al., 2015; WHO, 2010a; Xu et al., 2017), and there is a well-stablished relationship between individual socio-economic position and physical activity (Beenackers et al., 2012; Farrell, Hollingsworth, Propper, & Shields, 2014; Maestre-Miquel, Regidor, Cuthill, & Martínez, 2015; Marques, Martins, Peralta, Catunda, & Nunes, 2016). However, these patterns are not the same for the different types of physical activity; the highest socio-economic inequalities in physical activity have been reported for leisure-time and occupational physical activity (Beenackers et al., 2012; Cerin & Leslie, 2008) , while the relationship of individual socio-economic position and transport-related physical activity is less constant within the different studies (Beenackers et al., 2012).

Since the industrial revolution, the social, economic and labor changes affected by the introduction of the market economy have changed the way in which we move and in which we do physical activity. However, comparison of the secular physical activity levels in those years are unachievable due to the lack of data (Hallal et al., 2012), something that in the last 30 years has been partially achieved, as population representative panel questionnaires have facilitated physical activity surveillance (Hallal et al., 2012). Trend data from high-income countries suggest that leisure-time physical activity has slightly increased in adults (Hallal et al., 2012; Knuth & Hallal, 2009; Morseth, Jacobsen, Emaus, Wilsgaard, & Jorgensen, 2016), despite gender differences in this increase (Chau, Chey, Burks-Young, Engelen, & Bauman, 2017). Regardless the promising positive trends in leisure-time physical activity, other types of physical activity, such as incidental, transport-related and occupational physical activity, are falling in some countries (Hallal et al., 2012; Knuth & Hallal, 2009; Stamatakis, Ekelund, & Wareham, 2007). In Spain, using the National Health Survey Data, leisure-time physical activity has increased in the last 30 years, with no significant changes in occupational physical activity (Alonso-Blanco et al., 2012) (Figure 1), although social inequalities by educational level might have increased in these years (Maestre-Miquel et al., 2015).

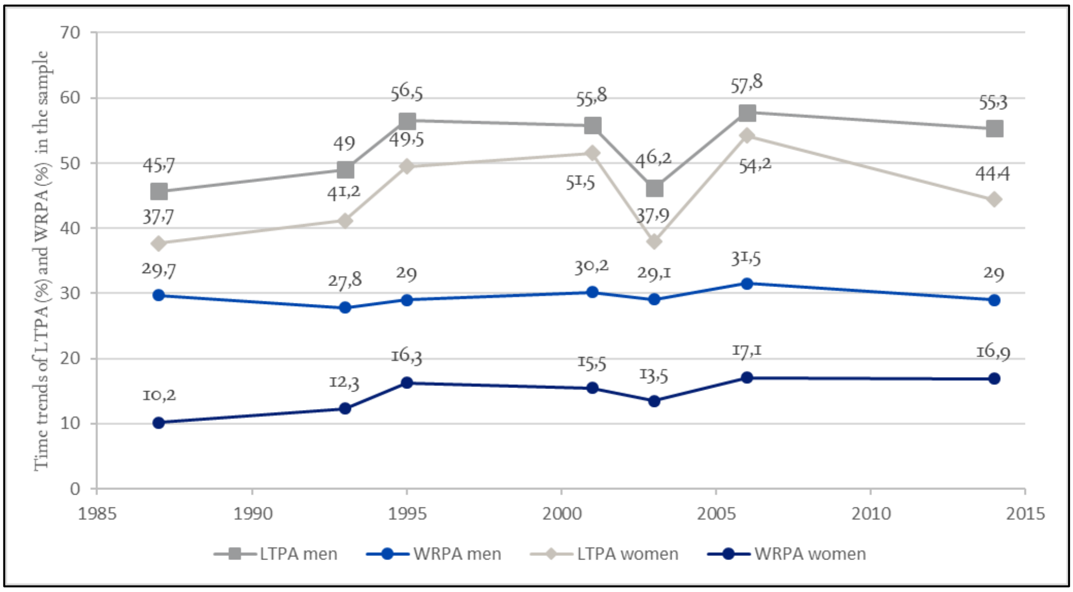

Figure 1. Time trends for the prevalence of leisure-time physical activity (LTPA) and work-related physical activity (WRPA). Values expressed as percentages are from the Spanish National Health Survey and Spain data from the European Health Survey (2014). Adapted and updated from Alonso-Blanco et al. (Alonso-Blanco et al., 2012)

1.1.4. Walking as physical activity

As it has been discussed before, physical activity can be conceptualized in many ways. In the previous section, we have classify physical activity in terms of the purpose (C. L. Craig et al., 2003); nevertheless, physical activity can be classified in terms of the type of movement that implies: walking, cycling, running, weight training….

In contrast to other forms of physical activity, walking has the advantage of being accessible to most people; it does not require any special skills and it does not require any membership or expensive equipment. Moderate intensity physical activities that can be incorporated into everyday life, such as walking, may be beneficial for improving adherence levels to reach the WHO daily recommendations for physical activity (Hu et al., 1999; WHO, 2010b).

Walking can be used for transportation (e.g. commuting to work or walking for daily activities) or for leisure, and both types have been associated with better health outcomes as well as reduced mortality (Hamer & Chida, 2008). Walking can be specifically important for older people and women. A recent review has shown that, consistently, women report higher levels of walking for leisure than men (Pollard & Wagnild, 2017). Moreover, as older people tend to have physical limitations to some moves, walking (especially for transport) might be the better way to achieve WHO recommendations (WHO, 2010b). In Spain walking is the most common type of physical activity in women (Peiró-Pérez et al., 2015).

1.2. Population prevention approach: back to Geoffrey Rose

1.2.1. Individual vs population prevention approach

In order to tackle high physical inactivity as well as the high prevalence of chronic diseases, researchers, health professionals and policy-makers have identified a range of different conceptual and causal approaches that might lead to future interventions. Following Geoffrey Rose's perspective (Rose G, 1985), there are two different issues when searching for disease etiology:

- The determinants of individual cases (e.g. why this person has hypertension?). Most of the epidemiological studies look for this "risk factors" of disease, which identify certain individuals as being more susceptible to disease (e.g. this person might have hypertension because of his salt consumption).
- The determinants of population incidence rate (e.g. why there are so many people with hypertension in my country while in other it is rare?). Following the same example as Rose's in his article "Sick Individuals and sick populations" (Rose G, 1985) the question in this case might be "Why is hypertension absent in the Kenyans and common in London?" (Figure 2). The answer to that question has to do with the determinants of the population mean; it is a shift of the whole distribution (a *mass influence*) acting on the population as a whole (e.g. different transportation options, different food systems…)

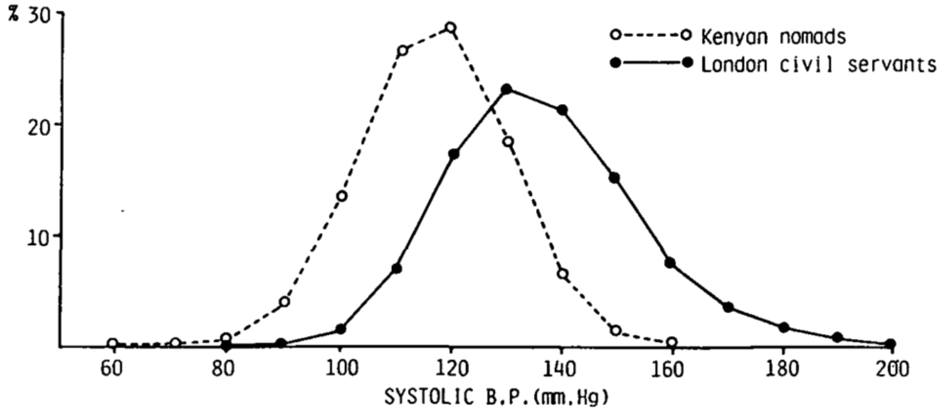

Figure 2. Distribution of systolic blood pressure in middle-aged men in Kenya and London city servants

These issues when addressing disease etiology drift as to two different prevention approaches: (1) High-risk strategy and (2) Population approach. High-risk strategies are the traditional medical approach to prevention; focused on individuals with high risk of disease, those at the extreme curve of the distribution. Examples of this are individual programs like smoking cessation programs or behavior change interventions. Despite high-risk approach has some advantages due to individual treatment (Rose G, 1985), there are scientific doubts of its effectiveness and the population impact of these interventions (Arnott et al., 2014). On the other hand, population approach tries to shift the whole distribution for a given disease (or risk factor, or condition) on a population, so the effect of the prevention is not limited to high-risk individuals. It focuses on contextual factors, those affecting the whole population. Thus, this approach is radical, that is, tackles the root of diseases (Frohlich, 2014).

1.2.2. Cities and neighborhood as mass influences for population prevention approach and physical activity prevention

Cities and neighborhoods have many opportunities for the prevention of non-communicable diseases or its risk factors (Franco, Bilal, & Diez-Roux, 2015). The nature of urban areas, with a high density of people, services, and social relationships, creates the perfect environment for policy development, implementation, and evaluation (Franco et al., 2015). In addition, cities are internally heterogeneous, with large within city variation in social and physical environments, which makes it ideal for study the city as a whole or its neighborhood as independent analysis units (Franco et al., 2015).

Physical inactivity follows a social gradient, with more disadvantaged populations and neighborhoods having a higher prevalence of physical inactivity (Farrell et al., 2014). If we are to understand the inequities in physical activity, prevalence, and control, we need to understand what makes certain neighborhoods have much higher rates of physical inactivity than others. If we are to bring the physical activity burden of poor neighborhoods closer to that of wealthier ones, we need to understand what factors drive these prevalence or incidence rates. These mass influences (Rose G, 1985) across areas or time are the macrosocial determinants of health (Franco et al., 2015).

1.3. Built environment in the city and walkability

1.3.1. Definition and framework for built environment

The built environment has been one of the most focused topics in the neighborhoods and health literature (Diez Roux, 2007). The definitions and frameworks for delimiting the scope of built environment research vary across the scientific literature. For the purpose of this dissertation, we will include in the built environment relatively stable aspects of the human-made or modified environment, such as buildings, transportation systems, architectural and urban design features, landscape elements, and cultivated green spaces (Gullon & Lovasi, 2017; Lovasi, 2012) (Figure 3). The structures that make up the built environment affect physical exposures within the local environment (e.g., air quality, pollutants, water quality, climate) and the social environment (e.g., social capital, social interaction).

The notion that where you live has consequences for our health is not new. From Engels studies on mortality in suburban areas in Liverpool (Krieger, 2001), to the concept of "walkable neighborhood", research on built environment has evolved in many ways. Jane Jacobs was one of the early writers to discuss how the built environment influences how people navigate their neighborhood. As an activist and author, she described as an ideal city planning that features "a most intricate and close-grained diversity of uses that give each other constant mutual support, both economically and socially" (Jacobs, 1961); thus, she advocated for designs that would mix uses, attract pedestrians to urban centers, and consequently improve the safety of a city by providing informal surveillance or "eyes on the street" (Jacobs, 1961). In recent years, measurement of place-based characteristics including features of the built environment in the health sciences is becoming more prominent (Prasad, Gray, Ross, & Kano, 2016).

The concept of the built environment has to be differentiated from other similar terms as "Urban design" or "Land use" (Handy, Boarnet, Ewing, & Killingsworth, 2002). "Urban design" usually refers to the design of the city and the physical elements within it, including both their arrangement and their appearance, and is concerned with the function and appeal of public spaces. "Land use" typically refers to the distribution of activities across space, including the proximity and density of different activities (usually using relatively coarse categories, such as residential, commercial, office, industrial, and other). The "built environment" is modifiable, subject to regulation and zoning changes, urban design, and investments in the transportation system. The actions of government feature prominently in the literature on built environment, but a range of other actors can be engaged, from local retail to community organizations.

Frameworks evoking the idea of the neighborhood built environment influencing health frequently point to causes and consequences of built environment characteristics at multiple nested levels, from national to individual. A variety of ecological frameworks informed by the social ecological theory (Sallis et al., 2009; Stokols, 1996) emphasize the multiple levels of contextual influence on individual behavior and health.

Several of the frameworks are tailored to the goals of observational and interventional research in different behavioral domains (Sallis et al., 2009). Drawing on previously used frameworks that highlight the role of the built environment (Northridge, Sclar, & Biswas, 2003), we can classify potential levers to change the built environment (Figure 3), distinguishing between the following: (1) land use (e.g., mixed use, residential, industrial); (2) transportations systems (e.g., street network design, public transportation infrastructure); (3) services (e.g., facilities, shopping areas, banking); (4) public resources (e.g., parks, open areas, cultural amenities); (5) zoning regulations (e.g., restricting commercial or residential uses); and (6) buildings (e.g., housing, offices, educational facilities). Moreover, it is important to keep in mind that the built environment is influenced by the socio-economic and political context (Borrell, Malmusi, & Muntaner, 2017) and that there are individual characteristics (notably socioeconomic position, and preferences that influence decisions on where to live) that may confound, interact with, or otherwise complicate observed associations along the pathways between built environment and health outcomes.

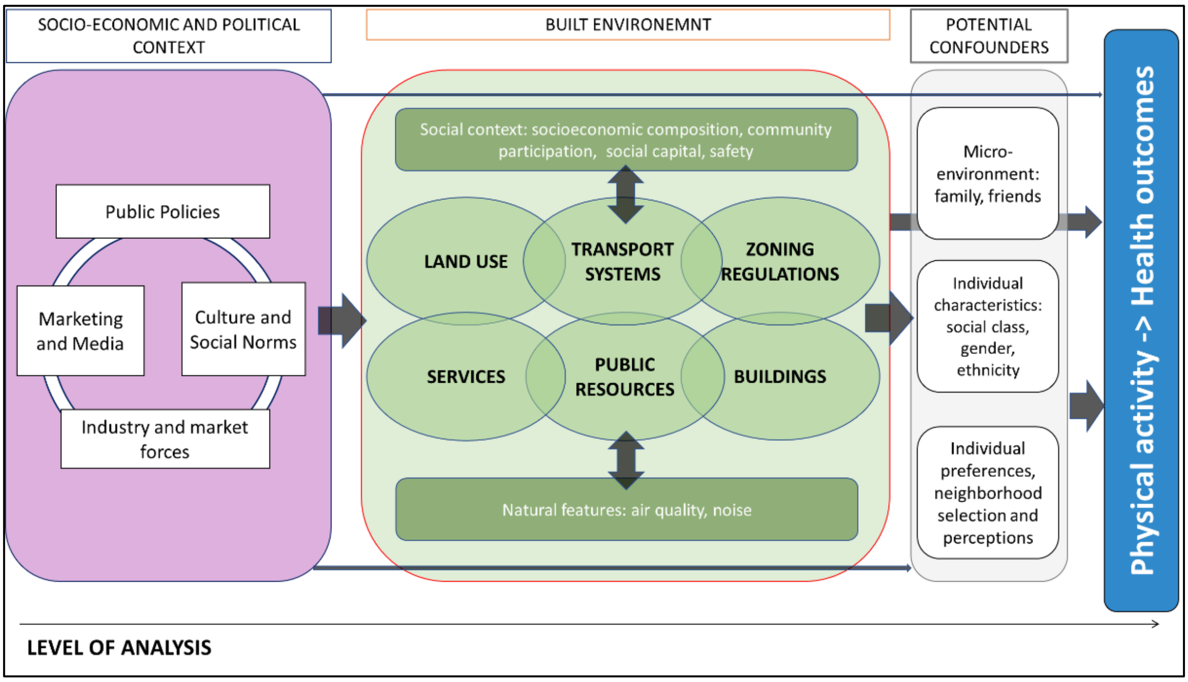

Figure 3. Framework to study built environment and health. Adapted from Gullon and Lovasi (Gullon & Lovasi, 2017)

1.3.2. Definition and framework for walkability

Within the built environment and health research, metrics of neighborhood walkability have been among the most commonly assessed aspects of the built environment (C. Leal & Chaix, 2011). Street connectivity, land use mix and residential density are three large-scale features of neighborhood designs that are commonly studied for their associations with physical activity, and they are commonly named the 3Ds of walkability (Density, diversity and design) (Cervero & Kockelman, 1997; Hajna et al., 2015).

Street connectivity is usually defined as the number of three or more-way intersections per square kilometer within a neighborhood buffer, where a greater number of intersections is indicative of increased ease of movement between origins (e.g., residences) and destinations (e.g., shops, parks) (Frank, Andresen, & Schmid, 2004). Neighborhoods with higher intersection density slow traffic as a result of multiple stopping sites and allow pedestrians to reach their destinations via a variety of routes, making non-motorized transport more appealing (Leslie et al., 2007). Land use mix is a measure of the different types of land uses in a neighborhood (Frank et al., 2004). Different land uses encourage walking by providing residencies located above street-level shops and in close proximity to services making it convenient for residents to walk to these locations (Leslie et al., 2007); single land-use neighborhoods make motorized transportation to points of interest a near necessity (Saelens, Sallis, & Frank, 2003). Residential density is defined as the number of residences per square kilometer of residential land area in the home buffer (Adams et al., 2014) or per square kilometer of the household (Frank et al., 2004). Neighborhoods with higher residential density are generally more conducive to non-motorized transport as a result of there being more people to visit and a greater demand for accessible services (Saelens et al., 2003). As street connectivity, land use mix and residential density are correlated (Frank, Schmid, Sallis, Chapman, & Saelens, 2005), researchers usually aggregate these three measures into a "walkability index" when estimating their associations with health outcomes (Frank et al., 2005). Living in these "high walkability index" areas is consistently associated, as shown by different systematic reviews, with achieving greater levels of total physical activity (Barnett, Barnett, Nathan, Van Cauwenberg, & Cerin, 2017), more daily steps (Hajna et al., 2015), higher odds of walking for transport and active transportation (Grasser, Van Dyck, Titze, & Stronegger, 2013; Saelens & Handy, 2008), and decrease in cardiovascular risk (Bhatnagar, 2017; Malambo, Kengne, De Villiers, Lambert, & Puoane, 2016).

Other aspects of the built environment may encourage or discourage walking. Examples that play a role in the perceived safety and attractiveness of neighborhoods for walking include sidewalk width (Cervero & Kockelman, 1997) or quality (Boehmer, Hoehner, Deshpande, Brennan Ramirez, & Brownson, 2007), the presence of natural features such as trees (Larsen et al., 2009), or human-scale architectural features of streetscapes (Ewing, Handy, Brownson, Clemente, & Winston, 2006). More ephemeral measures of the environment that may also be relevant to walking behavior include litter (Shenassa, Liebhaber, & Ezeamama, 2006) or physical disorder (Molnar, Gortmaker, Bull, & Buka, 2004).

Given this, different frameworks have widened the concept of walkability, including macro and the micro elements that could make a neighborhood "walkable" (Mertens et al., 2014). Difference between them are the scale effect; macro elements are defined for the whole neighborhood while micro elements are punctual and usually are proxy of more complex conceptual constructs (e.g. litter as a measure for neighborhood security; trees as aesthetics). For instance, using stakeholder interview and a Delphi study Australian researchers found four factors that may support walking behavior within your residency neighborhood: (1) function, (2) safety, (3) aesthetics and (4) destinations (T. Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003) (Table 1). *Function* relates to the physical attributes of the street and path that reflect the fundamental structural aspects of the local environment; *safety* features reflect the need to provide safe physical environments for people (including personal safety and traffic safety); *aesthetics* includes features that make streets and neighborhoods pleasant to walk in there; *destinations* are the presence of community and commercial facilities in neighborhoods, including local facilities, parks, public transportation, services and shops.

Table 1. *Factors that influence walking in the neighborhood* (T. Pikora et al., 2003)

Factors	***Definition***	***Elements' example***
Function	Physical attributes of the street and path that reflect the fundamental structural aspects of the local environment	Direct routes; Kerb type; Street type; Path width; Path surface
Safety	Features reflecting the need to provide safe physical environments for people	Personal safety (surveillance, lighting); traffic safety (crossing aids; traffic limitation)
Aesthetics	Features that make streets and neighborhoods pleasant to walk in there	Trees; Cleanliness; Architecture; Garden maintenance
Destinations	Presence of community and commercial facilities in neighborhoods	Local facilities; Parks; Public transport; Shops

This classification may have implications for physical activity interventions. For example, destinations are more important for walking for transport; while aesthetics might be more important for walking for recreation in leisure time (T. J. Pikora et al., 2006; Saelens & Handy, 2008)

As concepts such as neighborhood walkability (Frank et al., 2005; Moudon et al., 2006) have become more prominent, they have increasing power to shape policy discussions (Ottoson et al., 2009), real estate markets (Burchell & Mukherji, 2003; Dyck, Cardon, Deforche, & De Bourdeaudhuij, 2011), and thus the neighborhood environment.

1.4. Methods and tools for measuring built environment and walkability: integration and mixed methods

1.4.1. Classification of tools and methods to measure walkability

The development of reliable methods and tools to audit the qualities of the urban environment that likely impact physical activity remains an ongoing challenge for public health researchers, urban planners and policymakers. Some researchers classify these tools into subjective (questionnaires, interviews, qualitative and participative methods) and objective tools (direct observation with checklists, official dataset, etc.) (Diez Roux, 2007).

These characteristics can be gathered from large-scale GIS datasets. Geographic Information Systems (GIS) has been playing a crucial role. GIS and geographic information science (GIScience) combine computer-mapping capabilities with additional database management and data analysis tools. GIS helps to understand relationship of events and phenomena with a spatial component, it serves as an effective integrating tool, it permits an integration of all collected information together with contextual information such as street network, land parcel and building polygons. Moreover, the establishment of a georeferenced enables future analysis and modeling (Escobar, Green, Waters, & Williamson, 2000). Table 2 provides a summary of the different quantitative options for measuring built environment and walkability. Secondary GIS data, while seldom free of error, have the advantage of being independent of behavior or health assessments, avoiding same-source bias (Gullón, Bilal, & Franco, 2014). Such GIS data are, however, often limited in their coverage of features relevant to the pathway of interest.

Direct observation is another type of objective measurement, whereby trained observers undertake audits or checklists, which assess different aspects of the streets or neighborhoods. These observations can include focused measurement of one characteristic of the environment (e.g., the presence of crosswalks); integrative information about the environment (e.g., density of buildings or traffic (Chow et al., 2009)); or multifaceted assessments multiple items that represent different aspects of the environment (e.g., indicators of aesthetics or physical disorder). However, virtual audits are emerging as an option for independent assessment of the local built environment, tailored to the research questions of interest (Charreire et al., 2014). For logistical reasons, especially for studies in large geographic areas, there has been increasing interest for virtually measuring attributes of the built environment thought to be associated with health. Such virtual audits avoid travel time and related expenses, and leverage open-access mapping technologies and stored image repositories, such as Google Street View (Charreire et al., 2014).

Another intriguing new direction is to use mobile-devices for ecological momentary assessments (Dunton, Liao, Intille, Spruijt-Metz, & Pentz, 2011; Knell et al., 2017); by capturing perceptions of the environment and transient outcomes such as mood at multiple locations and over time, this strategy creates opportunities for within-person comparisons.

While concerns about information bias are often raised when built environment characteristics are reported by study subjects, the perspectives and perceptions of residents are important to understand, especially for psychosocial or behaviorally-mediated pathways (Blacksher & Lovasi, 2012). Ecometric approaches (Mujahid, Diez Roux, Morenoff, & Raghunathan, 2007) and audits conducted by community members (Hoehner, Ivy, Brennan Ramirez, Meriwether, & Brownson, 2006) are promising in that they incorporate perspectives of nearby residents, capturing aspects of the lived experience that may be missed by objective measures alone while avoiding reliance on the same person for reporting on the environment and outcome.

Another different approach is the use of qualitative methods (Moran et al., 2014) or participatory research approaches (Belon, Nieuwendyk, Vallianatos, & Nykiforuk, 2014). Qualitative methods can address some of the inconsistency results of quantitative measures and carry the potential to inform and complement quantitative research on neighborhoods and health. Qualitative methods use interactive strategies to understand the meanings of people's interactions with their environments. Consequently, these methods can help to explain not only what, but also how and why environmental factors relate to physical activity. Participatory methods (e.g. participation through photos using photovoice) go a step forward; it provides the opportunity to engage community residents in policy-change (Belon et al., 2014; Díez et al., 2017).

Table 2. *Options and technologies to provide quantitative measures for walkability and the built environment* (Gullon & Lovasi, 2017)

Measurement modalities		***Example measures***
Secondary data		Walkability index (residential density, land use, destinations, connectivity), access to parks and recreation facilities, public transport
Direct Observation	On-field Virtual imagery	Single characteristic of a street/block (e.g., the presence of crosswalks); integrative information about the environment (e.g., density of buildings or traffic); or multifaceted assessments multiple items that represent different aspects of the urban environment (e.g., indicators of physical disorder)
Mobile-devices		Ecological momentary assessment: perceptions of the environment and transient outcomes such as mood at multiple locations and over time
Questionnaires	Self-report Ecometric	Perceptions of access to destinations or outlets, distance to public transportation, safety, aesthetics

1.4.2. Integration of methods and tools and mixed methods analysis

All this methods and tools are usually used as different strategies to follow depending on their availability at the time. However, most of these tools and methods imply methodological and theoretical assumptions that should be taken into account when choosing the right methodology for achieving your objectives in urban health research.

Thus, integration of these different methods and tools is a key element for urban health research.

Mixed methods are an umbrella term encompassing multifaceted procedures that combine and synthesize methods, or triangulate subjective and objective data collection methods. Mixed-method designs include both qualitative and quantitative methods. Mixed methods are also key to illuminating complex research problems such as health disparities and urban health, therefore the use of this methodological approach has been increasing to understand public health issues (Creswell, Klassen, Plano, & Smith, 2011).

There are different approaches to integrate quantitative and qualitative data using a mixed methods analysis. One of the most easy-to-follow techniques is the concurrent integration approach. This strategy integrates data by a joint analysis presenting a merged result of quantitative and qualitative data. This concurrent integration approach to merging quantitative and qualitative data increases understanding or develops a complementary picture; nonetheless, sequential timing approach (e.g.: an initial phase of formative qualitative research followed by the design of quantitative tools) could be an alternative for large studies, where a formative research at the beginning of the study is essential for the development of quantitative tools.

1.5. Neighborhood dynamics

1.5.1. Theories of neighborhood dynamics and neighborhood change

Neighborhood and cities are not static entities, they change in its physical form and composition. There are different theories to explain the dynamics of cities and neighborhoods; as suggested by Van Ham (van Ham, Manley, Bailey, Simpson, & Maclennan, 2013), these theories can be summarized in three groups:

- *Neighborhood selection*: these theories place household behavior as central. People choose to live in (or not to, or leave) certain neighborhoods, and these decisions alter the composition of neighborhoods.
- *Internal changes*: these theories follow the path of the "non-movers". Neighborhood change because they change in the demographics and socio-economic composition of the people that already live there.
- *External shock*: structural changes to the neighborhood can also change the shape of the neighborhood, including changes in the labor market and large scale (re) generations. Within the external shock theories, there is the role of institutions such as banks or local and national governments.

Urban form changes at a slower pace than social composition, as citizens might move following a social gradient in response to changes in the housing prices market (Koschinsky & Talen, 2015). At the same time, urban form tends to change at a slow pace, given its constrains in some parts of the city (e.g. inner old city). In order to understand the socio-spatial inequalities in walkability there is a need to incorporate variables that can help to understand the dynamics and the history of the city.

1.5.2. Gentrification and urban renewal

Urban renewal projects aim to provide improvements in physical infrastructure, economical gains and social integration (Mehdipanah et al., 2014), with its final goal of creating healthier environments. There are some quasi-experimental design that have evaluated the effect of urban renewal on health inequalities (Mehdipanah et al., 2014) and its complex mechanisms with health (Mehdipanah et al., 2015).

However, urban renewal projects can lead to gentrification (Sorando & Ardura, 2016). Gentrification is a process of renovation of deteriorated urban neighborhoods by means of the influx of more affluent residents (Sorando & Ardura, 2016); therefore, urban renewal projects aiming at improving health outcomes may have their impact in new neighbors because to gentrification processes (Cole, Garcia Lamarca, Connolly, & Anguelovski, 2017). For example, in the US greater increases in destinations for walking were associated with higher median household income (Hirsch et al., 2016). In the last years, there has been an increasing academic interest to study the health effects of gentrification (McCartney et al., 2017; Wood et al., 2017), although more research is needed on the effects of urban renewal and gentrification processes with health and health inequalities.

1.6. Justification of this research

The theoretical concept of walkability was developed to explain active modes of transport—in particular, in the USA and Australia. Despite there has been an increasing interest in walkability, built environment, and health research in Europe (Sallis et al., 2016; Van Holle et al., 2012), most of the studies use the same methods and tools that were developed for US and Australia. However, Australian and American cities differ from the European ones in their shape and neighborhood composition, due to its different historical processes and urban and economic policies in the last 50 years (Kazepov, 2005; J. Leal & Sorando, 2016). For example, European cities tend to be more compact compared to US and Australian cities, and urban sprawl process (and thus, dependence to cars) that happened in the early-50s in the US has been delayed in European cities (particularly in Mediterranean cities like Madrid) until recent years (Kasanko et al., 2006; Oueslati, Alvanides, & Garrod, 2015). Therefore, there is a need to adapt and create different tools, methods and indicators that are suitable and cost-effective for European settings (Grasser, van Dyck, Titze, & Stronegger, 2016; Schwarz, 2010).

While some of the associations between walkability and health outcomes may in part be mediated by higher physical activity and hence energy expenditure, they may also be mediated by energy intake relating to the availability of outlets selling energy dense food. Moreover, this measures and tools are often presented as separate pieces or the puzzle on the relationship between neighborhoods and health.. Thus, there is an important gap here to cover: to integrate walkability with other quantitative and qualitative measures of a "cardiovascular healthy" neighborhood. To do so, mixed methods (Creswell et al., 2011) are the best strategy to follow.

Lastly, as is appointed in the "Neighborhood dynamics" section of the introduction, in order to understand the socio-spatial inequalities in walkability there is a need to incorporate variables that can help to understand the dynamics and the history of the city. In this study, we try to encompass this challenge by incorporating variables of change in social composition and the age of the neighborhood.

1.7. Setting: The Heart Healthy Hoods project

The Heart Healthy Hoods (HHH) project (hhhproject.eu), 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 in relation to cardiovascular health in the whole municipality of Madrid (Franco et al., 2015). The HHH project focuses of four domains of the urban domains: physical activity, food, tobacco and alcohol environments (Carreño, Franco, Gullón, & Carreño, 2015).

Specifically, for this project it will be assessed the food, physical activity and tobacco environments of the city of Madrid, Spain, using three complementary approaches: inhabitant perceptions, geographic information systems and systematic social observation. These observations will then be correlated with cardiovascular health data obtained from two different sources: first, a primary care-based cohort study including 2200 persons from 31 Primary Health Care Centers, and second, a whole-population study including every citizen 40-75 years old using primary care electronic health records (>99% coverage). This study will combine ecometrics, geography, sociology and anthropology, to obtain a comprehensive description of the environments within which our population resides and works. In addition, the cohort study will include direct measures of cardiovascular health indicators, constituting a robust and multi-faceted source of data. The whole-population study offers the potential to have a complete portrait of the cardiovascular health of the ~1.5 million inhabitants of Madrid.

This PhD dissertation takes place at the first stages of the Heart Healthy Hoods project, aiming at designing novel methods to better characterize the physical environment of Madrid (in these case, the physical activity environment and the walkability of Madrid). Also, it uses data from the HHH pilot study that took place in a Median Socioeconomic Neighborhood of Madrid.

2. GENERAL AND SPECIFIC OBJECTIVES

General objective

The general objective of this PhD dissertation is the development and integration of different tools and methods to measure walkability, and to explore the socio-spatial distribution of these measures. As this is a broad issue to address, different specific objectives are proposed; each of these objectives correspond to a different study.

Specific objectives

1. To develop and validate an audit tool (Madrid Systematic Pedestrian and Cycling Environment Scan – M-SPACES) to measure walkability and bikeability in the streets of Madrid
    - 1.1. To test if the M-SPACES can differentiate walking and cycling environments across different urban-form areas in Madrid
    - 1.2. To assess the validity of the M-SPACES in a virtual urban setting using Google Street View
    - 1.3. To assess the reliability (intra- and inter-rater) of the M-SPACES audit tool

2. To explore the integration of the M-SPACES walkability with other quantitative, qualitative and health indicators of the physical and social environment in a median sociodemographic area in Madrid
    - 2.1. To explore different quantitative and qualitative measurements to characterize the social and physical urban environment in relation to food, alcohol, tobacco and physical activity
    - 2.2. To describe the cardiovascular health profile of a population over 15,000 residents living in this area analyzing the Madrid Primary Health Care System electronic health records

3. To study the distribution of small area-level walkability measured with secondary datasets for all the census sections of the city of Madrid in 2014

3.1. To evaluate the association between small area-level socioeconomic status and walkability in Madrid

3.2. To evaluate the potential effect modification by indicators of neighborhood dynamics (gentrification and neighborhood age)

3. OVERVIEW OF DATA AND METHODS

In order to reach the specific objectives, three studies are proposed, each of them with its different methodology approach:

3.1. Study 1

Three areas (clusters of 12 census section each) of diverse population density (low, medium, high) were selected in Madrid. These 36 census sections were composed of 500 street segments, defined as the street from one intersection to another. M-SPACES was used to audit street segments physically and virtually (Google Street View) by two researchers in 2013-2014. The tool assessed four factors: function, safety, aesthetics and destinations. Audit scores were compared by area and by measurement method; also, intra- and inter-rater agreement was assessed.

3.2. Study 2

We conducted this study in an area of 16,000 residents in Madrid (Spain). We obtained cardiovascular health and risk factors data from all residents aged 45 and above using Electronic Health Records from the Madrid Primary Health Care System. We used several quantitative audit tools to assess: the type and location of food outlets and healthy food availability; tobacco and alcohol points of sale; walkability of all streets and use of parks and public spaces. We also conducted 11 qualitative interviews with key informants to help understanding the relationships between urban environment and cardiovascular behaviors. We integrated quantitative and qualitative data following a mixed-methods merging approach.

3.3. Study 3

All census sections of the city of Madrid (n = 2415) were included. Area-level SES was measured using a composite index of 7 indicators in 4 domains (education, wealth, occupation and living conditions). Two neighborhood dynamics factors were computed: gentrification, proxied by change in education levels in the previous 10 years, and neighborhood age, proxied by median year of construction of housing units in the area. Walkability was measured using a composite index of 4 indicators (Residential Density, Population Density, Retail Destinations and Street Connectivity). We modeled the association using linear mixed models with random intercepts.

4. PUBLICATIONS

4.1. Assessing walking and cycling environments in the city of Madrid: comparing on-field and virtual audits

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Assessing Walking and Cycling Environments in the Streets of Madrid: Comparing On-Field and Virtual Audits

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Usama Bilal, Francisco Escobar, Alba Cebrecos, Julia Diez,
and Manuel Franco

ABSTRACT *Audit tools are useful for exploring the urban environment and its association with physical activity. Virtual auditing options are becoming increasingly available potentially reducing the resources needed to conduct these assessments. Only a few studies have explored the use of virtual audit tools. Our objective is to test if the Madrid Systematic Pedestrian and Cycling Environment Scan (M-SPACES) discriminates between areas with different urban forms and to validate virtual street auditing using M-SPACES. Three areas (N=500 street segments) were selected for variation in population density. M-SPACES was used to audit street segments physically and virtually (Google Street View) by two researchers in 2013–2014. For both physical and virtual audits, all analyzed features score significantly different by area ($p<0.05$). Most of the features showed substantial (ICC=0.6–0.8) or almost perfect (ICC≥0.8) agreement between virtual and physical audits, especially neighborhood permeability walking infrastructure, traffic safety, streetscape aesthetics, and destinations. Intra-rater agreement was generally acceptable (ICC>0.6). Inter-rater agreement was generally poor (ICC<0.4). Virtual auditing provides a valid and feasible way of measuring residential urban environments. Comprehensive auditor training may be needed to guarantee good inter-rater agreement.*

KEYWORDS *Physical activity, Validation studies, Urban environment, Omnidirectional image, Virtual image*

Abbreviations: CVD – Cardiovascular diseases; GSV – Google Street View; SPACES – Systematic Pedestrian and Cycling Environmental Scan; NZ-SPACES – New Zealand Systematic Pedestrian and Cycling Environmental Scan; M-SPACES – Madrid Systematic Pedestrian and Cycling Environmental Scan; HHH – Heart Healthy Hoods; ICC – Intraclass correlation coefficient

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BACKGROUND

Cardiovascular diseases (CVD) are the leading cause of death in Europe[1] and their social, medical and economic burden will likely increase over the coming decades.[2] One of the major risk factors for CVD is physical inactivity.[3] Walking and cycling, as a mean of active transportation and commuting[4], are the main determinants of physical activity levels when considering population health approaches.[5, 6] Worldwide, it is estimated that the failure to spend 15–30 min a day briskly walking is responsible for 6–10 % of the burden of major noncommunicable diseases.[7]

In order to tackle this problem, researchers, health professionals, and policy-makers have identified a range of population approaches to support physical activity accumulation throughout the day. Population approaches for disease prevention attempts to shift the whole distribution of a population for a given risk factor, so the effect of the prevention is not limited to high-risk individuals.[8] This approach focuses on contextual factors, such as physical and social environments, and is often conceptualized within a socioecological framework.[9] Physical activity behaviors are increasingly studied within socioecological frameworks, with one of the possible areas for investigation being the urban environment.[10–14]

The development of reliable tools and methods to audit the physical qualities of the urban environment that likely impact physical activity remains an ongoing challenge for public health researchers. More than 30 field audit instruments have been developed in recent years,[15] which can be further classified into subjective (questionnaires and interviews) and objective tools (direct observation with checklists, official dataset, etc.).[11, 16, 17] The use of subjective or objective tools depends on the objective of the study and the availability of research resources.[16]

Direct observation is one type of objective measure, whereby trained observers undertake audits or checklists, which assess different aspects of the urban environment. These can be simple measures of one characteristic of the environment, such as the distance to specific destinations; information about general environment (e.g., density of buildings or traffic);[11] or assess multiple items that represent different aspects of the urban environment. The study of specific urban domains for walking (e.g., streets quality, pedestrians' safety) and cycling (e.g., cycle lanes, cycle storage) has been one of the main focuses when developing audit tools to study the relationship between urban environment and physical activity[16].

For logistical reasons, especially for studies in large geographic areas, there has been increasing interest for virtually measuring attributes of the urban environment thought to be associated with physical activity. Furthermore, many of these measures lend themselves well to using open-access mapping technologies, such as Google Earth, Google Street View, or Microsoft Visual Earth.[18] Compared with physical audits, virtual audits may provide a faster, easier, cheaper, safer, and more reliable method to assess the urban environment.[18] To date, Google Street View is the most available and accessible form of omnidirectional imagery, providing coverage for most European, USA, and Australasian urban areas.

Experiences of using open-source mapping technologies have emerged mostly in the USA[15, 19–24], but also in Canada,[25, 26] Australia,[27] New Zealand[28], UK,[29] Netherlands,[30] and Belgium.[31] Due to historical reasons, European cities[32] have different urban forms compared to cities in North America or Australia, and therefore, the study of the urban environment in Europe has its own challenges. As there are few experiences in Europe where the validity of applying a streetscape audit tool virtually has been assessed, another European context is warranted. Besides, within the European context, Mediterranean cities are characterized for being more compact in terms of urban sprawl.[33]

The objectives of this study are the following: (1) to test if the Madrid Systematic Pedestrian and Cycling Environment Scan (M-SPACES) can differentiate walking and cycling environments across different urban-form areas in Madrid, Spain; (2) to assess the validity of the M-SPACES in a virtual urban setting using Google Street View; and (3) to assess the reliability (intra- and inter-rater) of the M-SPACES audit tool.

METHODS

Setting

This study is part of the Heart Healthy Hoods (HHH) project (http://hhhproject.eu/). The HHH project examines the association between the social and physical features of the urban environment in relation to adults' cardiovascular health living in the city of Madrid, Spain.

In 2011, Madrid city had an estimated population of 3,198,645 citizens.[34] Madrid is structured in 21 districts, each of which is subdivided into neighborhoods. Neighborhoods are also divided in units of ~1000–1500 residents, called census sections. A total of 36 census sections were selected for this study, providing an estimated population of 49,260 residents.[34] Three areas, each comprising 12 census sections, were selected in Madrid based on variation (low, medium, high) in residential population per square mile and on homogeneity in terms of sociodemographic characteristics (all three areas had average scores in terms of education, immigration and aging).[34] In order to obtain clusters of 12 census sections, the Kulldorff' spatial scan statistic software was used (Fig. 1).[35] These 36 census sections included a total of 500 street segments defined as the street line from one intersection to another. These areas were located in the districts of Carabanchel, Ciudad Lineal, and Chamartín, respectively. Population density was used as a proxy of different urban form; also, population density has been positively related with walking in a recent systematic review.[36]

Measurement

Development of M-SPACES The M-SPACES is an observational audit tool of urban attributes associated with walking and cycling along a street network. The original tool was developed by Australian researchers to represent physical environments that may promote or inhibit walking or cycling.[37] Using stakeholder interviews and a Delphi study, four factors were identified that likely support physical activity behavior within the neighborhood environment: function, safety, aesthetics, and destinations.[37] Each factor consisted of different elements, which were further reduced to items. Within the same Delphi group, depending on the importance for supporting neighborhood walking and cycling, weights were applied.

As part of the URBAN study,[38] the SPACES tool was further refined by adjusting the item weights for the New Zealand context.[28] From the NZ-SPACES tool, small adjustments were made for the M-SPACES measure to be applied to Madrid, as some features of the audit tool could not be differentiated in this urban context. Small adjustments were: summing the item weights for "negotiation of footpath"

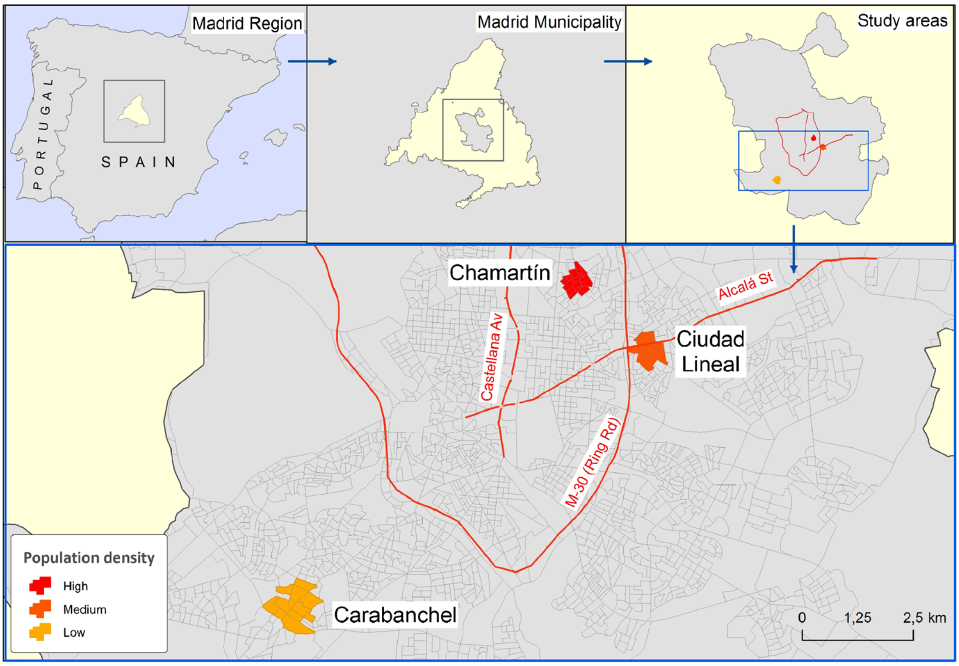

FIG. 1 Madrid city with the study areas selected.

and "type of footpath" into a single item called "type of footpath"; similarly, we aggregated "footpath smoothness" and "footpath smoothness/condition" into a variable called "footpath smoothness." We also modified the "Destinations" item by adding the number of destinations present in the street segment, as most of Madrid's segments presented many destinations, and we considered important to discriminate the number of destinations. These adjustments did not affect the final weights of the elements and factors. Final items, elements, factors and their weights are shown in Table 1. M-SPACES audit tool can be found in the online supplementary material.

M-SPACES Training Two field researchers underwent familiarization training, where practice physical and virtual audits occurred using the M-SPACES. Both researchers piloted the tool with supervision for 2 h in Ciudad Lineal. Training audits were completed following the SPACES protocol outlined in the manual.[39]

On Field and Virtual Measurements Two researchers conducted physical and virtual audits of the 36 census sections previously identified using the M-SPACES audit tool (Fig. 2). Between February and May 2014 the field researchers completed the M-SPACES physical audit by walking together along both sides of the street segments. Virtual audits of the streetscapes were completed using Google Street View software. Images of the 36 census sections were recorded by Google between May 2008 and February 2014 (Fig. 3); 152 segments (30.4 %) were recorded before 2010. The order of measurement of the three areas was not randomized; starting with the medium density area (Ciudad Lineal) followed by the high (Chamartín) and the low (Carabanchel) density areas. Within each area, we randomly selected half of the census sections for physical audit first, followed by the virtual audit; the

TABLE 1 M-SPACES tool: factors, elements, and items for walking and cycling

Factor	Element	Element weight	Item	Item weight
Walking				
Function	Walking surface	1.00	Type of path	0.25
			Path smoothness	0.20
			Path material	0.10
			Slope	0.20
			Continuity	0.20
			Curb type	0.05
	Neighborhood permeability	1.00	Other routes available	0.50
			Neighborhood legibility	0.50
	Walking infrastructure	0.33	Seats	0.50
			Trees/verandas	0.50
Safety	Street (lanes)	0.33	Number of lanes	1.00
	Fixed traffic controls	0.33	Traffic control devices present	1.00
	Path safety	0.66	Path location	0.30
			Fixed obstacles on path	0.10
			Street lights	0.20
			Surveillance	0.20
			Graffiti/vandalism	0.20
	Traffic safety	0.66	Crossing type	0.50
			Crossing aids	0.30
			Visible driveways	0.20
Aesthetics	Streetscape aesthetics	0.66	Trees	0.25
			Gardens maintained	0.25
			Verges maintained	0.25
			Cleanliness	0.25
	View aesthetics	0.66	Views	1.00
	Subjective walking assessment	0.33	Attractiveness	0.50
			Physical difficulty	0.50
Destinations	Land use mix	1.00	Number of destinations present	Out of 10
Cycling				
Function	Cycling surface	1.00	Path type	0.30
			On-road cycle lane	0.30
			Slope	0.20
			Road condition	0.10
			Curb type	0.10
	Neighborhood permeability	1.00	Other routes available	0.50
			Neighborhood legibility	0.50
	Cycling infrastructure	0.33	Cycle storage	1.00
Safety	Streets (lanes)	0.66	Number of lanes	1.00
	Fixed traffic controls	0.66	Traffic control devices present	1.00
	Traffic safety	0.33	Crossing type	0.50
			Crossing aids	0.30
			Visible driveways	0.20

TABLE 1 ***Continued***

Factor	Element	Element weight	Item	Item weight
Aesthetics	Streetscape aesthetics	0.33	Trees	0.25
			Gardens maintained	0.25
			Verges maintained	0.25
			Cleanliness	0.25
	View aesthetics	0.33	Views	1.00
	Subjective cycling assessment	0.33	Attractiveness	0.50
			Physical difficulty	0.50
Destinations	Land use mix	1.00	Number of destinations present	Out of 10

remaining half were audited in the reverse order to reduce the effect of taking the same measures of the same streetscape.

Time taken to complete the audit for each street segment was recorded for both virtual and on-field measurements. Also, time travel to each of the areas by public transportation was calculated using Google Maps software. To do so, Instituto de Salud Carlos III (Avenida Monforte de Lemos 5, 28029, Madrid, Spain) was used as the departure location for all areas, and its closest point of the area as the arrival location. Monday 8:00 A.M. was chosen as the departure hour.

Inter-Rater and Intra-Rater Reliability Inter-rater agreement was assessed between the two researchers for both physical and virtual audits. In order to measure intra-rater reliability, physical and virtual audit data collected in April 2013 by one of the researchers were compared for the median-density area (Ciudad Lineal). The

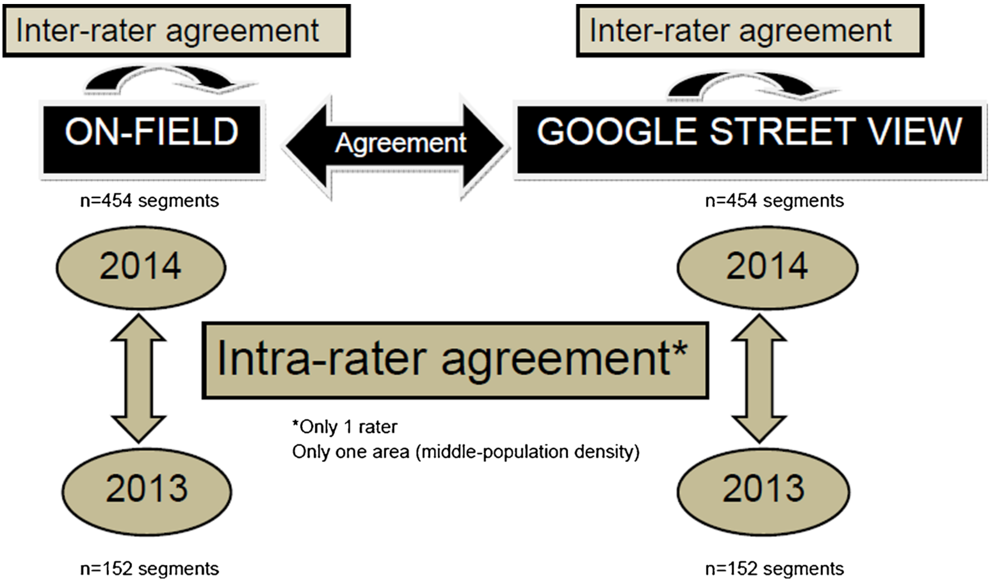

FIG. 2 Description of the M-SPACES assessment by two raters across the study areas.

FIG. 3 Picture of a street feature as it was observed in physical (*left*) and virtual audit (*right*).

adjustments to the M-SPACES audit tool (i.e., grouping and refining items) were made after this first assessment; therefore "Destinations" was excluded for the intra-rater agreement analysis.

Statistical Analysis

In order to test if the M-SPACES scores differed by urban form, we performed an analysis of variance (ANOVA) of mean scores by area. Level of significance was set as $p<0.05$.

A two-way mixed model intraclass correlation coefficient (ICC) was used to measure the following: (a) agreement between physical and virtual audits, (b) inter-rater agreement between the two researchers, and (c) intra-rater agreement comparing M-SPACES assessments in 2013 and 2014.[40, 41] The ICC measured the percentage of total variability for a given street segment:

$$\mathrm{ICC} = \frac{k\cdot \mathrm{ISS}-\mathrm{TSS}}{(k-1)\cdot \mathrm{TSS}}$$

Where "k" refers to the number of street segments, "TSS" total sum of squares, and "ISS" inter-group sum of squares.

Following Landis and Koch classification, the cutoff ranges for ICC values used were as follows: 0.0–0.20 (weak agreement), 0.21–0.40 (poor agreement), 0.41–0.60 (moderate agreement), 0.61–0.80 (substantial agreement), and 0.81–1.00 (almost perfect agreement).[42]All analyses were conducted using Stata SE version 12.1 (StataCorp., College Station, TX, USA).

Mapping

Geographic information systems (GIS) were adopted with a twofold aim. On the one hand, it constitutes the underlying technology allowing for the integration of all collected information together with contextual information such as street network, land parcel and building polygons. On the other hand, the establishment of a geo-referenced database on the subject will make possible future analysis and modeling. All data layers, both collected and downloaded from official sources, were first projected and referenced to a common system. Absolute differences between on-field and virtual audits of M-SPACES total scores for walking and cycling were then joined to the attribute table of the street segment data sets by means of relational union in order to represent it in a map. All GIS-related operations were undertaken with ArcGIS software (ESRI, Redlands, CA, USA).

RESULTS

A total of 454 street segments (90.8 %) included in the three study areas were measured both physically and virtually. Of the 46 street segments that were not audited, 20 were excluded as Google Street View imagery was unavailable (i.e., pedestrian streets that were inaccessible to the vehicles where images are captured from). The remaining excluded street segments (*n*=26) were too short to measure, and their characteristics were subsequently absorbed into the closest street segment.

Differentiation of Areas with M-SPACES in Madrid

Data presented in Table 2 show the scores for the M-SPACES factors across the three different residential density areas. Function for walking scores was higher in the medium-density area (Ciudad Lineal), while cycling functionality was higher in the lowest-density area (Carabanchel). Safety factor scores for walking and cycling were higher in the highest density area (Chamartín). Also, Chamartín had the highest scores for destinations to walk and cycle. Destinations yielded the greatest difference between the areas, whereby Chamartin (0.55) almost doubled Carabanchel's mean score for destinations present (0.29). All differences were statistically significant ($p<0.05$).

Google Street View Validity

Physical and virtual audits reported substantial (ICC>0.60–0.80) or almost perfect agreement (ICC>0.80) for 6/11 elements for walking and 5/10 elements for cycling, and also for total scores (Table 3). Walking infrastructure, traffic safety, streetscape aesthetics, and destinations demonstrated almost perfect agreement (ICC=0.86, 0.89, 0.80, and 0.85, respectively). However, walking surface and cycling infrastructure showed poor agreement (ICC=0.36 and 0.39, respectively), while cycling surface, streets lane, and subjective walking and cycling assessment showed

TABLE 2 Differences in M-SPACES factors between the three study areas

	Mean (SD) (*n*=454 street segments)			
Factors	High-density area (Chamartín), *n*=124 street segments	Median-density area (Ciudad Lineal), *n*=152 street segments	Low-density area (Carabanchel), *n*=178 street segments	*p* Value[a]
Walking factors				
Function	1.18 (0.28)	1.41 (0.31)	1.35 (0.33)	0.002*
Safety	1.07 (0.22)	1.03 (0.24)	1.03 (0.22)	0.026*
Aesthetics	0.75 (0.25)	0.77 (0.27)	0.91 (0.29)	<0.001*
Destinations	0.55 (0.29)	0.43 (0.27)	0.29 (0.21)	<0.001*
Cycling factors				
Function	0.87 (0.24)	0.93 (0.23)	1.00 (0.29)	<0.001*
Safety	1.05 (0.21)	0.94 (0.25)	1.02 (0.23)	0.005*
Aesthetics	0.44 (0.16)	0.45 (0.18)	0.55 (0.17)	<0.001*
Destinations	0.55 (0.29)	0.43 (0.27)	0.29 (0.21)	<0.001*

[a] Statistical significance of the difference in means across the study areas in each factor ($p<0.05$)

TABLE 3 Levels of agreement between elements assessed physical and virtual audits (*n*=454 street segments)

Factor	Element	Physical audit score	Virtual audit score	ICC	95 % CI
Walking					
Function	Walking surface	0.92	0.96	0.36[b]	0.28–0.44
	Neighborhood permeability	0.56	0.56	0.69[d]	0.64–0.73
	Walking infrastructure	0.19	0.18	0.86[e]	0.84–0.89
Safety	Streets (lane)	0.88	0.89	0.41[c]	0.33–0.48
	Fixed traffic controls	0.43	0.43	0.58[c]	0.52–0.64
	Path safety	0.35	0.35	0.48[c]	0.41–0.55
	Traffic safety	0.87	0.87	0.89[e]	0.87–0.91
Aesthetics	Streetscape aesthetics	0.33	0.36	0.80[e]	0.77–0.84
	View aesthetics	0.56	0.53	0.75[d]	0.71–0.79
	Subjective walking assessment	0.56	0.64	0.55[c]	0.48–0.61
Destinations	Land use mix	0.41	0.41	0.85[e]	0.83–0.88
Total	Sum of factors weights	4.00	4.06	0.87[e]	0.85–0.89
Cycling					
Function	Cycling surface	0.65	0.41	0.51[c]	0.44–0.57
	Neighborhood permeability	0.56	0.56	0.69[d]	0.64–0.73
	Cycling infrastructure	0.01	0.01	0.39[b]	0.31–0.47
Safety	Streets (lane)	0.88	0.89	0.40[c]	0.33–0.48
	Fixed traffic controls	0.43	0.43	0.58[c]	0.52–0.64
	Traffic safety	0.87	0.87	0.89[e]	0.87–0.91
Aesthetics	Streetscape aesthetics	0.32	0.36	0.80[e]	0.77–0.84
	View aesthetics	0.56	0.53	0.75[d]	0.71–0.79
	Subjective cycling assessment	0.56	0.64	0.53[d]	0.46–0.59
Destinations	Land use mix	0.42	0.42	0.85[e]	0.83–0.88
Total	Sum of factors weights	3.29	3.35	0.77[d]	0.72–0.80

ICC intraclass correlation coefficient, *CI* confidence interval

[a] Weak agreement (ICC <0.2)

[b] Poor agreement (ICC 0.2–0.4)

[c] Moderate agreement (ICC 0.4–0.6)

[d] Substantial agreement (ICC 0.6–0.8)

[e] Almost perfect agreement (ICC >0.8)

moderate agreement (ICC=0.51, 0.41, 0.55, and 0.53, respectively). Figure 4 shows walking and cycling total scores' difference between physical and virtual audits.

Intra-Rater Reliability

Most elements demonstrated moderate or substantial intra-rater agreement (ICC=0.40–0.80) (Table 4). Walking infrastructure, streets lane, traffic safety, and view aesthetics had almost perfect agreement (ICC>0.80). Intra-rater agreement for the virtual auditing was higher for aesthetics (ICC=0.81) than the intra-rater agreement for aesthetics in the physical audits (ICC=0.45).

Vast differences existed for view aesthetics (physical audit: ICC=0.15; virtual audit: ICC=0.88). Path safety, cycling surface (only for the physical measurement)

FIG. 4 Absolute differences between physical and virtual audits for walking (*left*) and cycling (*right*) total M-SPACES score.

and cycling infrastructure had an ICC=0.00, and thus were regarded as being highly unreliable.

Inter-Rater Reliability

In general, inter-rater agreement was low (Table 5). The agreement between the two observers was better for the physical audits when compared with the virtual audits.

TABLE 4 Intra-rater agreement between elements assessed by one rater twice (2013 and 2014) (*n*=152 street segments)

		Physical		Virtual	
Factor	Element	ICC	95 % CI	ICC	95 % CI
Walking					
Function	Walking surface	0.54[c]	0.43–0.66	0.30[b]	0.15–0.45
	Neighborhood permeability	0.49[c]	0.37–0.61	0.48[c]	0.35–0.60
	Walking infrastructure	0.85[e]	0.80–0.89	0.82[e]	0.76–0.90
Safety	Streets (lane)	0.92[e]	0.89–0.94	0.91[e]	0.89–0.94
	Fixed traffic controls	0.59[c]	0.49–0.69	0.74[d]	0.66–0.81
	Path safety	0.00[a]	0.00–0.17	0.00[a]	0.00–0.16
	Traffic safety	0.77[d]	0.71–0.84	0.80[e]	0.74–0.86
Aesthetics	Streetscape aesthetics	0.72[d]	0.65–0.80	0.69[d]	0.60–0.77
	View aesthetics	0.15[a]	0.00–0.30	0.88[e]	0.85–0.92
	Subjective walking assessment	0.42[c]	0.29–0.55	0.52[c]	0.40–0.64
Destinations	Land use mix	N.A.	N.A.	N.A.	N.A.
Cycling					
Function	Cycling surface	0.33[b]	0.18–0.47	0.00[f]	0.00–0.17
	Neighborhood permeability	0.49[c]	0.37–0.61	0.48[c]	0.35–0.60
	Cycling infrastructure	0.00[f]	0.00–0.00	0.00[f]	0.00–0.00
Safety	Streets (lane)	0.92[e]	0.89–0.94	0.91[e]	0.89–0.94
	Fixed traffic controls	0.59[c]	0.49–0.69	0.74[d]	0.66–0.81
	Traffic safety	0.77[d]	0.71–0.84	0.80[e]	0.74–0.86
Aesthetics	Streetscape aesthetics	0.72[d]	0.65–0.80	0.69[d]	0.60–0.77
	View aesthetics	0.15[a]	0.00–0.30	0.88[e]	0.85–0.92
	Subjective cycling assessment	0.41[c]	0.28–0.54	0.42[c]	0.29–0.55
Destinations	Land use mix	N.A.	N.A.	N.A.	N.A.

N.A. not assessed, *ICC* intraclass correlation coefficient, *CI* confidence interval

[a] Weak agreement (ICC <0.2)

[b] Poor perfect agreement (ICC 0.2–0.4)

[c] Moderate agreement (ICC 0.4–0.6)

[d] Substantial agreement (ICC 0.6–0.8)

[e] Almost perfect agreement (ICC >0.8)

[f] ICC truncated at zero

Both physical and virtual walking and cycling surface elements showed weak inter-rater agreement (ICC<0.20). Apart from virtual cycling infrastructure (e.g., cycle storage) (ICC=0.47), physical and virtual audits of walking and cycling infrastructure showed substantial agreement (ICC=0.60–0.80). Aesthetics and subjective assessments tended to have lower agreement (ICC<0.40) than the streetscape aesthetics. Virtual path safety inter-rater agreement was weak (ICC=0.08), especially when compared with the inter-rater agreement using the physical audit (ICC=0.32).

Time Taken to Complete the Audits

Overall, the time taken to measure each street segment was faster for on-field auditing (2.45 min per segment) than virtual auditing (2.76 min per segment), and this was consistently shown across the three areas. In Chamartín, virtual auditing took 2.87 min per street segment compared with 2.42 min for the physical assessment. In Ciudad Lineal it took a meantime of 2.84 min virtually and 2.33 min

TABLE 5 Inter-rater agreement between physical and virtual elements by two raters in three study areas (*n*=454 street segments)

		Physical		Virtual	
Factor	Element	ICC	95 % CI	ICC	95 % CI
Walking					
Function	Walking surface	0.02a	0.00–0.12	0.00f	0.00–0.09
	Neighborhood permeability	0.39b	0.31–0.47	0.41c	0.33–0.49
	Walking infrastructure	0.66d	0.60–0.71	0.60d	0.52–0.65
Safety	Streets (lane)	0.79d	0.76–0.83	0.33b	0.25–0.41
	Fixed traffic controls	0.27b	0.18–0.36	0.21b	0.12–0.30
	Path safety	0.32b	0.24–0.40	0.08a	0.00–0.17
	Traffic safety	0.43c	0.36–0.51	0.41c	0.33–0.48
Aesthetics	Streetscape aesthetics	0.61d	0.56–0.67	0.59c	0.52–0.65
	View aesthetics	0.28b	0.19–0.36	0.18a	0.09–0.27
	Subjective walking assessment	0.30b	0.22–0.39	0.29b	0.21–0.38
Destinations	Land use mix	0.67d	0.61–0.72	0.57c	0.51–0.63
Cycling					
Function	Cycling surface	0.10a	0.01–0.19	0.00f	0.00–0.0f
	Neighborhood permeability	0.39b	0.31–0.47	0.41c	0.33–0.49
	Cycling infrastructure	0.75d	0.71–0.79	0.47c	0.40–0.53
Safety	Streets (lane)	0.79d	0.76–0.83	0.33b	0.25–0.41
	Fixed traffic controls	0.27b	0.18–0.36	0.21b	0.12–0.30
	Traffic safety	0.43c	0.36–0.51	0.41c	0.33–0.48
Aesthetics	Streetscape aesthetics	0.61d	0.56–0.67	0.59c	0.52–0.65
	View aesthetics	0.28b	0.19–0.36	0.18a	0.09–0.27
	Subjective cycling assessment	0.44c	0.36–0.51	0.33b	0.25–0.42
Destinations	Land use mix	0.67d	0.61–0.72	0.57c	0.51–0.63

ICC intraclass correlation coefficient, *CI* confidence interval
aWeak agreement (ICC <0.2)
bPoor agreement (ICC 0.2–0.4)
cModerate agreement (ICC 0.4–0.6)
dSubstantial agreement (ICC 0.6–0.8)
eAlmost perfect agreement (ICC >0.8)
fICC truncated at zero

physically per street segment. In Carabanchel, virtual auditing was faster (2.62 min per street segment), and physical audits were slower (2.57 min per street segment) compared with Carabanchel and Chamartín. Time travel from Instituto de Salud Carlos III to the study areas was estimated as 36 min to Chamartin, 40 min to Ciudad Lineal and 60 min to Carabanchel.

DISCUSSION

These findings showed that M-SPACES is a useful tool to measure walking and cycling environments in the streets segments of a European city like Madrid. SPACES original tool and its variants are based on a conceptual framework which makes it an easy tool to compare different urban forms and has been used and validated in several other settings.[28, 43, 44] Google Street View was, for most features of the streetscape, a valid instrument to assess physical urban environment using M-SPACES when the physical and virtual audits were compared. Furthermore, most elements had substantial (neighborhood permeability) or almost perfect agreement (walking infrastructure, traffic safety, streetscape aesthetics, and destinations). Despite that, some features did not reach acceptable agreement when virtual and physical measures were compared. For some of these elements (walking and cycling surface and streets lane), the use of supplementary information via other secondary spatial sources (e.g., council databases) could be used to improve reliability. However, the differences shown for cycling infrastructure (cycle storage) may be a temporal issue, whereby new cycling infrastructure (e.g., bicycle parking) in Madrid were not present when the Google Street View imagery was taken. In summary, our findings are compatible with the work of other studies,[45] that have found that the more subjective characteristics (e.g., sidewalk conditions) have lower agreement between virtual and physical audits. However, in our findings view aesthetics and streetscape aesthetics showed an acceptable agreement. Furthermore, little availability for some elements (e.g., low prevalence of cycling storage) could explain low levels of agreement with ICC due to low variability.[41]

It was not anticipated that the mean time auditing the street segments using Google Street View would be slower than conducting physical audits; however, time taken to go to the areas by public transportation also has to be taken into account. Nevertheless, other studies conducted in Australia, New Zealand, and UK found that virtual audits were faster than physical audits.[28, 30] A possible explanation may be that the greater complexity of the street structures in Mediterranean and continental Europe cities may eliminate the time advantage of undertaking virtual audits.[32] Given this fact, in this study, time spent auditing street segments in the low-density (where the streets segments are expected to be longer) area was similar when measuring the environment physically or virtually. Despite this, virtually assessing urban environments has other advantages as virtual audits: (1) are not affected by daylight restriction or weather changes; (2) require limited resources (computer and internet connection); (3) are less financially costly than physical audits;[28] (4) are useful for regional and international comparisons; (5) may be a good alternative when measuring unsafe areas;[21] and (6) it provides an alternative when visiting the study area physically is not possible. Also, metadata provided by Google Street View allow researchers to match environmental conditions.

Our intra-rater reliability results are comparable with previous studies.[30, 31] These results, besides demonstrating the intra-reliability of M-SPACES both physically and virtually, showed that in most cases, the urban environment in these three areas did not change between 2013 and 2014. Lower levels of agreement were found for cycling infrastructure and surface, as also path safety, which may be due to low variability of these elements in the study area, as also some new elements (e.g., cycle storage) that were not present in 2013.

Inter-rater agreement between the two observers was low. Only walking infrastructure, streets lane (physical audit), streetscape aesthetics, and destinations have acceptable levels of agreement. One possible explanation for the low agreement observed might be systematic auditor training differences. Even though both researchers received training with the SPACES manual, this manual was not translated and adapted to the Madrid context, which may have resulted in different understanding of the different options to choose in the audit tool. Potentially due to these reasons, our findings are not consistent with the results of Kelly et al., which found high levels of agreement between four auditors when measuring the streetscape with Google Street View.[22] In their work, all auditors received systematically 4 h of training; our auditors read the SPACES manual[39] and piloted the tool in Ciudad Lineal for 2 h. Griew et al. found that inter-rater agreement was different between different types of neighborhood (industrial, residential, etc.).[29] However, we did not find any differences between inter-rater agreements for our three areas that could help us to understand this low agreement between observers.

Limitations and Strengths

We acknowledge that this study has several limitations. The M-SPACES tool was designed to measure the streetscape, therefore did not assess access to parks, pedestrian- or cycling-only paths, recreation centers, or other facilities, and it is possible that these residential features are associated with walking behavior. Images from Google Street View were taken between 2008 and 2014 (30.4 % before 2010); so there may be some areas for which the images are not updated. As there has been an acceptable agreement for both intra-rater and physical-virtual, we donot believe that timing of the Google Street View pictures was a major problem in this study; however, this may be an important topic to take into account when using virtual assessments to study the relationship between urban environment and health results. Google Street View was the web-based tool used to measure the streets, and when used in conjunction with other measures, such as Google Earth or MS Visual Oblique, may provide additional environmental context; however, we did not explore these additional datasets. Ten percent of the street segments could not be measured by Google Street View, as there were no images, almost all of them being pedestrian streets. It is important to note that pedestrian streets are very relevant to develop walkable neighborhoods in European cities, so it is important to create specific tools to assess pedestrian streets, as also ways to measure it virtually (e.g., not 3D satellite images). Low variability affects ICC agreement values, so the assessment of some aspects of the streets (especially cycling infrastructure and surface characteristics) may need to be completed with other concordance methodologies. Despite this, we regarded Google Street View as being the most accessible and most appropriate web tool for measuring fine-grained streetscape elements.[23]. Inter-rater agreement was low, and in the future, we would recommend developing systematic training adapted to the study area. The question for Destinations was adapted between the 2013 and 2014 auditing, and therefore was not included the agreement of this factor in the intra-rater analysis; future work needs to explore the reliability of this factor for the M-SPACES.

The present study also presents several strengths. As far as we know, there are no other studies that have used such a large number of street segments set to test the accuracy of virtual audits. Previous studies have used between 48 and 369 street segments.[18] This is also the first study to test the validity of the virtual assessment of an audit tool that measures streets characteristics that may influence both walking and cycling in Europe, and compared areas based on residential density, a factor potentially related to physical activity. Moreover, to our knowledge, this is the first study to study the agreement between virtual and on-field tools in a Mediterranean context, where urban form patterns differ greatly from the more sprawled North-American or Australasian cities.

CONCLUSIONS

The M-SPACES audit tool is able to discriminate between different population-density areas. Google Street View provided a valid way of measuring most aspects of the residential environment in a European city like Madrid, especially neighborhood permeability walking infrastructure, traffic safety, streetscape aesthetics, and destinations. However, for some features (e.g., street lane), the audits may need to be completed with other secondary spatial databases. Characteristics of the streets that may inhibit or promote cycling had lower correlation between on-field and virtual audits. Inter-rater agreement was, in general, weak; therefore, intensive observer training and the use of complementary objective techniques may be required. Intra-auditor agreement was substantially better when measuring urban environments virtually.

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Authors' Contributions. MF, UB, and JD conceived the research idea. PG and HB contributed to the final design. PG and SA conducted data collection. FE and AC organized the database and prepared all the maps. PG conducted the statistical analysis. PG, HB, SA, FE, AC, JD, and MF reviewed and worked in the interpretation of the results. The first draft of the manuscript was prepared by PG and MF and reviewed by all authors. All authors have contributed and approved the final report.

REFERENCES

1. Nichols M, Townsend N, Scarborough P, Rayner M. Cardiovascular disease in Europe: epidemiological update. *Eur Heart J*. 2013; 34(39): 3028–34.
2. Beaglehole R, Bonita R. Global public health: a scorecard. *Lancet*. 2008; 372(9654): 1988–96.
3. WHO. *Global status report on noncommunicable diseases 2010*. Geneva, Switzerland: World Health Organization; 2011.
4. Shephard RJ. Is active commuting the answer to population health? *Sports Med*. 2008; 38(9): 751–8.
5. Lindstrom M. Means of transportation to work and overweight and obesity: a population-based study in southern Sweden. *Prev Med*. 2008; 46(1): 22–8.
6. Hamer M, Chida Y. Walking and primary prevention: a meta-analysis of prospective cohort studies. *Br J Sports Med*. 2008; 42(4): 238–43.
7. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet*. 2012; 380(9838): 219–29.

8. Rose G. Sick individuals and sick populations. *Int J Epidemiol*. 1985; 14(1): 32–8.
9. Giles-Corti B, Donovan RJ. The relative influence of individual, social and physical environment determinants of physical activity. *Soc Sci Med*. 2002; 54(12): 1793–812.
10. Mozaffarian D, Afshin A, Benowitz NL, et al. Population approaches to improve diet, physical activity, and smoking habits: a scientific statement from the American Heart Association. *Circulation*. 2012; 126(12): 1514–63.
11. Chow CK, Lock K, Teo K, Subramanian SV, McKee M, Yusuf S. Environmental and societal influences acting on cardiovascular risk factors and disease at a population level: a review. *Int J Epidemiol*. 2009; 38(6): 1580–94.
12. Townshend T, Lake AA. Obesogenic urban form: theory, policy and practice. *Health Place*. 2009; 15(4): 909–16.
13. Jackson RJ, Dannenberg AL, Frumkin H. Health and the built environment: 10 years after. *Am J Public Health*. 2013; 103(9): 1542–4.
14. Franco M, Bilal U, Diez-Roux AV. Preventing non-communicable diseases through structural changes in urban environments. *J Epidemiol Community Health*. 2015; 69(6): 509–11.
15. Wilson JS, Kelly CM, Schootman M, et al. Assessing the built environment using omnidirectional imagery. *Am J Prev Med*. 2012; 42(2): 193–9.
16. Diez Roux AV. Neighborhoods and health: where are we and were do we go from here? *Rev Epidemiol Sante Publique*. 2007; 55(1): 13–21.
17. Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the built environment for physical activity: state of the science. *Am J Prev Med*. 2009; 36(4 Suppl): S99–123. **e112**.
18. Charreire H, Mackenbach JD, Ouasti M, et al. Using remote sensing to define environmental characteristics related to physical activity and dietary behaviours: a systematic review (the SPOTLIGHT project). *Health Place*. 2013; 25C: 1–9.
19. Vargo J, Stone B, Glanz K. Google walkability: a new tool for local planning and public health research? *J Phys Act Health*. 2012; 9(5): 689–97.
20. Clarke P, Ailshire J, Melendez R, Bader M, Morenoff J. Using Google Earth to conduct a neighborhood audit: reliability of a virtual audit instrument. *Health Place*. 2010; 16(6): 1224–9.
21. Rundle AG, Bader MD, Richards CA, Neckerman KM, Teitler JO. Using Google Street View to audit neighborhood environments. *Am J Prev Med*. 2011; 40(1): 94–100.
22. Kelly CM, Wilson JS, Baker EA, Miller DK, Schootman M. Using Google Street View to audit the built environment: inter-rater reliability results. *Ann Behav Med*. 2013; 45(Suppl 1): S108–12.
23. Ben-Joseph E, Lee JS, Cromley EK, Laden F, Troped PJ. Virtual and actual: relative accuracy of on-site and web-based instruments in auditing the environment for physical activity. *Health Place*. 2013; 19: 138–50.
24. Kelly C, Wilson JS, Schootman M, Clennin M, Baker EA, Miller DK. The built environment predicts observed physical activity. *Front Public Health*. 2014; 2: 52.
25. Janssen I, Rosu A. Measuring sidewalk distances using Google Earth. *BMC Med Res Methodol*. 2012; 12: 39.
26. Carson V, Janssen I. Neighborhood disorder and screen time among 10–16 year old Canadian youth: a cross-sectional study. *Int J Behav Nutr Phys Act*. 2012; 9: 66.
27. Taylor BT, Fernando P, Bauman AE, Williamson A, Craig JC, Redman S. Measuring the quality of public open space using Google Earth. *Am J Prev Med*. 2011; 40(2): 105–12.
28. Badland HM, Opit S, Witten K, Kearns RA, Mavoa S. Can virtual streetscape audits reliably replace physical streetscape audits? *J Urban Health*. 2010; 87(6): 1007–16.
29. Griew P, Hillsdon M, Foster C, Coombes E, Jones A, Wilkinson P. Developing and testing a street audit tool using Google Street View to measure environmental supportiveness for physical activity. *Int J Behav Nutr Phys Act*. 2013; 10: 103.

30. Bethlehem JR, Mackenbach JD, Ben-Rebah M, et al. The SPOTLIGHT virtual audit tool: a valid and reliable tool to assess obesogenic characteristics of the built environment. *Int J Health Geogr*. 2014; 13: 52.
31. Vanwolleghem G, Van Dyck D, Ducheyne F, De Bourdeaudhuij I, Cardon G. Assessing the environmental characteristics of cycling routes to school: a study on the reliability and validity of a Google Street View-based audit. *Int J Health Geogr*. 2014; 13(1): 19.
32. Kazepov Y. *Cities of Europe: changing contexts, local arrangement and the challenge to urban cohesion*. Oxford, United Kingdom: Wiley; 2005.
33. Kasanko M, Barredo JI, Lavalle C, et al. Are European cities becoming dispersed?: A comparative analysis of 15 European urban areas. *Landsc Urban Plan*. 2006; 77(1–2): 111–30.
34. Censo de Población y viviendas. *Resultados municipales Madrid. Instituto Nacional de Estadística*. 2011. http://www.ine.es/censos2011_datos/cen11_datos_resultados.htm. **Accessed 11/19/2013**.
35. Kulldorff M. A spatial scan statistic. *Comm Stat Theor Meth*. 1997; 26(6): 1481–96.
36. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *Int J Behav Nutr Phys Act*. 2011; 8: 125.
37. Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. *Soc Sci Med*. 2003; 56(8): 1693–703.
38. Badland HM, Schofield GM, Witten K, et al. Understanding the Relationship Between Activity and Neighbourhoods (URBAN) study: research design and methodology. *BMC Public Health*. 2009; 9: 224.
39. Pikora T. SPACES instrument: observers manual
40. Bartko JJ. The intraclass correlation coefficient as a measure of reliability. *Psychol Rep*. 1966; 19(1): 3–11.
41. DeVellis RF. *Scale development: theory and applications*. Thousand Oaks, CA: SAGE Publications; 2003.
42. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977; 33(1): 159–74.
43. Pikora TJ, Giles-Corti B, Knuiman MW, Bull FC, Jamrozik K, Donovan RJ. Neighborhood environmental factors correlated with walking near home: using SPACES. *Med Sci Sports Exerc*. 2006; 38(4): 708–14.
44. Jago R, Baranowski T, Zakeri I, Harris M. Observed environmental features and the physical activity of adolescent males. *Am J Prev Med*. 2005; 29(2): 98–104.
45. Curtis JW, Curtis A, Mapes J, Szell AB, Cinderich A. Using Google Street View for systematic observation of the built environment: analysis of spatio-temporal instability of imagery dates. *Int J Health Geogr*. 2013; 12: 53.

4.2. Population cardiovascular health and urban environments: The Heart Healthy Hoods exploratory study in Madrid, Spain

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RESEARCH ARTICLE

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Population cardiovascular health and urban environments: the Heart Healthy Hoods exploratory study in Madrid, Spain

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Abstract

Background: Our aim is to conduct an exploratory study to provide an in-depth characterization of a neighborhood's social and physical environment in relation to cardiovascular health. A mixed-methods approach was used to better understand the food, alcohol, tobacco and physical activity domains of the urban environment.

Methods: We conducted this study in an area of 16,000 residents in Madrid (Spain). We obtained cardiovascular health and risk factors data from all residents aged 45 and above using Electronic Health Records from the Madrid Primary Health Care System. We used several quantitative audit tools to assess: the type and location of food outlets and healthy food availability; tobacco and alcohol points of sale; walkability of all streets and use of parks and public spaces. We also conducted 11 qualitative interviews with key informants to help understanding the relationships between urban environment and cardiovascular behaviors. We integrated quantitative and qualitative data following a mixed-methods merging approach.

Results: Electronic Health Records of the entire population of the area showed similar prevalence of risk factors compared to the rest of Madrid/Spain (prevalence of diabetes: 12 %, hypertension: 34 %, dyslipidemia: 32 %, smoking: 10 %, obesity: 20 %). The food environment was very dense, with many small stores ($n = 44$) and a large food market with 112 stalls. Residents highlighted the importance of these small stores for buying healthy foods. Alcohol and tobacco environments were also very dense ($n = 91$ and 64, respectively), dominated by bars and restaurants ($n = 53$) that also acted as food services. Neighbors emphasized the importance of drinking as a socialization mechanism. Public open spaces were mostly used by seniors that remarked the importance of accessibility to these spaces and the availability of destinations to walk to.

Conclusion: This experience allowed testing and refining measurement tools, drawn from epidemiology, geography, sociology and anthropology, to better understand the urban environment in relation to cardiovascular health.

Keywords: Cardiovascular disease, Residential environment, Neighborhoods, Mixed methods, Spain

Abbreviations: CVD, Cardiovascular diseases; EHR, Electronic health records; GIS, Geographic information systems; HFAI, Healthy food availability index; NEMS-R, Nutrition environment measure survey-restaurants; NEMS-S, Nutrition environment measure survey-stores; SOPARC, System for Observing Play and Recreation in Communities; SPACES, Systematic pedestrian and cycling environment scan; UK, United Kingdom of Great Britain and Northern Ireland; US, United States of America.

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Background

Cardiovascular diseases (CVD) remain the leading cause of death worldwide [1]. Their burden is projected to escalate in the following decades due to increased prevalence [2]. The large costs associated with CVD fall both on the social and economic side and the lack of effective preventive measures will make these costs difficult to deal with for governments worldwide [3, 4]. Individual risk factors directly associated with CVD include behavioral traits as smoking, unhealthy diets, lack of physical activity and excessive consumption of alcohol [5]. These behavioral risk factors and their associated increases in biological risk factors as hypertension, dyslipidemia and diabetes represent a large proportion of the excess CVD risk in populations. In particular, it has been estimated that there's an opportunity to prevent even more CVD deaths in Spain if we can curb the increase in some risk factors such as diabetes [6].

Prevention efforts are much needed to continue decreasing the incidence of CVD. The population preventive approach [7] has previously shown large reductions in CVD, either through well-designed whole population campaigns [8] or through large political or economic changes [9]. This approach has a large potential preventive effect since it tackles the root causes, which are mostly social, political and economic [10], of the distribution of chronic diseases in a given population. One of the social units that may better exemplify whole population preventive strategies are urban neighborhoods [10]. Public health research at the neighborhood level tries to characterize which features of the local residential environment are key in the distribution of disease risk among populations. Methodological advances in the last decades, such as multilevel modeling [11], have allowed for simultaneous analysis of individual and contextual effects, removing much of the limitations of individual or ecological based analysis.

At the same time the growing use of electronic health records (EHRs) offers a tremendous opportunity to public health researchers to measure residents health outcomes [12] by neighborhood. Results from these EHRs studies will expand the evidence to improve cardiovascular health at a population level.

In terms of being able to fully characterize the urban environment [13], borrowing methodologies and techniques from social sciences such as geography are key. Current attained level of development of Geographic Information Systems (GIS) has made possible relevant advances in this area.

However, previous research has shown that objective neighborhood resources are not always consistent with residents' perceptions. Qualitative methods, such as semi-structured interviews, enable the examination of this complex association between neighborhoods and the impact on residents' health outcomes. This combined use of different perspectives and methodologies has been recently defined as mixed-methods research [14], focusing on research questions that call for real-life contextual understandings, multi-level perspectives, and cultural influences [14, 15].

This is an exploratory study framed within a larger study, the Heart Healthy Hoods [10, 16], aiming at characterizing the entire city of Madrid (Spain) and the cardiovascular health of its residents. A photographic depiction of the study area of the present manuscript can be found elsewhere [16] (the middle income area). Results from this experience can help other researchers design urban health studies that completely characterize a residential environment and the health of its residents. We aim to fully characterize an urban area using several measurement tools and approaches, basing our strategy on a theory-driven approach shown in Fig. 1. As proposed by Sacristan [17], we started with a theory-driven framework where we will explore its feasibility and add new hypotheses as a result of this exploratory study.

In the spirit and recommendations of Thabane et al. [18], we do not present any hypothesis testing results, but rather leave open several questions for future research in the main study. This is also in concordance with the approach proposed by Shankdardass and Dunn [19], who advocate for more "intensive" neighborhoods research, as opposed to "extensive" research. In summary, extensive research seeks to draw inferences about the quantification of neighborhood effects in the "general" population of neighborhoods. Intensive research instead seeks to uncover *how* neighborhood effects work and what are the best points of action to affect them.

The objective of this study is therefore to: (a) describe the cardiovascular health profile of a population over 15,000 residents living in this area analyzing the Madrid Primary Health Care System electronic health records; and (b) explore different quantitative and qualitative measurements to characterize the social and physical urban environment in relation to food, alcohol, tobacco and physical activity.

Methods

Study design and setting

This is an exploratory study conducted in 12 contiguous census sections of Madrid (Fig. 2) between March 2013 and June 2014 describing the Cardiovascular Health profile and Risk Factors of its residents and the social and physical urban environment in which they live. In order to conduct our study in an area that was not extreme in sociodemographic or urban form terms, we selected these 12 census sections using the Median Neighborhood Index. This method selects clusters of

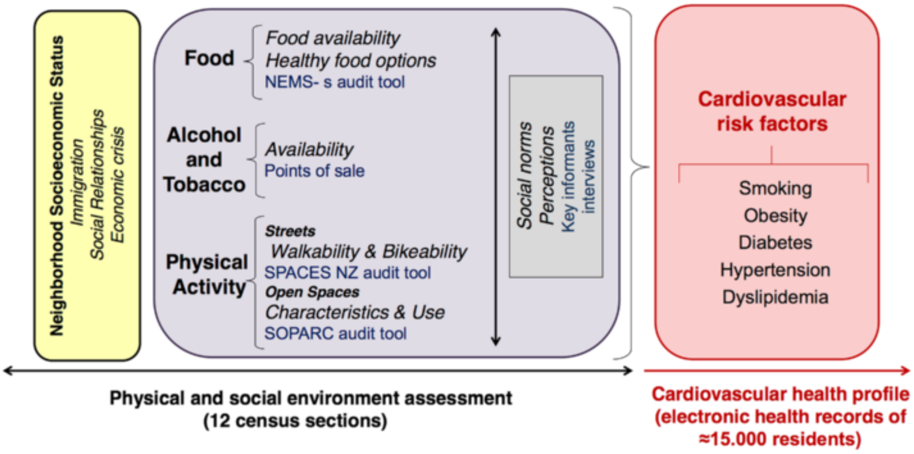

Fig. 1 Conceptual framework of this study. The environmental outcomes assessed are shown in italics, whereas the type of measurement are shown in blue. The cross-cutting approach of the qualitative methodology is highlighted throughout the grey box

census sections that are on average closest to the median neighborhood in four variables: % above 65 years of age or older, % with low education, % foreign-born and population density. More details on this method can be found in the Additional file 1: S1.

Quantitative measurements of cardiovascular health and risk factors

Spain's National Health System (SNS) is publicly funded, providing universal health care coverage free of charge at the point of use. The National Health System structure is

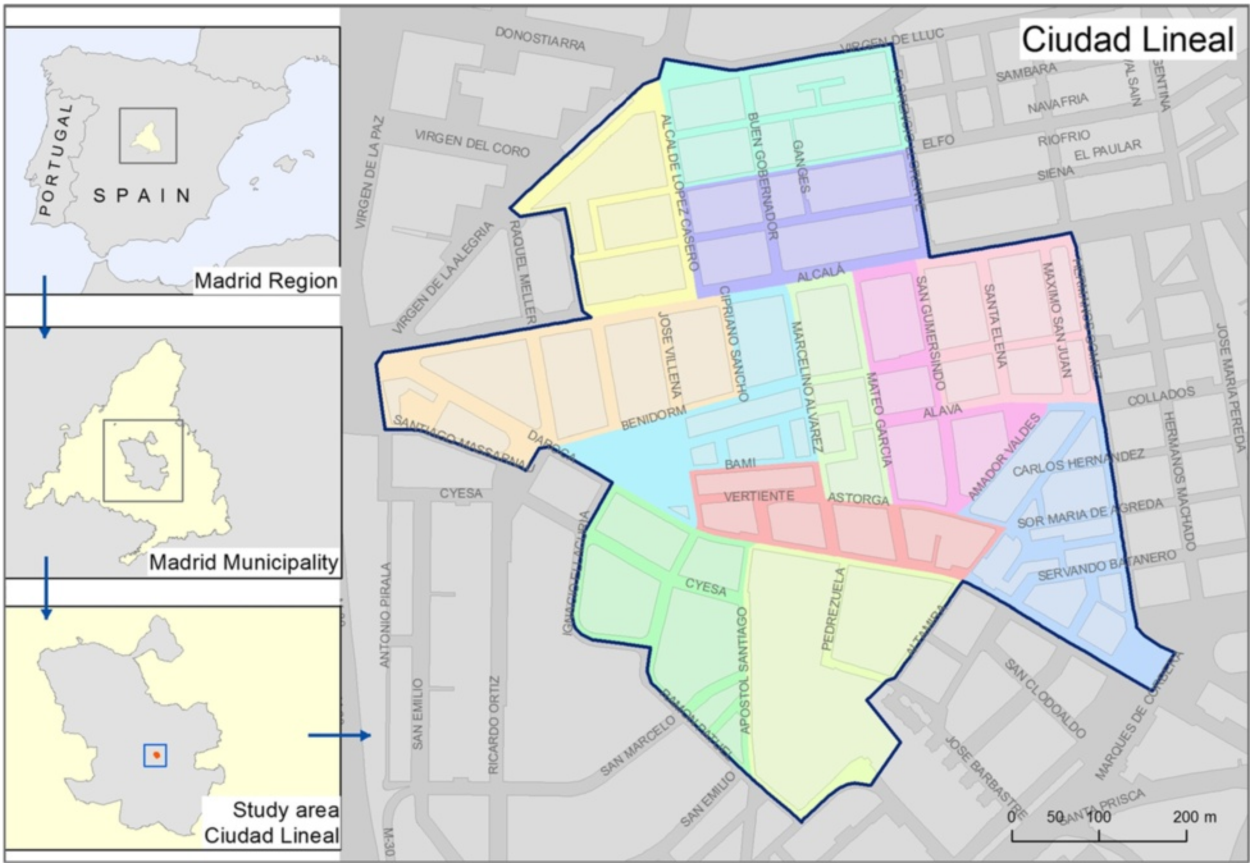

Fig. 2 Heart Healthy Hoods exploratory study setting (12 census sections in Ciudad Lineal, Madrid, Spain)

region-based, and organized into health areas and basic health zones. Electronic health records share the same system and software at the region-level. These records include diagnoses for conditions such as diabetes or hypertension that have been previously validated [20, 21] and other diagnoses such as dyslipidemia, obesity or smoking.

The study population was restricted to those individuals aged 45 and above, holding a health care identification card and living within the 12 census sections. Cardholders needed to have visited their primary care health center in the last year at least once prior to the data mining. We collected anonymized data from electronic health records on cardiovascular health and risk factors (tobacco use, obesity, hypertension, diabetes mellitus, dyslipidemia) and sociodemographic variables (age, sex). In all cases of diabetes, hypertension and dyslipidemia, the diagnoses were physician-based. Obesity was assessed by computing BMI (kg/m^2) from the last available measure of height and weight and was defined as a BMI > =30 kg/m^2. Smoking was assessed by asking individuals about current cigarette smoking. According to the internal primary care guidelines, all individuals aged 14 or above should have at least two of the risk factors mentioned above (plus sedentarism and alcohol consumption) measured in the previous 5 years. Moreover, all individuals without prevalent cardiovascular disease or diabetes and aged between 40 and 65 (which includes our study population) should get their cardiovascular risk assessed every 2 to 5 years (for medium/high and low risk individuals, respectively). This cardiovascular risk assessment includes the measurement of blood pressure and lipids and assessing tobacco use (as described above). Anonymization was conducted by removing all personally identifiable information (address, name, identifiers) and aggregating the results to the census section level.

Quantitative measurements of the urban environment

We selected audit tools from other countries (mostly the US and Australia) given the scarcity of studies measuring specific characteristics of urban environments in Spain. All audit tools selected below were selected based on their simplicity and similarity to Spanish urban environments. When possible, we elected to do the fewest amount of adaptations possible to improve comparability with other international studies.

Food environment

We identified all food stores in the area by direct observation. We classified and conducted a direct auditing of all food stores present. Classification was done ad hoc following Table 1. This classification, which relates to the size, and range of food options available at the food stores, follows the categorization used by the Nutrition Environment Measurement in Stores (NEMS-S) [22]. A trained data collector conducted direct auditing of all food stores following a brief version of the NEMS-S tool (For the brief instrument and the adaptations see Additional file 1: S2). We then computed a Healthy Food Availability Index for each store following the scoring system in the Additional file 1: S2. This HFAI score ranges from 0–28, with a higher score indicating a greater availability of healthy foods. We also assessed public markets in the area and classified each stall as either a specific specialty store (e.g.: fruit/vegetable) or a small grocery store (selling a variety of items). Public markets in Spain are a collection of tens of stalls (in our case, more than 100) mostly dedicated to retailing a single category of foods (e.g.: fruits/vegetables, fish, meat, bakery products, etc.). For this reason and considering that the NEMS-S was designed around measuring scattered discrete stores, we decided not to compute a Healthy Food Availability Index for the public market and just describe the number and type of stalls.

Table 1 Classification and description of food store types

Type of Store	
Public Market	Municipally owned building where vendors sell fresh food from open stalls.
Supermarket	Large corporate owned "chain" food stores with several employees and cash registers.
Small Grocery	Non-corporate-owned small food stores, with no more than 1 cash register.
Specialty Store	Small food store that sells only one group of foods (eg: fruits/vegetables, butchers, fishmongers)
Corner Store	Small store with long shopping hours and (generally) owned by ethnic minorities.
Convenience Store/Gas Station	Food stores with a limited selection of foods, with long shopping hours (>18 h/day), attached or not to a gas station.

Food services (restaurants, bars, fast food options, etc.) were classified into fast food restaurants and sitting down restaurants using the same classification as the Nutrition Environment Measurement in Restaurants (NEMS-R) inventory [23].

Alcohol and tobacco environment

We identified all tobacco and alcohol outlets in the area by direct observation (analogous to the observation of food stores). We characterized the tobacco and alcohol environment by classifying all retail outlets that sold either tobacco or alcohol into the following categories: tobacco stores and vending machines; bars or restaurants (selling alcohol for consumption on-site), food stores selling alcohol (a majority of the food stores present in the area) and liquor stores. Spanish law heavily regulates retail sales of tobacco, that can only be conducted through tobacco stores (called “Estancos”) or vending machines, which have to be located in establishments previously authorized from the *Commissioner for the Tobacco Market* (such as newspaper stands located on public roads, certain convenience stores or bars and restaurants). The number of vending machines per area is also regulated and is linked to the number of tobacco stores in the area.

Physical activity environment

We measured two aspects of the physical activity environment, the characteristics of streets and the use of open spaces. To characterize streets, we used the Systematic Pedestrian and Cycling Environment Scan (SPACES) [24], an observational audit of urban infrastructure that can influence walking and cycling [25] and that has been validated in Madrid [26]. We collected information on every street segment of the study area ($n = 152$) for the four SPACES factors: function, safety, aesthetics and destinations. We have previously published more details on this procedure and its measurement properties (reliability and validity) in Madrid [26]. In order to measure the use of parks and open spaces within and next to the study area, two field researchers completed the System for Observing Play and Recreation in Communities (SOPARC) instrument [27] in all parks and open spaces of the area (identified through direct observation, $n = 10$). The two researchers stood on a pre-specified location of the park and observed park usage for 1 h. Every individual using the park was observed and classified regarding basic sociodemographic characteristics (age, gender, ethnicity) and type of park use regarding levels of activity (sedentary, walking or vigorous).

GIS-based data integration

Aiming at the implementation of a comprehensive georeferenced database of the pilot study area, we collected information from the following sources:

- Spanish National Spatial Data Infrastructure (IDEE), National Mapping Agency (IGN): line and polygon vector layers such as street sections, administrative boundaries and blocks.
- Madrid Regional Spatial Data Infrastructure: point vector layers on retail stores, restaurants and gas stations.

These layers were loaded into ArcGIS 10.01 and projected to a common system (ED50 UTM 30). Fieldwork results on both street-based and Google Street Map-based audits were then joined to the street sections layer by means of relational union. All other layers (different types of administrative boundaries and blocks) were introduced to the final maps as reference information.

Qualitative interviews on the urban environment

In order to provide insights and to improve the understanding of our quantitative findings, we performed a second assessment of the area through qualitative methods. We conducted a series of semi-structured interviews with key informants (according to the sociodemographic structure of the area, including age and ethnicity, and the domains we wanted to gather information about) that had lived in the area for a long time, choosing information-rich cases selected using stratified purposeful sampling [28]. We included the following 11 key informants: a health care provider (female), the director of the health promotion center of the area, a local food store owner, four local residents (two females and two males, 45–65 years and > 65 years respectively), two immigrants (female and male), one primary school teacher and one community activist. These interviews included general questions about health and the environment and more focused questions about the neighborhood sociodemographics, neighborhoods boundaries, their individual perception on environmental characteristics and social norms regarding food, physical activity, alcohol and tobacco. Analysis of the interviews was carried out by three researchers following the validity criterion of investigator triangulation [29] and according to the steps of analysis in progress [30], incorporating an interpretative phenomenological analysis [31] perspective.

Mixed method approach

In this exploratory study we decided to combine the different quantitative and qualitative data, following a merging data approach [14, 32] presented in the result and discussion sections. Our objective with this merging phase was two-fold: (a) to provide insights on the phenomena behind our quantitative findings; and (b) to use qualitative research as a formative research phase that would guide our future data collection.

Results

Cardiovascular health profile and risk factors results

Fourteen and eight hundred fifty-seven thousandths residents of the study area are holders of a Health ID card and are assigned to one of the three Primary Care Centers present in the area. This represents 96.3 % of the 15422 residents living in the study area according to the municipal registry. The average age of this population was 45 years and 55.1 % were female. Table 2 shows the total prevalence of cardiovascular risk factors by gender in the population of the study area aged 45 and older. About 12 % of the population above 45 had diagnosis diabetes, 32 % had a diagnosis of dyslipidemia,

Table 2 Population cardiovascular health profile and risk factors of the residents aged 45 and older in the study area

Prevalence (%)	Men	Women	Total
Diabetes	14.0	10.0	11.6
Dyslipidemia	27.4	34.8	31.8
Hypertension	30.2	36.2	33.7
Smoking	12.6	7.9	9.8
Obesity	17.3	21.5	19.8

Diabetes, dyslipidemia and hypertension are physician diagnosed. Smoking is defined as current vs. not smoking. Obesity was defined as a BMI > = 30 kg/m^2, computed from the last available measure of height and weight

34 % had a diagnosis of hypertension, 10 % reported current smoking and 20 % were obese.

Food environment

Forty-four food stores were located in the study area (Fig. 3). Supermarkets scored highest in terms of Healthy Food Availability (25.5 out of 28) and convenience stores the lowest (7.5 out of 28). Two food markets (the “Las Ventas” and “Bami” markets) were present in the area. The “Las Ventas” public market is a 3-storied indoors market with 112 stalls (most of them selling fruits/vegetables, meat/dairy or fish). There were 61 food service business present (Fig. 4) and most of them (*n* = 53) were regular sitting down restaurants.

Qualitative results showed several important concepts: the concept of affordability, where high quality and healthier food options are perceived as more expensive; and the concept of “distance to stores”, which is also believed to be an important determinant for accessibility, especially for the elderly.

> *“I have my children and many years, so I know what is good and what is bad…what one can afford is different” (woman, >65 years)*

Interviews also highlighted the importance of the concept of “lifetime store”, owned by local people that have a long history of dealing with neighbor’s needs and trust.

Alcohol environment

The alcohol environment in the area is very intertwined with the food environment. All but one of the 91 alcohol outlets in the study area (Fig. 4) was also either a food store (only 1 of the 32 off-sale alcohol outlets was a liquor store) or as a bar/restaurant (all 59 alcohol on-sale outlets). Qualitative interviews showed that alcohol consumption is believed to be mostly influenced by individual choices rather than the social environment. Besides, there is a perception that excessive alcohol consumption has low prevalence. The alcohol environment is also linked to socialization, with positive connotations, but perceived to be affected by the economic crisis:

> *“I get along well (with neighbors); I drink beer with whomever I want to” (man, <65 years).*
> *“Social drinking customs are disappearing, we used to go on Sundays to have a vermouth with your neighbors and your friends. Nowadays, people are doing it less, because of the economic crisis” (Food store owner).*

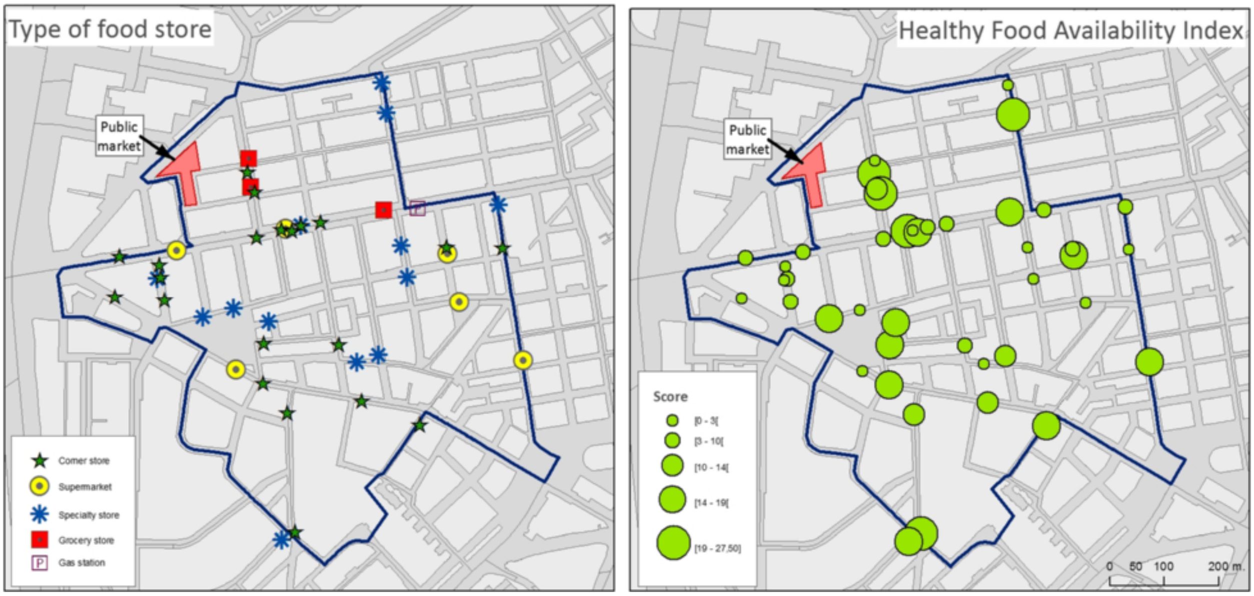

Fig. 3 Food environment results in the study area (12 census sections), including type of food stores (*left*) and their healthy food availability index scores in quintiles (*right*)

Fig. 4 Alcohol (*left*), Food Services (*middle*) and Tobacco (*right*) environments in the study area

Tobacco environment

There were 64 tobacco outlets in the area. Of these, 6 were exclusive tobacco outlets and 58 were automatic vending machines located in bars or restaurants (and therefore sharing space with food and alcohol retailing) (Fig. 4). As seen below (Fig. 4), tobacco outlets or vending machines are ubiquitous within the area. Interviews revealed contradictions regarding trends in smoking prevalence: smokers perceive that the local availability of tobacco remains stable while non-smokers perceive the opposite.

Physical activity environment

The walking environment showed heterogeneity around the study area (Fig. 5). The two main avenues of the study area (*Calle Alcala* and *Avenida Daroca*) had the highest scores for walkability, especially due to the size of their sidewalks and the presence of a large amount of destinations. Qualitative research highlighted architectural barriers influencing mobility patterns of elder residents:

> *"When we are older, because I'm on a wheelchair in the street … If I had benches there, I would not need the wheelchair, because walking 20 m is fine, but maybe 25 m isn´t." (Woman, > 65 years)*

Regarding open spaces and parks, the results from the SOPARC instrument show that the majority of users of all parks were male (66 % of all park users, a majority in all 10 parks but one) and adult or seniors (64 and 17 % of all park users, respectively). The level of activity varied each open space: in 4 of them the main level of

Fig. 5 Walkability index in the study area, on-field visits (*left*) and Google Street View (*right*)

activity was sedentary, in 2 the main use was for walking and in 4 was there was a majority of people doing vigorous physical activity. Contrary to our observations, interviews with residents highlighted the more intense use of parks by young immigrants or minorities. Moreover, neighbors also expressed reluctance to use these open spaces where the proportion of immigrant people was high:

> *"There have been parks that have been taken over by gangs of immigrant kids; at certain times one is afraid of passing through; even as an adult" (Man < 65 years).*

Emerging results from qualitative in-depth interviews

The analysis of these 11 interviews showed four important emergent categories: 1) the individualized definition of neighborhood boundaries, 2) the effect of the current economic crisis on neighbors' behavior, 3) the role of immigration, and 4) the importance of social relationships in neighborhood use (See Table 3). The economic crisis is a cross-sectional element in the discourse of the interviewees.

Discussion

This study allowed us to test the feasibility of doing an in-depth study of a neighborhood and its environmental and social determinants of cardiovascular health. Through a series of quantitative and qualitative techniques we were able to measure different aspects pertaining to cardiovascular health that were included in our framework: the food, physical activity, tobacco and alcohol environments, and habits and social norms related with them. By using the electronic health records of the Universal Primary Health Care system we were able to obtain a picture of the cardiovascular health of the residents in the area. We drew methods from epidemiology, geography, sociology and anthropology, and combined them to make the best possible characterization of a neighborhood cardiovascular environment.

Table 3 Emerging categories in in-depth interviews

Neighborhood boundaries are subjective.
"We take a compass and put the center of the compass (from his home) to Quintana and the circle is round. That would be my neighborhood "(Food store owner)
Economic crisis influences neighbors behavior.
"… Nowadays there are a lot of grandparents taking care of the family…. Many unemployed descendants. So there is little time for healthy habits like exercise… " (health care provider, woman)
Immigration is seen as very influential element in neighborhood life.
"… In the past other people would go there [park], but now the Romanians are there…" (men, < 65 years)
Social relationships affect the use of the neighborhood.
"I'm happy with people in my neighborhood. Since my husband died, … adults and kids alike, boys like my sons, 50 years-old, [have told me] "hey, I work on this, if I can help you… I will help you with stuff if you ask me"" (woman, > 65 years)

Cardiovascular health in the area was similar to the Madrid total population in terms of prevalence of cardiovascular risk factors such as hypertension, diabetes and dyslipidemia. The validity of electronic health records as methods to estimate prevalence has been shown for hypertension and diabetes in Madrid [20]. Smoking prevalence was lower in electronic health records compared to population surveys, potentially reflecting underreporting of smoking prevalence in primary care. Future work should emphasize the need for a more systematic validation of electronic health records data (see Table 4). One of the main advantages of using electronic health records of a universal primary care health system is the feasibility to scale up the measurement, that, in the case of Spain, can be done up to the regional level (Madrid Region, more than 6,000,000 people). These measurements are available down to a small scale (census sections, around 1000 people) and allow for small area comparisons similar to what has been done in studies in the US [33] or the UK [34] or even Spain for mortality [35]. Spain has almost universal coverage of public insurance (>99 %) and we were able to ascertain that we had data on more than 96 % of the people living in the area (according to the municipal registry). The use of these systems for continuous chronic disease surveillance (see Table 4) will increase opportunities for prevention, as seen in cases like New York [36].

On the side of the exposure, in this case urban environments, we found a very rich food environment. An important challenge we found in this exploratory study was the measurement of public markets. The area had two of these, one of them with long opening hours and more than 100 stalls. Standard tools for healthy food availability measures (like our abbreviated NEMS-S tool) can fail to capture the effect of these type of retailers (see Table 4). A second challenge is the lack of an appropriate food affordability measure. Interviews with neighbors showed that prices determine what people can afford and therefore the food and that they can buy (see Table 4). Moreover, they also expressed concern for the lack (or availability) of ethnic foods. Affordability and cultural acceptability are two of the four key aspects of the local food environment (with the other two being accessibility and availability, measured with our current tools) [37, 38]. Therefore we need to adapt tools such as Market Basket Surveys to the Spanish context (see Table 4) [39].

The alcohol and tobacco environment was mostly dominated by bars and restaurants. There were only 5 exclusive tobacco stores (heavily regulated in availability and prices by the government) and only one exclusive

Table 4 Conclusions of the Heart Healthy Hoods exploratory study: challenges and opportunities for measuring urban environments and cardiovascular health

	Quantitative measurements	Qualitative measurements	Geographic Information Systems
Electronic Health Records	Validation of EHR diagnosis (beyond diabetes and hypertension). Use of EHR for continuous surveillance of chronic diseases.	Not available. Can be performed in a selected subset.	GIS allows for data integration of location and attributes of features of each domain, administrative boundaries, public transportation network, parks and street segments. With this data integration, geospatial analysis of various kinds can be performed. Future data should include accessibility, other distance-based indicators, the use of more detailed geostatistics (dispersion, centrality, etc.) and other tools (such as map algebra). Availability of sufficient quality data. Design and validation of a cartographic model, based on a combination of the above analyses, to produce meaningful composite indices.
Food environment	More emphasis should be placed on the measurement of affordability. A further culturally adapted NEMS-S survey is needed. Public markets are a unique feature in Spain.	A more in-depth approach to dietary patterns is needed. Better insights to the effects of family composition on dietary patterns.	
Alcohol environment	Use of implementation science tools to measure compliance.	Further exploration of spaces of consumption and social norms associated to these.	
Physical activity environment	Validation of virtual audit methods (Google Street View)	More in-depth insights on barriers to physical activity (including physical and social barriers)	
Tobacco environment	Measurement of exposure to second-hand tobacco. Use of implementation science tools to measure compliance with tobacco regulations	Perceptions regarding smoking need to be stratified by smoking status. More research is needed on social norms that influence smoking and the implementation of smoking regulations	

liquor store. Every other retail business for tobacco was either a bar or a restaurant, coinciding with on-sale alcohol outlets (where alcohol is consumed on site) that also provide food services. This combination, in a single business, of on-sale alcohol outlets, tobacco automatic selling machines and food services are a staple business in Spanish neighborhoods and are therefore one of the most relevant components of the food, alcohol and tobacco environment in Spain. Most research conducted outside of Spain focus on specific off-sale outlets that are specialized in alcohol retailing. Our tools did not capture off-sale alcohol availability in food stores (supermarkets, corner stores, grocery stores) but these are the most commonly used points of sale for alcohol in Spain. Future re-designing of these tools must incorporate this intertwined nature of the food and alcohol environment. Interviews with neighbors showed the cultural importance of alcohol consumption in these bars as a social cohesion mechanism. In other contexts alcohol outlet density has been related to alcohol consumption and crime before [40], but we are not aware of similar research conducted in Spain. We are currently exploring other alcohol environment measures that may vary more by context, like marketing and advertisement outside of bars and restaurants. Tobacco outlet density has been linked to tobacco consumption or reduced chances of tobacco quitting [41], but the availability of exclusive tobacco stores is heavily regulated by the government in Spain. Tobacco sales in bars/restaurants in Spain happens under automatic vendor machines. There is exiting data on the location (and sales) of these machines, gathered by the regulatory commission of tobacco in Spain. After several requests (for research purposes), we have not been able to obtain such data for unclear "economic" reasons.

In the physical activity environment most open spaces were used by adults, especially seniors without a clear intent to engage into physically active. This may be due to the design of these open spaces as more than two thirds of the open spaces did not have a design conductive for anything but walking or passive use. Interviews with neighbors showed an interesting duality regarding preferred places to walk: while parks were well perceived, their use is conditioned on the presence of certain behaviors (such as alcohol consumption or immigrant presence), and some people preferred walking in streets with a high density of retail business, rather than walking on parks or other open spaces. While some of our tools were able to capture these characteristics, they were resource-intensive and required prolonged times of observation. We validated the SPACES audit tool for walkability measurements using Google Streetview [26] (see Table 4), but found that virtual measurement time was analogous to on-field measurement time (with only the advantage of not having to travel to the study area). We are now exploring and validating measurements of walkability that do not require extensive audits and leverage the power of GIS [42].

The integration of all collected data using Geographic Information Systems is an opportunity to accommodate the different domains that make up a given urban environment.

GIS also allows for geospatial analysis and the construction of more detailed indicators. Two main challenges resulted from this exploratory study: (a) the development of meaningful composite indices that combine the study domains; and (b) the integration of the temporal dimension, including business hours (for accessibility) [43] and activity time-spaces of the residents [44] (see Table 4).

The qualitative part of our mixed methods approach let us to get a clear picture of the area from the "experts", that is, the neighbors that live in them. These methods allow vulnerable populations (that may not be covered in quantitative studies) to get a voice in research [45]. Semi-structured interviews allowed us to get access to individual perceptions, but proved to be less useful in topics like alcohol and tobacco (see Table 4). Given the intense social component of alcohol and cigarette smoking we believe that methods like focus groups [46] or concept mapping [47] may be more useful. Moreover, we were also able to uncover the different levels at which neighbors perceive that the environment affects them. While, as mentioned above, neighbors perceived that smoking was less affected by neighborhood characteristics, neighbors remarked the importance of national level (macro) policies in reducing smoking prevalence. Moreover, while neighbors did not perceive that the local environment influenced alcohol consumption, they did emphasize the importance of social interactions (micro) and drinking. Food and, more importantly, physical activity, were domains in which neighbors did perceive strong influences of their local environments. Being cognizant of the levels at which each health outcome is determined is an important task in neighborhoods effects (and other social epidemiologic) research.

The combination (in our case, concurrent integration) of qualitative and quantitative data through a mixed methods approach is an adequate approximation to complex social phenomena [14]. This concurrent integration approach to merging quantitative and qualitative data increases understanding or develops a complementary picture; nonetheless, we also believe that a sequential timing approach (e.g.: an initial phase of formative qualitative research followed by the design of quantitative tools) would have helped us in avoiding some of the pitfalls described in this manuscript. We acknowledge that mixed method approaches have their own difficulties, like the scarcity of a training infrastructure, the necessity to work under two epistemological traditions or the complexity of data integration [48, 49]. Nonetheless we believe they remain a useful approach to study neighborhoods where "the whole is greater than the sum of the parts" [50].

Conclusions

This experience allowed testing and refining measuring tools to understand neighborhood characteristics in relation to cardiovascular health (See Table 4 for a complete list of future challenges and opportunities). Several quantitative epidemiological and geographical methodologies showed to be complementary and relevant when describing the specific features of the urban environment. The inclusion of qualitative methodologies provided important insights adding emergent categories to the characterization of neighborhoods such as: subjective neighborhood boundaries, the effect of the economic crisis on businesses and on neighbor's consumption patterns, the importance of social networks and the relevance of immigration in neighborhoods life. The combination of urban environment measurements, quantitative and qualitative, and universal electronic health records from the primary care health system, will provide useful data to examine the relationship of neighborhood characteristics and cardiovascular health shedding important light to develop sound population preventive approaches.

Additional file

Additional file 1: S1. The Median Neighborhood Index Methodological Details. **S2.** Adapted NEMS-S Audit Tool. (DOCX 137 kb)

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Availability of data and materials

The urban environment datasets collected and/or analyzed during the current study are available from the corresponding author on reasonable request. The individual-level electronic health records datasets are not available on request due to restrictions on data sharing imposed by the Institutional Review Board.

Authors' contributions

UB, JD and MF designed the study and drafted the manuscript. JD, PG and SA collected quantitative environment data. IC coordinated electronic health record data collection. FE performed all geographical analysis and mapped results. MS conducted and analyzed qualitative interviews. MF led the study and obtained funding for it. All authors interpreted results and revised the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Consent for publication

This manuscript does not contain details, images or videos related to individual participants.

Ethics approval and consent to participate

This study was approved by the Ethics in Research Committee of the Madrid Health Care System. Participants interviewed in the qualitative part of this study provided oral consent after receiving information about the study.

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References

1. Beaglehole R, Bonita R. Global public health: a scorecard. Lancet. 2008;372(9654):1988–96.
2. Franco M, Cooper RS, Bilal U, Fuster V. Challenges and opportunities for cardiovascular disease prevention. Am J Med. 2011;124(2):95–102.
3. Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, Das SR, de Ferranti S, Despres JP, Fullerton HJ, et al. Executive Summary: Heart Disease and Stroke Statistics-2016 Update: A Report From the American Heart Association. Circulation. 2016;133(4):447–54.
4. Townsend N, Nichols M, Scarborough P, Rayner M. Cardiovascular disease in Europe–epidemiological update 2015. Eur Heart J. 2015;36(40):2696–705.
5. Eckel RH, Jakicic JM, Ard JD, de Jesus JM, Houston Miller N, Hubbard VS, Lee I-M, Lichtenstein AH, Loria CM, Millen BE, et al. 2013 AHA/ACC Guideline on Lifestyle Management to Reduce Cardiovascular Risk: A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Circulation. 2014;129(25 suppl 2):S76–99.
6. Franco M, Cooper R, Bilal U, Fuster V. Control of coronary heart disease risk factors and evidence-based therapies: joint efforts for coronary heart disease prevention in Spain. Rev Esp Cardiol. 2011;64(11):962–4.
7. Rose G. Sick individuals and sick populations. Int J Epidemiol. 1985;14(1):32–8.
8. Vartiainen E, Laatikainen T, Peltonen M, Juolevi A, Männistö S, Sundvall J, Jousilahti P, Salomaa V, Valsta L, Puska P. Thirty-five-year trends in cardiovascular risk factors in Finland. Int J Epidemiol. 2010;39(2):504–18.
9. Franco M, Bilal U, Orduñez P, Benet M, Morejón A, Caballero B, Kennelly JF, Cooper RS. Population-wide weight loss and regain in relation to diabetes burden and cardiovascular mortality in Cuba 1980–2010: repeated cross sectional surveys and ecological comparison of secular trends. BMJ. 2013, 346.
10. Franco M, Bilal U, Diez-Roux AV. Preventing non-communicable diseases through structural changes in urban environments. J Epidemiol Community Health. 2015;69(6):509–11.
11. Diez-Roux AV. Multilevel analysis in public health research. Annu Rev Public Health. 2000;21:171–92.
12. Murdoch TB, Detsky AS. THe inevitable application of big data to health care. JAMA. 2013;309(13):1351–2.
13. Cummins S, Curtis S, Diez-Roux AV, Macintyre S. Understanding and representing 'place' in health research: a relational approach. Soc Sci Med. 2007;65(9):1825–38.
14. Creswell JW, Clark VLP. Designing and Conducting Mixed Methods Research. Los Angeles: SAGE Publications; 2007.
15. Pluye P, Hong QN. Combining the Power of Stories and the Power of Numbers: Mixed Methods Research and Mixed Studies Reviews. Annu Rev Public Health. 2014;35(1):29–45.
16. Carreño V, Franco M, Gullón P, Carreño V. Studying city life, improving population health. Int J Epidemiol. 2015. [Epub ahead of print].
17. Sacristan JA. Exploratory trials, confirmatory observations: a new reasoning model in the era of patient-centered medicine. BMC Med Res Methodol. 2011;11:57.
18. Thabane L, Ma J, Chu R, Cheng J, Ismaila A, Rios LP, Robson R, Thabane M, Giangregorio L, Goldsmith CH. A tutorial on pilot studies: the what, why and how. BMC Med Res Methodol. 2010;10(1):1–10.
19. Shankardass K, Dunn JR. Chapter 7: How Goes the Neighbourhood? Rethinking Neighbourhoods and Health Research in Social Epidemiology. In: by O'Campo P, Dunn JR, editors. Rethinking Social Epidemiology: Towards a Science of Change. edn. Dordrecht: Springer Netherlands; 2011.
20. de Burgos-Lunar C, Salinero-Fort M, Cardenas-Valladolid J, Soto-Diaz S, Fuentes-Rodriguez C, Abanades-Herranz J, del Cura-Gonzalez I. Validation of diabetes mellitus and hypertension diagnosis in computerized medical records in primary health care. BMC Med Res Methodol. 2011;11(1):146.
21. Gil Montalban E, Ortiz Marron H, Lopez-Gay Lucio-Villegas D, Zorrilla Torras B, Arrieta Blanco F, Nogales Aguado P. Validity and concordance of electronic health records in primary care (AP-Madrid) for surveillance of diabetes mellitus. PREDIMERC study. Gaceta sanitaria / SESPAS. 2014;28(5):393–6.
22. Glanz K, Sallis JF, Saelens BE, Frank LD. Nutrition Environment Measures Survey in Stores (NEMS-S): Development and Evaluation. Am J Prev Med. 2007;32(4):282–9.
23. Saelens BE, Glanz K, Sallis JF, Frank LD. Nutrition Environment Measures Study in Restaurants (NEMS-R): Development and Evaluation. Am J Prev Med. 2007;32(4):273–81.
24. Pikora T, Giles-Corti B, Bull F, Jamrozik K, Donovan R. Developing a framework for assessment of the environmental determinants of walking and cycling. Soc Sci Med. 2003;56(8):1693–703.
25. Badland HM, Keam R, Witten K, Kearns R. Examining public open spaces by neighborhood-level walkability and deprivation. J Phys Act Health. 2010;7(6):818–24.
26. Gullon P, Badland HM, Alfayate S, Bilal U, Escobar F, Cebrecos A, Diez J, Franco M. Assessing Walking and Cycling Environments in the Streets of Madrid: Comparing On-Field and Virtual Audits. J Urban Health. 2015;92(5):923–39.
27. McKenzie TL, Cohen DA, Sehgal A, Williamson S, Golinelli D. System for Observing Play and Recreation in Communities (SOPARC): Reliability and Feasibility Measures. J Phys Act Health. 2006;3 Suppl 1:S208–22.
28. Patton MQ. Qualitative Research & Evaluation Methods. Newbury Park: SAGE Publications; 2002.
29. Golafshani N. Understanding Reliability and Validity in Qualitative Research. Qual Rep. 2003;8(4):597–607.
30. Taylor SJ, Bogdan R. Introduction to qualitative research methods: the search for meanings. New York City: Wiley; 1984.
31. Smith JA. Qualitative Psychology: A Practical Guide to Research Methods. London: SAGE Publications; 2007.

32. Creswell JW, Klassen AC, Plano Clark VL, Smith KC. Best practices for mixed methods research in the health sciences, vol. 10. Bethesda, MD: National Institutes of Health; 2011.
33. Hembree C, Galea S, Ahern J, Tracy M, Markham Piper T, Miller J, Vlahov D, Tardiff KJ. The urban built environment and overdose mortality in New York City neighborhoods. Health Place. 2005;11(2):147–56.
34. Jarup L, Best N, Toledano MB, Wakefield J, Elliott P. Geographical epidemiology of prostate cancer in Great Britain. Int J Cancer. 2002;97(5):695–9.
35. Borrell C, Marí-Dell'Olmo M, Serral G, Martínez-Beneito M, Gotsens M. Inequalities in mortality in small areas of eleven Spanish cities (the multicenter MEDEA project). Health Place. 2010;16(4):703–11.
36. Paul MM, Greene CM, Newton-Dame R, Thorpe LE, Perlman SE, McVeigh KH, Gourevitch MN. The State of Population Health Surveillance Using Electronic Health Records: A Narrative Review. Popul Health Manag. 2015;18(3):209–16.
37. Franco M, Bilal U, Díez J. Food Environment. In: Caballero B, Finglas PM, Toldrá F, editors. Encyclopedia of Food and Health. Oxford: Academic; 2016. p. 22–6.
38. Neff R. Introduction to the US Food System: Public Health, Environment, and Equity. San Francisco: Wiley; 2014.
39. Horning ML, Fulkerson JA. A Systematic Review on the Affordability of a Healthful Diet for Families in the United States. Public Health Nurs. 2015;32(1):68–80.
40. Gorman DM, Speer PW, Gruenewald PJ, Labouvie EW. Spatial dynamics of alcohol availability, neighborhood structure and violent crime. J Stud Alcohol. 2001;62(5):628–36.
41. Reitzel LR, Cromley EK, Li Y, Cao Y, Dela Mater R, Mazas CA, Cofta-Woerpel L, Cinciripini PM, Wetter DW. The effect of tobacco outlet density and proximity on smoking cessation. Am J Public Health. 2011;101(2):315–20.
42. Frank LD, Sallis JF, Saelens BE, Leary L, Cain K, Conway TL, Hess PM. The development of a walkability index: application to the Neighborhood Quality of Life Study. Br J Sports Med. 2010;44(13):924–33.
43. Widener MJ, Metcalf SS, Bar-Yam Y. Dynamic Urban Food Environments: A Temporal Analysis of Access to Healthy Foods. Am J Prev Med. 2011;41(4):439–41.
44. Perchoux C, Chaix B, Cummins S, Kestens Y. Conceptualization and measurement of environmental exposure in epidemiology: accounting for activity space related to daily mobility. Health Place. 2013;21:86–93.
45. Bamberger M, Tarsilla M, Hesse-Biber S. Why so many "rigorous" evaluations fail to identify unintended consequences of development programs: How mixed methods can contribute. Eval Program Plann. 2016;55:155–62.
46. Egan M, Kearns A, Mason P, Tannahill C, Bond L, Coyle J, Beck S, Crawford F, Hanlon P, Lawson L, et al. Protocol for a mixed methods study investigating the impact of investment in housing, regeneration and neighbourhood renewal on the health and wellbeing of residents: the GoWell programme. BMC Med Res Methodol. 2010;10:41.
47. Burke JG, O'Campo P, Peak GL, Gielen AC, McDonnell KA, Trochim WM. An introduction to concept mapping as a participatory public health research method. Qual Health Res. 2005;15(10):1392–410.
48. O'Cathain A, Murphy E, Nicholl J. Three techniques for integrating data in mixed methods studies. BMJ. 2010;341:c4587.
49. O'Cathain A, Nicholl J, Murphy E. Structural issues affecting mixed methods studies in health research: a qualitative study. BMC Med Res Methodol. 2009;9:82.
50. Barbour RS. The case for combining qualitative and quantitative approaches in health services research. J Health Serv Res Policy. 1999;4(1):39–43.

4.3. Intersection of neighborhood dynamics and socioeconomic status in small-area walkability: The Heart Healthy Hoods project

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RESEARCH

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Intersection of neighborhood dynamics and socioeconomic status in small-area walkability: the Heart Healthy Hoods project

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Abstract

Background: Previous studies found a complex relationship between area-level socioeconomic status (SES) and walkability. These studies did not include neighborhood dynamics. Our aim was to study the association between area-level SES and walkability in the city of Madrid (Spain) evaluating the potential effect modification of neighborhood dynamics.

Methods: All census sections of the city of Madrid (n = 2415) were included. Area-level SES was measured using a composite index of 7 indicators in 4 domains (education, wealth, occupation and living conditions). Two neighborhood dynamics factors were computed: gentrification, proxied by change in education levels in the previous 10 years, and neighborhood age, proxied by median year of construction of housing units in the area. Walkability was measured using a composite index of 4 indicators (Residential Density, Population Density, Retail Destinations and Street Connectivity). We modeled the association using linear mixed models with random intercepts.

Results: Area-level SES and walkability were inversely and significantly associated. Areas with lower SES showed the highest walkability. This pattern did not hold for areas with an increase in education level, where the association was flat (no decrease in walkability with higher SES). Moreover, the association was attenuated in newly built areas: the association was stronger in areas built before 1975, weaker in areas built between 1975 and 1990 and flat in areas built from 1990 on.

Conclusion: Areas with higher neighborhood socioeconomic status had lower walkability in Madrid. This disadvantage in walkability was not present in recently built or gentrified areas.

Keywords: Physical activity, Neighborhood/pace, Urbanisation, GIS

Background

A quarter of the population in Europe is estimated to be physically inactive [1]. Reducing physical inactivity is one of the key targets to control non-communicable diseases [2] as it is estimated to be responsible for 6–10% of the burden of major non-communicable diseases worldwide [3]. Cities, due to the possibility of population approaches [4, 5], represent an opportunity for public health interventions on physical inactivity [6, 7].

Walkable neighborhoods (dense, compact, with availability of walking destinations) are associated with improved walking behaviors [8–10]. In addition, physical inactivity follows a social gradient, with more disadvantaged populations having a higher prevalence of physical inactivity [11–13]. Thus, the interaction between urban form (defined as physical form of the city [14]) and social disadvantage could provide insights on how socio-spatial inequalities in physical activity are shaped [15]. Previous evidence suggests that the relationship between Neighborhood Socioeconomic Status (SES) and neighborhood walkability may be complex [16]. In particular, previous research has found that lower SES neighborhoods are more walkable (measured

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using objective measures) [16–19], while on the other hand residents of more deprived neighborhoods report worst aesthetics and safety of their neighborhoods [20, 21], which may also be important contributors to walking behaviors. However, most of the studies looking at the relationship between social and urban form have been conducted mainly in the US and Australia, where the shape of urban environments [22] and socioeconomic segregation processes [23] differs widely from European cities.

Moreover, neighborhoods and cities are not static entities, they are dynamic in its form and composition [24]. Urban form changes at a slower pace than social composition, as citizens might move following a social gradient in response to changes in the housing prices market [25]. At the same time, urban form tends to change at a slow pace, given its constrains in some parts of the city (e.g. inner old city). In order to understand the socio-spatial inequalities in walkability there is a need to incorporate variables that can help to understand the dynamics and the history of the city. In our study, we try to encompass this challenge by incorporating variables of change in social composition and the age of the neighborhood.

The Heart Healthy Hoods project (HHH) aims to study how urban environment relates to cardiovascular health of Madrid's residents [6, 26, 27]. Within this project, some measures of physical activity environment have been tested [28]. Taking all the above into consideration, our aim was to evaluate the association between small area-level socioeconomic status and walkability in the city of Madrid (Spain) and to evaluate the potential effect modification by indicators of neighborhood dynamics (gentrification and neighborhood age).

Methods

Study setting

We conducted our study in the City of Madrid, Spain. In 2014, Madrid was divided into 21 districts that housed 128 neighborhoods, that were further divided into 2415 census sections [29]. The Census Section was the unit for all the analysis as this is the smallest area for which census and other relevant data were available. Census Sections had resident populations of between 1000 and 1500 people. Madrid's socio-spatial configuration is one of the most segregated in Europe [30]. As most of European cities, it has a historic city center, and neighborhoods separated from it by an orbital motorway [31]. Since the 60s, it has experienced a huge economic and population growth due to the industrialization of some parts of the region and the migration from rural areas. Higher social class tend to accumulate in the northern part of the city [30].

Area socioeconomic status

The main exposure of this study was a composite SES index made of 7 indicators. These were: (1) Low education (defined as % people above 25 years of age with primary studies or below), (2) High education (defined as % people above 25 years of age with university education or above), (3) Part-time employment (% workers in part-time jobs), (4) Temporary employment (% workers in temporary jobs), (5) Manual occupational class (% workers in manual or unqualified jobs), (6) Average housing prices (per sq. m), and (7) Unemployment rate. These indicators were selected based in the 4 domains present in the Spanish Commission to Reduce Health Inequalities [32] (education, wealth, occupation and living conditions). Using this framework, the SOPHIE project have investigated the effect of structural policies on health inequalities [33]. Indicator data were obtained from the Padrón (a continuous and universal census collected for administrative purposes), the social security and employment services registries and the IDEALISTA report (a report from a large real estate corporation in Spain). All data were available for the year 2014. Table 1 (and Additional file 1) contains more details on the operationalization of indicators.

To create the SES index, we constructed a weighted index from the variables described above. For this we centered (to the mean) and scaled (by the standard deviation) all selected variables. We then weighted the four domains equally (0.25 per domain) and weighted all variables within each domain equally (e.g.: overall, each education variable has a weight of $0.25 \times 0.5 = 0.125$). We then averaged all standardized variables to obtain the SES Index. We compared this index to a score obtained using the principal component of a Principal Component Analysis and found a Pearson correlation of 0.997 between them.

Neighborhood dynamics

For neighborhood dynamics, we selected 2 indicators: gentrification and neighborhood age. An indicator for gentrification was obtained by ranking all census sections in 2005 and in 2014 in terms of % residents with high education (university education or above) and computing the change in rank from 2005 to 2014, where we defined a gentrified neighborhood as those in the top 95% percentile of rank change. Neighborhood age was proxied by the median year of construction of all housing units in the census section, obtained from the Cadastre (*Catastro*, a universal tax registry of all housing units). We created three categories: up to 1985, from 1985 to 1997, from 1997 onwards. These categories were created based on the time of creation of the land-use planning regulations

Table 1 Area Socioeconomic status, Walkability and neighborhood dynamics indicators

Construct	Domain	Indicator	Operationalization	Source	Level
SES	Education	Low Education	Residents with mandatory studies or below/all residents aged 25 or above	Padron	Census section
		High Education	Residents with university education or above/all residents aged 25 or above	Padron	Census section
	Occupation	Part time Jobs	Workers in part-time jobs/all workers	Social security	Neighborhood
		Temporal 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	Employment service	Neighborhood
Walkability	Density	Residential Density	Occupied Dwellings/km^2	Housing census	Census section
	Density	Population Density	Residents/km^2	Padron	Census section
	Destinations	Retail Destinations	Retail and Service Destinations/km^2	Retail spaces census	Census section
	Street Structure	Street Connectivity	Kernel Density in 3 mx3m pixels of the density of street intersections	CARTOCIUDAD	Census section
Neighborhood dynamics	Gentrification	Increase in Education level	Rank difference in high education from 2005 to 2014 (>p95)	Padron	Census section
	Neighborhood age	Year of construction	Median year of construction (categorized)	Catastro	Census section

of the city [34]. Table 1 (and Additional file 1) contains more details on the operationalization of indicators.

Walkability

A walkability index for the 2415 census sections was created, reflecting known barriers and promoters to walking behaviors [9]. The core components of walkability indexes are the presence of places to walk to, a street network that facilitates such walking and enough density to guarantee that destinations are not too far apart [9]. Based on these, many previous measures of walkability have been developed [35]. Here, we used an index based on work by Creatore et al. [36] with modifications based on European recommendations [37]. The following indicators were used: Residential Density (occupied dwellings/km^2), Population Density (Residents/km^2), Retail Destinations (Retail and services destinations/km^2) and Street Connectivity (Kernel Density in 3 m × 3 m pixels of the density of street intersections). Data were obtained from the Housing part of the Spanish Census (that includes data on occupied dwellings), the Padrón (sociodemographic data), the Retail Spaces Census (curated by the local government for licensing purposes, that includes data on economic activities of all occupied commercial spaces) and CARTOCIUDAD (the National Mapping Agency initiative that collects and makes available official geo-referenced urban data, including street structure and administrative boundaries in shapefile format). All data were available for 2014 except for the Spanish Census, available for 2011. Table 1 (and Additional file 1) contains more details on the operationalization of indicators. To create the walkability index, we followed the same procedure as for the exposure (see above), and weighted the four indicators equally.

Statistical analysis

The objective of this analysis was to study the association between area-level socioeconomic status and area-level walkability, and how neighborhood dynamics influence these associations. We conducted exploratory and descriptive analysis of the exposure and the outcome variables, by tertile of neighborhood SES (Additional file 2: Table S2). We also plotted the distribution of SES and walkability indexes and examined their association using a non-parametric *lowess* [38] estimator, to provide an idea of the best operationalization of the neighborhood SES indicator.

To study the association between neighborhood SES and walkability we used linear mixed models with the walkability index as the dependent variable. These models included a random intercept for neighborhood (as census sections are nested into neighborhoods). We assessed whether a third level (for district) was needed by adding a random intercept for district and performing a likelihood ratio test of the nested models. Afterwards, we further included the SES Index operationalized as deciles, with the sixth decile as the reference. Based on the exploratory analysis above, we also conducted an analysis where we modeled the association using restricted cubic splines with 5 knots placed in the percentiles recommended by Harrell [39]. The number of knots was decided after testing 3–6 knots models and selecting the best fitting model based on Akaike Information Criterion (AIC).

We tested for effect modification by neighborhood dynamics indicators by adding an interaction term between the gentrification or neighborhood age indicator(s) and each restricted cubic spline. We checked for the significance of this interaction by conducting a likelihood ratio test in nested models with and without the interaction. All analyses were conducted using Stata SE version 14.1 (StataCorp., College Station, TX, USA).

Results

Spatial distribution of SES and walkability

The spatial distribution of SES and walkability indexes is shown in Fig. 1. Walkability was higher in the downtown area of Madrid (inside the M-30 orbital motorway of Madrid). There are also some pockets of high walkability in the areas adjacent to the M-30 orbital motorway, especially in the Southeastern and Southwestern parts of the city. Socioeconomic status followed a major North–South decreasing gradient (higher SES in the Northern areas of the city), while the Southern peripheral neighborhoods of the city had a lower SES.

Association between SES and walkability

Table 2 shows the main results of the study, obtained from a three-level mixed effects model. All SES Index deciles showed statistical significant differences compared to the reference group (sixth decile). Lower SES census sections had the highest walkability: there was an increase of 2.19 SD (CI 95% 1.36; 3.01 $p < 0.001$), 2.87 SD (CI 95% 2.19; 3.54 $p < 0.001$) and 2.02 SD (CI 95% 1.46; 2.59 $p < 0.001$) of walkability in the first, second and third decile of SES respect to the reference group. Fourth and fifth SES-deciles also ranked higher in walkability than the reference. Higher SES deciles had lower walkability: there was a decrease in walkability of 2.93 SD (CI 95% −3.60; −2.26 $p < 0.001$) and 3.86 SD (CI 95% −4.61; −3.12 $p < 0.001$) for the ninth and tenth SES-deciles.

Figure 2 shows the results of the model using restricted cubic splines with 5 knots. This figure shows a dose–response association for most of the SES distribution, with the only exception of a slight change in the

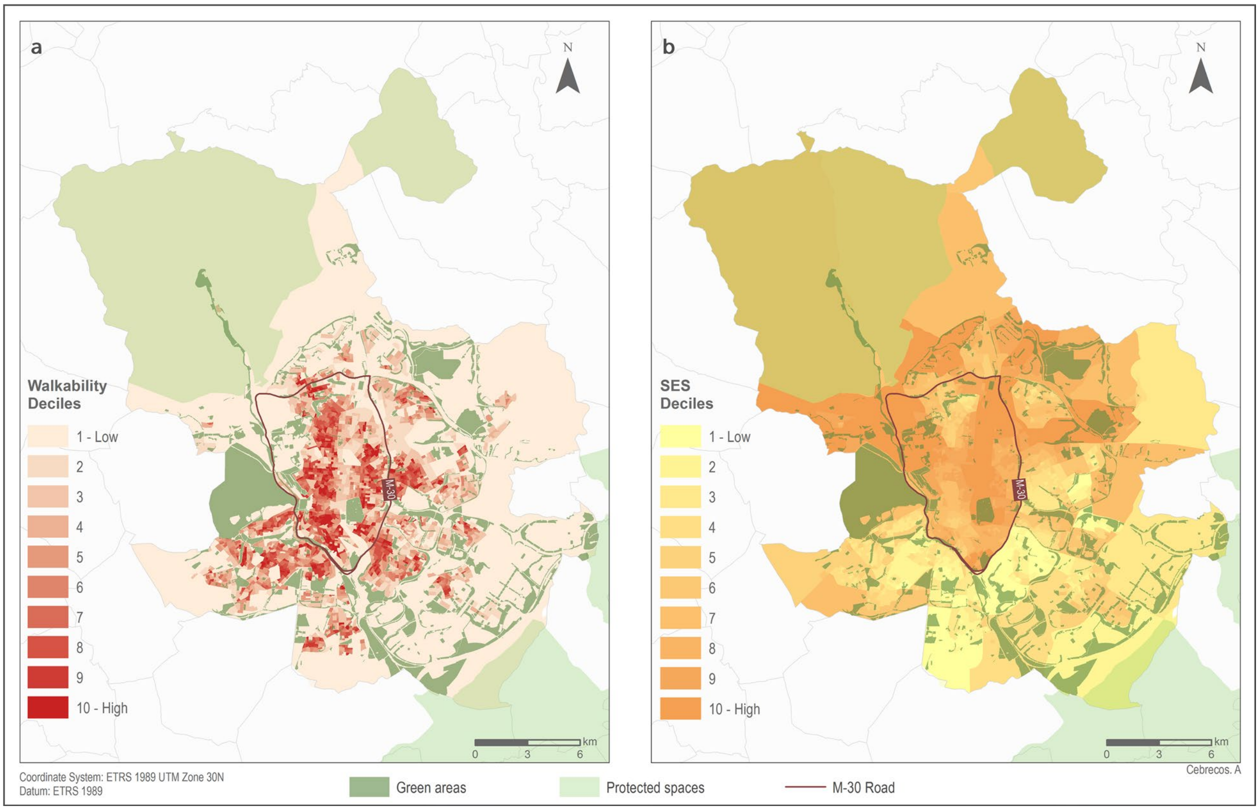

Fig. 1 Spatial distribution of Walkability Index (**a**) and Socio-Economic Status Index (**b**) by deciles in the census section (N = 2415) of the city of Madrid

Table 2 Results from multilevel regression analysis between area SES Index and walkability Index (N = 2415 census sections)

SES Index decile	β	95% CI	p value
1	2.19	1.36; 3.01	<0.001
2	2.87	2.19; 3.54	<0.001
3	2.02	1.46; 2.59	<0.001
4	1.26	0.73; 1.80	<0.001
5	0.53	0.06; 0.99	0.027
6		Ref	
7	−1.65	−2.17; −1.13	<0.001
8	−2.23	−2.85; −1.61	<0.001
9	−2.93	−3.60; −2.26	<0.001
10	−3.86	−4.61; −3.12	<0.001

association in the lowest tail of SES, where walkability decreases as SES decreases.

Interaction by neighborhood dynamics

Figure 3 shows the results of the interaction with neighborhood dynamics. Panel A shows the analysis by change in education level (gentrification), where we found a significant interaction between SES and change in education level ($p < 0.001$): while areas with stable or decreasing education level showed the same overall pattern (decrease in walkability with increasing SES), areas that increased its education level had a flat pattern with no association between neighborhood SES and walkability. Panel B show the analysis by neighborhood age, where we also found a significant interaction ($p < 0.001$). The association was similar in shape for areas built before 1985 and between 1985 and 1997 (albeit these second group showed an overall decrease in walkability regardless of SES). Areas built after 1997 showed a flat association, with no decrease in walkability in areas with higher SES.

Discussion

Our results indicate that census sections with higher socioeconomic status had a less walkable-urban form, as defined by our Walkability Index. This association followed, for the most part, a dose–response linear pattern. Moreover, we found that this association is heterogeneous, as there are significant interactions by a marker of gentrification and neighborhood age.

The negative association between area SES and walkability has been found in other studies [16–19, 21]. For

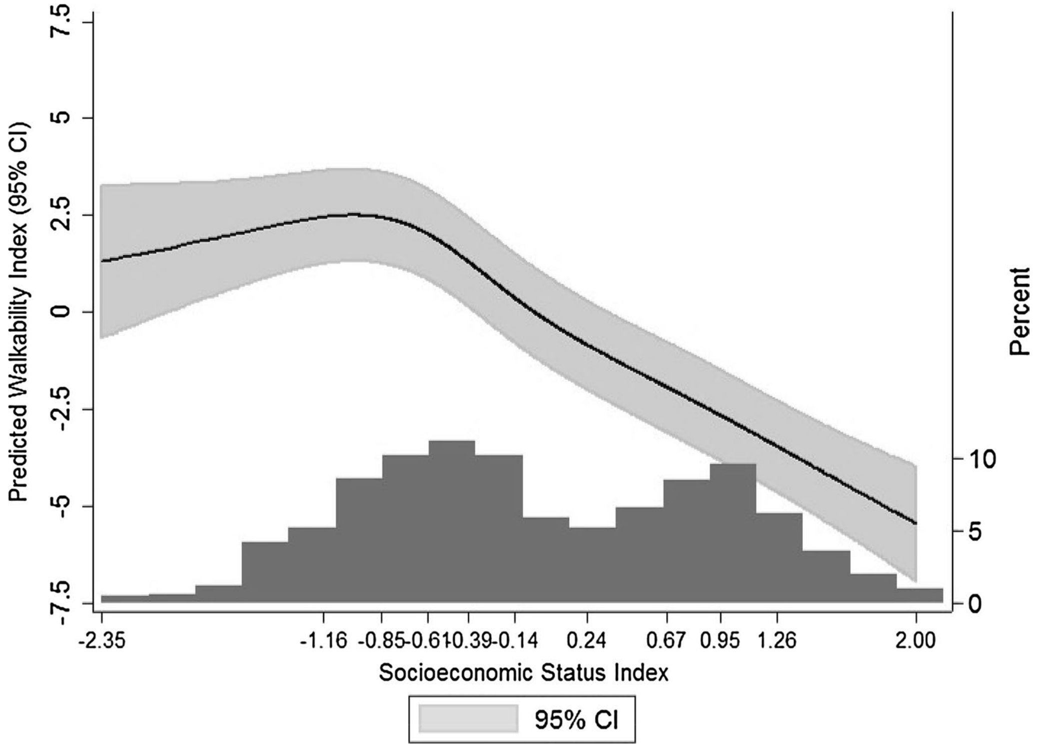

Fig. 2 Restricted cubic splines with 5 knots placed in the percentiles recommended by Harrell [39] showing the relationship between SES and walkability indexes in all Madrid census sections (N = 2415). X axis represents the min, max and 10 deciles of the SES Index, and Y axis represents the predicted Walkability Index. The *line* represents the predicted walkability through SES level and its 95% CI. *Histogram* represents the SES Index distribution of the 2415 census sections

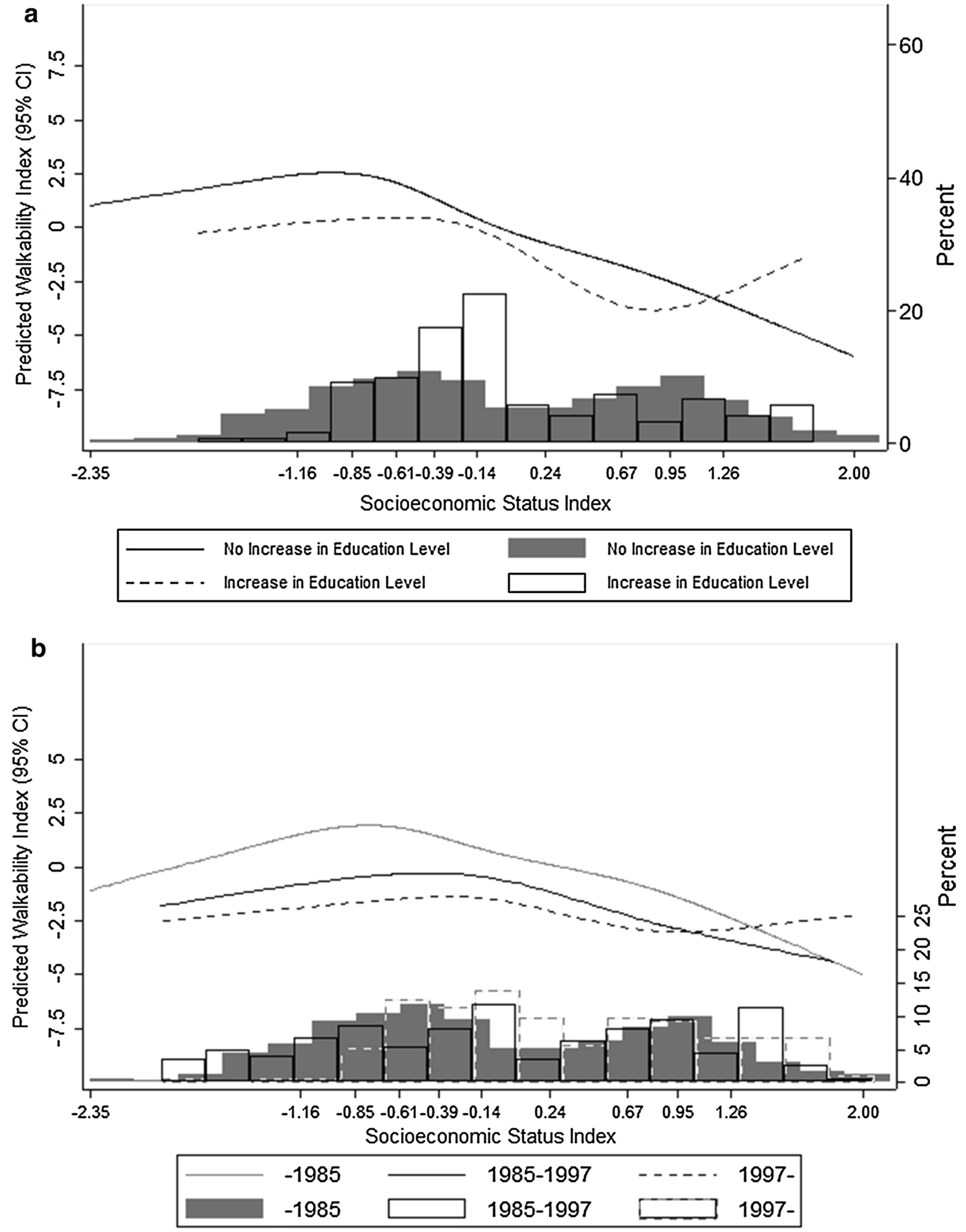

Fig. 3 Interaction effect by indicators of neighborhood dynamics (**a** gentrification, **b** neighborhood age) using restricted cubic splines with 5 knots placed in the percentiles recommended by Harrell [39]

example, Carpenter et al. [19] found a positive relationship between street connectivity and neighborhood poverty. King et al. [16] found that disadvantaged neighborhoods in terms of median income were more walkable (shorter block length, greater street node density, more developed land use, and higher density of street segments); on the other hand, they also found that more educated neighborhoods were also more walkable [16]. In our study, we created a composite Index, which allow us to better measure SES by using information from several indicators and therefore reduce the degree of measurement error. Other studies found that residents of more deprived neighborhoods report worst aesthetics and safety of their neighborhoods [20, 21]. Mixed-methods between quantitative and qualitative methods [40] could represent an alternative in order to understand the different associations between objective and subjective walkability measures.

We found an interaction with our marker of gentrification (top 95% percentile of rank change in high-education level in the last 10 years). Non-gentrified areas showed an inverse association between SES and walkability, while gentrified areas show a flat association between SES and walkability. As opposed to non-gentrified areas, where a "disadvantage" [16] in walkability was evident for higher-SES census sections, this phenomenon was not present in gentrified areas where higher-SES census sections had a similar walkability as lower SES ones. One potential explanation for this phenomenon is an increasing popularity of walkable neighborhoods (reflected by the increase of housing prices), where lower-SES residents are not able to continue living due to a decrease in affordable housing, causing a replacement of lower-SES residents for higher SES residents [25]. These gentrification and urban renewal processes have launched popular movements and social mobilization against them [41].

We also found an interaction by neighborhood age (assessed by our indicator of median year of building construction). The newest areas (those with its median year of construction after 1997) had a flat curve compared with the older neighborhoods (built before 1997). Independent of SES, historic and old neighborhoods tend to have a greater walkability due mostly to a denser street network [42]. Similarly to our gentrification analysis, there is a lack of a walkability disadvantage in higher SES areas built from 1997 onwards. Conversely, there is a lack of an "advantage' in walkability in lower SES areas, probably reflecting the newer developments of lower SES housing in the periphery of Madrid, with a less dense street network and lower availability of destinations. Recent research has shown an initiation of sprawling patterns in Mediterranean cities the last decades [43].

This study has several strengths. First, as far as we know, this is the first study to explore the walkability-SES association in an Southern European setting, characterized by its overall higher density [22], and to look at what is the effect that social and urban form dynamics have on it. We have also built a strong SES and walkability measures using GIS and an integrated composite index, which allow us to better measure SES by using information from several indicators and therefore reduce the degree of measurement error. Our walkability Index has been adapted for one used in Canada [36], but the changes followed some adaptations that could be needed for European context, using different measures for connectivity and land-use [37]. Most of the walkability literature has been conducted in the US, Canada and Australia or New Zealand, in cities with a much shorter lifespan than European cities [9]. We believe that conducting this type of research in European cities with a longer historical trajectory, a presence of different urban form structures (like historical mixed-use downtown areas) provides a different mechanistic insight into the determinants of walkability and can help inform policies in European cities in a more appropriate way.

This study has some limitations. We only measure the association of area-SES with walkability, a very specific set of features that promote walking behaviors, and may be missing another physical activity environment measures which could be important for public health, such as perception of crime and safety which are important determinants specially in low SES areas [21]. We were not able to link our data to individual-level health behavior (e.g. walking) or outcome (e.g. obesity) data, which could give us a better understanding on the effects of walkability in shaping health inequities. Our marker of gentrification is an unspecific one, as a change in education proportions may reflect both residential mobility phenomena (linked to gentrification) and changes in the non-moving population (linked to social mobility). Further research in Madrid with residential mobility data should explore the impact of these two phenomena on our inferences.

Our study supports the idea that low-income neighborhoods had a more-walkable urban form; however, neighborhood dynamics in terms of social composition (gentrified neighborhood) and in terms of neighborhood age (newest areas) did not follow the same pattern. These findings are key to understand how to address physical activity inequities within a city. If new neighborhoods in Madrid are built following a different socio-spatial distribution of walkability (more favorable for the wealthy, or with a loss of a walkability advantage for the poor), and the wealthy people are moving to the walkable neighborhoods [25], there is a need to balance with safeguards to preserve affordability and avoid the displacement of low-SES populations, keeping the "right to the city" with adequate housing reforms [44]. Therefore, continued attention needs to be paid to equity in urban policies to change the urban form to ensure changes do not have the unintended consequence of increased health inequities [45].

Conclusions

In conclusion, our study shows that higher SES areas of Madrid had lower walkability compared with lower SES areas. However, neighborhood dynamics in terms of social (gentrification) an urban form (neighborhood age) modified this association; newest and gentrified neighborhoods had a flat curve between area-SES and walkability. A deeper understanding of the dynamic relationship between urban form and neighborhood composition would provide further insights into mobility and health behaviors and outcomes, and inform urban planning policy in European cities to preserve health equities.

Additional files

Additional file 1: Additional information on the operationalization of the variables.

Additional file 2. Table S2: Census section sociodemographic and walkability indicators according to socioeconomic status (SES) tertiles (N = 2415).

Authors' contributions

MF and PG conceived the idea. PG and UB conceptualized and designed the study, conducted data collection and data managing and performed all statistical analyses. AC obtained the GIS data and mapped all results. PG, UB and MF wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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References

1. Gerovasili V, Agaku IT, Vardavas CI, Filippidis FT. Levels of physical activity among adults 18-64 years old in 28 European countries. Prev Med. 2015;81:87–91. doi:10.1016/j.ypmed.2015.08.005.
2. WHO. Global status report on noncommunicable diseases 2014 [Internet]. World Health Organization. 2014. http://www.who.int/topics/cardiovascular_diseases/en/.
3. Lee I, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and. Lancet. 2012;380:219–29. doi:10.1016/S0140-6736(12)61031-9.
4. Rose G. sick individuals and sick populations GEOFFREY ROSE. Int J Epidemiol. 1985;14:32–8.
5. Benach J, Malmusi D, Yasui Y, Martínez JM. A new typology of policies to tackle health inequalities and scenarios of impact based on Rose's population approach. J Epidemiol Community Health. 2013;67:286–91. http://www.jech.bmj.com/content/67/3/286.abstract%5Cnhttp://jech.bmj.com/content/67/3/286.full.pdf.
6. Franco M, Bilal U, Diez-Roux A-V. Preventing non-communicable diseases through structural changes in urban environments. J Epidemiol Community Health. 2014;69:509–11. doi:10.1136/jech-2014-203865.
7. Diez Roux A-V. Neighborhoods and health: where are we and were do we go from here? Rev Epidemiol Sante Publique. 2007;55:13–21. http://linkinghub.elsevier.com/retrieve/pii/S0398762006000046.
8. Sallis JF, Cerin E, Conway TL, Adams MA, Frank LD, Pratt M, et al. Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. Lancet. 2016;387:2207–17.
9. Hajna S, Ross NA, Brazeau A-S, Bélisle P, Joseph L, Dasgupta K. Associations between neighbourhood walkability and daily steps in adults: a systematic review and meta-analysis. BMC Public Health. 2015;15:768. http://www.biomedcentral.com/1471-2458/15/768.
10. Ferdinand AO, Sen B, Rahurkar S, Engler S, Menachemi N. The relationship between built environments and physical activity: a systematic review. Am J Public Health. 2012;102:7–13.
11. Farrell L, Hollingsworth B, Propper C, Shields MA. The socioeconomic gradient in physical inactivity: evidence from one million adults in England. Soc Sci Med. 2014;123:55–63. doi:10.1016/j.socscimed.2014.10.039.
12. Beenackers MA, Kamphuis CBM, Giskes K, Brug J, Kunst AE, Burdorf A, et al. Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: a systematic review. Int J Behav Nutr Phys Act. 2012;9:116. http://www.scopus.com/inward/record.url?eid=2-s2.0-84866279745&partnerID=tZOtx3y1.
13. Pascual C, Regidor E, Alvarez-Del Arco D, Alejos B, Santos JM, Calle ME, et al. Sports facilities in Madrid explain the relationship between neighbourhood economic context and physical inactivity in older people, but not in younger adults: a case study. J Epidemiol Community Health. 2013;67:788–94.
14. Huang J, Lu XX, Sellers JM. A global comparative analysis of urban form: applying spatial metrics and remote sensing. Landsc Urban Plan. 2007;82:184–97.
15. Turrell G, Haynes M, Wilson LA, Giles-Corti B. Can the built environment reduce health inequalities? A study of neighbourhood socioeconomic disadvantage and walking for transport. Health Place. 2013;19:89–98. doi:10.1016/j.healthplace.2012.10.008.
16. King KE, Clarke PJ. A disadvantaged advantage in walkability: findings from socioeconomic and geographical analysis of national built environment data in the United States. Am J Epidemiol. 2015;181:17–25.
17. Thornton CM, Conway TL, Cain KL, Gavand KA, Saelens BE, Frank LD, et al. Disparities in pedestrian streetscape environments by income and race/ethnicity. SSM Popul Health. 2016;2:206–16. doi:10.1016/j.ssmph.2016.03.004.
18. Zhu X, Lee C. Walkability and safety around elementary schools. economic and ethnic disparities. Am J Prev Med. 2008;34:282–90.
19. Carpenter A, Peponis J. Poverty and connectivity. J Sp Syntax. 2010;1:108–20. http://128.40.150.106/joss/index.php/joss/article/viewFile/23/pdf_10.

20. Sallis JF, Slymen DJ, Conway TL, Frank LD, Saelens BE, Cain K, et al. Income disparities in perceived neighborhood built and social environment attributes. Health Place. 2011;17:1274–83. doi:10.1016/j.healthplace.2011.02.006.
21. Sugiyama T, Howard NJ, Paquet C, Coffee NT, Taylor AW, Daniel M. Do relationships between environmental attributes and recreational walking vary according to area-level socioeconomic status? J Urban Health. 2015;92:253–64.
22. Kazepov Y. Cities of Europe: changing contexts, local arrangement and the challenge to urban cohesion. Oxford: Wiley; 2005.
23. Musterd S. Social and ethnic segregation in Europe: levels, causes, and effects. J Urban Aff. 2005;27:331–48.
24. van Ham M, Manley D, Bailey N, Simpson L, Maclennan D, editors. Understanding neighbourhood dynamics. Dordrecht: Springer; 2013. doi:10.1007/978-94-007-4854-5.
25. Koschinsky J, Talen E. Affordable housing and walkable neighborhoods: a national urban analysis. Cityscape A J Policy Dev Res. 2015;17:13–56.
26. Bilal U, Díez J, Alfayate S, Gullón P, Del Cura I, Escobar F, et al. Population cardiovascular health and urban environments: the Heart Healthy Hoods exploratory study in Madrid, Spain. BMC Med Res Methodol. 2016;16:104. http://www.ncbi.nlm.nih.gov/pubmed/27549991.
27. Carreño V, Franco M, Gullón P, Carreño V. Studying city life, improving population health. Int J Epidemiol. 2015;. doi:10.1093/ije/dyv207.
28. Gullón P, Badland HM, Alfayate S, Bilal U, Escobar F, Cebrecos A, et al. Assessing walking and cycling environments in the streets of madrid: comparing on-field and virtual audits. J Urban Health. 2015;92:923–39. http://www.ncbi.nlm.nih.gov/pubmed/26349472.
29. INE. Estadísticas del padrón continuo 2014. Madrid; 2014. http://www.ine.es/jaxi/menu.do?type=pcaxis&path=/t20/e245/&file=inebase.
30. Leal J, Sorando D. Economic crisis, social change and segregation processes in Madrid. Socioecon Segreg Eur Cap Cities East Meets West. 2016;214–37.
31. Gago García C, Serrano Cambronero M, Antón Burgos FJ. Repercusiones de las carreteras orbitales de la Comunidad de Madrid en los cambios de usos del suelo. Ann Geogr. 2004;145–67. http://cat.inist.fr/?aModele=afficheN&cpsidt=17632244.
32. Ministerio de Sanidad Servicios Sociales e Igualdad. Avanzando hacia la equidad. Propuesta de políticas e intervenciones para reducir las desigualdades sociales en salud en España. 2015;17–23. http://www.mspsi.gob.es/profesionales/saludPublica/prevPromocion/promocion/desigualdadSalud/docs/Propuesta_Politicas_Reducir_Desigualdades.pdf.
33. Borrell C, Malmusi D, Muntaner C. Introduction to the "Evaluating the Impact of Structural Policies on Health Inequalities and Their Social Determinants and Fostering Change" (SOPHIE) Project. Int J Health Serv. 2017;47:10–7. doi:10.1177/0020731416681891.
34. González Pérez JM. Urban planning system in contemporary Spain. Eur Plan Stud. 2007;15:29–50.
35. Feng J, Glass TA, Curriero FC, Stewart WF, Schwartz BS. The built environment and obesity: a systematic review of the epidemiologic evidence. Health Place. 2010;16:175–90. doi:10.1016/j.healthplace.2009.09.008.
36. Creatore MI, Glazier RH, Moineddin R, Fazli GS, Johns A, Gozdyra P, et al. Association of neighborhood walkability with change in overweight, obesity, and diabetes. JAMA 2016;315:2211. http://jama.jamanetwork.com/article.aspx?doi=10.1001/jama.2016.5898.
37. Grasser G, van Dyck D, Titze S, Stronegger WJ. A European perspective on GIS-based walkability and active modes of transport. Eur J Public Health. 2016;. doi:10.1093/eurpub/ckw118.
38. Cleveland WS, Devlin SJ. Locally weighted regression: an approach to regression analysis by local fitting. J Am Stat Assoc. 1988;83:596–610. doi:10.1080/01621459.1988.10478639.
39. Harrell FE. Regression modeling strategies. Cham: Springer International Publishing; 2015. doi:10.1007/978-3-319-19425-7.
40. Meissner H, Creswell J, Klassen AC, Plano V, Smith KC. Best practices for mixed methods research in the health sciences. Bethesda: National Institutes of Health; 2011.
41. Díaz Orueta F. Madrid: urban regeneration projects and social mobilization. Cities. 2007;24:183–93.
42. Friedman B, Gordon SP, Peers JB. Effect of neotraditional neighborhood design on travel characteristics. Transp Res Rec. 1994;63–70. http://trid.trb.org/view.aspx?id=425323.
43. Munoz F. Lock living: urban sprawl in mediterranean cities. Cities. 2003;20:381–5.
44. Kadi J, Ronald R. Market-based housing reforms and the "right to the city": the variegated experiences of New York, Amsterdam and Tokyo. Int J Hous Policy. 2014;14:268–92. doi:10.1080/14616718.2014.928098.
45. Hirsch JA, Grengs J, Schulz A, Adar SD, Rodriguez DA, Brines SJ, et al. How much are built environments changing, and where?: patterns of change by neighborhood sociodemographic characteristics across seven US metropolitan areas. Soc Sci Med. 2016;169:97–105. doi:10.1016/j.socscimed.2016.09.032.

5. DISCUSSION

5.1. Summary of findings

The first study of this PhD has shown that Madrid Systematic and Pedestrian Cycling Scan (M-SPACES) is a useful tool to measure walkability and bikeability in the streets segments of Madrid. Moreover, virtual measures with Google Street View was, for most features of the street, a valid instrument to assess walking and cycling environment when compared with the on-field M-SPACES measures. However, mean time auditing the street segments virtually was higher than on-field. Intra-rater agreement, both physically and virtually, was acceptable, showing that the urban environment and the items in the M-SPACES did not change between 2013 and 2014. Despite this, inter-rate agreement between the observers was low; training with the SPACES manual should have been adapted and improved for Madrid.

The second general objective was to explore the integration of the M-SPACES walkability with other quantitative, qualitative and health indicators of the physical and social environment in a median sociodemographic area in Madrid. Thus, the second study tested the viability of integrating in-depth information from different environmental and social determinants of cardiovascular health, as well as health data from the electronic health records provided by the Primary Health Care System. The quantitative data, through the integration in a GIS dataset, is an opportunity to accommodate the different domains that make up the urban environment. The qualitative part of our mixed methods approach let us to get a clear picture of the area from the "experts", that is, the neighbors that live in them. Cardiovascular health in the area was similar to the Madrid total population in terms of prevalence of cardiovascular risk factors such as hypertension, diabetes and dyslipidemia.

The third study used a different approach to measure walkability. In this case, walkability was measured as an index using variables from secondary datasets for the whole city of Madrid. Using this walkability index, this study indicates that census sections with higher socioeconomic status had less punctuation in the walkability index following, for the most part, a dose–response linear pattern. Moreover, we found that this association is heterogeneous, as there are significant interactions by a marker of gentrification and neighborhood age. Newest and gentrified neighborhoods had a flat curve between area-SES and walkability.

5.2. Use of on-field and virtual audits to measure walkability

In this study, Google Street View was a valid instrument to measure walkability using on-field visits with the Madrid Systematic Pedestrian and Cycling Scan (M-SPACES) as the gold standard. This was true for most of the features of the streets. Certain elements had substantial (neighborhood permeability) or almost perfect agreement (walking infrastructure, traffic safety, streetscape aesthetics, and destinations) between on-field and virtual audits. On the other hand, some elements had worse agreement between on-field and Google Street View measures; for instance, walking surface and cycling infrastructure had poor agreement.

Other studies are compatible with these findings (H. M. Badland, Opit, Witten, Kearns, & Mavoa, 2010; Charreire et al., 2014). Virtual imagery, as the one that can be obtained from Google Street View, provides a valid alternative to on-field measures to measure walkability and the walking surface. However, not all features of the street that might be important for walking are so easy to replicate with virtual imagery; for instance, more subjective elements, like aesthetics or general condition, had lower agreement with on-field measures in other studies (Charreire et al., 2014; Curtis, Curtis, Mapes, Szell, & Cinderich, 2013). In this study, some of these subjective characteristics, such as the sidewalk condition, had lower agreement between on-field and virtual audits; however, other subjective characteristics, like aesthetics and streetscape aesthetics, had acceptable levels of agreement.

Assessing virtually the urban environments have substantial advantages over going along the neighborhoods, according to other studies:

- Virtual audits might be time-saving while auditing (H. M. Badland et al., 2010; Bethlehem et al., 2014; Rundle, Bader, Richards, Neckerman, & Teitler, 2011).
- Large savings in time travel to the study area (Rundle et al., 2011).
- Use of these free geospatial services make it easier and cheaper to conduct studies of this kind, especially on large and/or dispersed area, as they do not require special resources (H. M. Badland et al., 2010).
- Virtual auditing is safer when measuring unsafe neighborhoods (Marco, Gracia, Martín-Fernández, & López-Quílez, 2017; Rundle et al., 2011).

- They are not affected by daylight restrictions of weather changes.
- Virtual auditing might useful for international comparisons in areas where imagery is available.

It can be discussed if some of these advantages can be applied to this research. In this study, mean time auditing the street segments using Google Street was slower than conducting physical audits. One possible explanation might be that the complex street structure of European cities (greater density and connectivity; thus, shorter street segments) might eliminate the time advantage of undertaking virtual audits (Kazepov, 2005). Despite these advantages, these measures can be difficult to apply to large areas, as there are single measures for each street segment; one alternative could be to sample a set of streets and then extrapolate and estimate contiguous streets (Mooney et al., 2014).

This study also tested the reliability of the M-SPACES itself. Intra-rater agreement was acceptable, as most elements had acceptable levels of agreement between audits in 2013 and 2014. Lower levels of agreement were found for cycling infrastructure and surface, as also path safety, which may be due to low variability of these elements in the study area, as also some new elements (e.g., cycle storage) that were not present in 2013. On the other hand, inter-rate agreement was low. It is possible that there are systematic differences in the training process. Even though the SPACES manual was followed, for other uses it should be translated and adapted specifically for Madrid's context and the M-SPACES changes.

This instruments for direct observation (no matter if they are used on-field or virtually) provides opportunity to measure specific elements of the built environment that are more difficult to measure through the integration of secondary datasets in a GIS set. Also, direct observation avoid the possibility of same source bias when asking residents about their environment and self-reported outcomes (Gullón et al., 2014); moreover, perceived environments are well correlated with direct observation (Chiang, Sullivan, & Larsen, 2017).

There are other measures that can be used for measuring walkability and the built environment, as it was set in the introduction of the dissertation (table 2). In the experience of this first study, M-SPACES provides a valid tool to measure walkability both on-field and virtually; however, despite the savings in transportation with the Google Street View audits, it might be difficult to measure large-scale areas, such a big city.

5.3. Integration of walkability with other quantitative and qualitative measures of the physical and social environment

Most neighborhood and health research treat different urban environment domains (built environment, food environment, tobacco outlets…) as single characteristics that relate in some way to health outcomes, in particular cardiovascular health risk factors and behaviors (physical activity, diet, tobacco or alcohol consumption). However, cardiovascular health risk factors are often correlated (Loprinzi, 2015); thus, there is a need to incorporate a relational approach in order to fully understand the relationship between neighborhoods and health (Cummins, Curtis, Diez-Roux, & Macintyre, 2007).

Bringing together different methods, tools and strategies from medicine, public health, geography or other social science is key for achieving this point. The sustained level of development of Geographic Information Systems (GIS) (Escobar et al., 2000) has made possible relevant advances in this area.

Also, in the last years, there has been an increasing interest in Public Health for the concept of mixed methods (Creswell et al., 2011). As set in the introduction, mixed methods are an umbrella term to the different ways of combining qualitative and quantitative data through triangulation. Triangulation is premised on the reasoning that no single method ever adequately solves the problem of rival explanations, and that the weakness in a single method will be compensated by the counter-balancing strengths of another. The benefits of mixed methods include: converging or corroborating findings; minimizing alternative explanations for conclusions drawn from research data; elucidating divergent aspects of a phenomenon; and obtaining a more accurate and comprehensive perspective of participants' experiences (Stewart, Makwarimba, Barnfather, Letourneau, & Neufeld, 2008). Thus, mixed methods are also useful to understand complex research problems such as health disparities and urban health (Creswell et al., 2011; Stewart et al., 2008). However, mixed method approaches have their own difficulties, like the scarcity of a training infrastructure, the necessity to work under two epistemological traditions or the complexity of data integration (O'Cathain, Nicholl, & Murphy, 2009).

This study tested the feasibility of doing an in-depth study of a neighborhood and its environmental and social determinants of cardiovascular health. Through a series of quantitative and qualitative techniques different aspects pertaining to cardiovascular health were measured: food, physical activity, tobacco and alcohol environments, and habits and social norms related with them. Moreover, by using the electronic health records of the Universal Primary Health Care system, we were able to obtain a picture of the cardiovascular health of the residents in the area. To do so, a median area in the city of Madrid, in terms of selected sociodemographic characteristics, was selected. This methodology, known as the Median Neighborhood Index, could be useful for future international comparisons of "median neighborhoods" in different settings.

Regarding physical activity environment, two measures were used: SPACES audit tool for the streets in the area, and the System for Observing Play and Recreation in Communities (SOPARC) (McKenzie, Cohen, Sehgal, Williamson, & Golionelli, 2006) to measure the uses of open spaces and parks in the area. Open spaces were used by adults, especially seniors without a clear intent to engage into physically active. However, the design of this spaces it not conductive for anything but walking or passive use. Interviews with neighbors showed an interesting duality regarding preferred places to walk: while parks were well perceived, their use is conditioned on the presence of certain behaviors (such as alcohol consumption or immigrant presence), and some people preferred walking in streets with a high density of retail business, rather than walking on parks or other open spaces. In the case of food environment, the area had a rich food environment; however, qualitative interviews emphasized the importance of public markets, which quantitative healthy food availability tools might fail to capture. Alcohol and tobacco environment was mostly dominated by bars and restaurants; neighbors showed the cultural importance of alcohol consumption in these bars as a social cohesion mechanism.

Despite the integration of all the different data through GIS and the analysis with mixed methods concurrent analysis is a positive experience to a deep understanding of a small-area of Madrid; some improvements could be taken into account for future analysis: for instance, (1) quantitative integration into one index is an interesting approach that allow to better characterize and associate different domains with health outcomes (Cebrecos et al., 2016); (2)direct on-field audit tools, even measured with virtual imagery, could not be cost-effective for large areas; another mixed-methods approaches could be taken into account (e.g. sequential time approach with an initial phase of formative qualitative research followed by the design of quantitative tools).

5.4. Distribution of walkability and the role of neighborhood dynamics

As opposed from the other two studies, a different approach to measure walkability was used. As derived from studies 1 and 2, direct audit systematic observation tools may not be the best choice for auditing the whole city, despite the ability to provide in-depth information not dependent from the availability of secondary sources. Therefore, a European-based walkability index was created, based on the work of Creatore (Creatore et al., 2016) in Canada, with European adaptations (Grasser et al., 2016).

Regarding the spatial distribution of walkability and SES in Madrid, walkability was higher in the down- town area of Madrid (inside the M-30 orbital motorway of Madrid), while Socioeconomic status followed a major North–South decreasing gradient (higher SES in the Northern areas of the city), while the Southern peripheral neighborhoods of the city had a lower SES. The regression model determined that census sections with higher socioeconomic status had a less walkable-urban form, as defined by the GIS-based Walkability Index created for the third study. This association followed, for the most part, a dose–response linear pattern. Besides, the association was heterogenous, as there were significant interactions by a marker of gentrification and neighborhood age.

These results means that, in general, some neighborhoods in Madrid might have a "disadvantaged advantage in walkability" (King & Clarke, 2015); low-SES areas in Madrid might have a protection against physical activity inequalities through high-walkability. This results are consistent to some other studies, where street connectivity (Carpenter & Peponis, 2010), shorter block length, greater street node density, more developed land use, and higher density of street segments (King & Clarke, 2015) are inversely correlated with indicators of area-SES. However, other measures of walkability, such as perceived aesthetics or safety (Sallis et al., 2011; Sugiyama et al., 2015) are more present in more deprived areas. These mixed results are key to understand the disparities in low and high-income neighborhoods in physical activity.

However, this "advantage" in walkability in low-SES neighborhoods is not present in gentrified areas (top 95% percentile of rank change in high-education level in the last 10 years) and newest-built areas of Madrid (those with its median year of construction after 1997). This has important implications, as it might mean that dynamics in terms of population change and construction of new areas are playing a key role in perpetuating or even increasing socioeconomic inequalities in physical activity in Madrid.

5.5. Strengths and limitations of this research

5.5.1. Limitations

The present research has limitation that were not fully-controlled. Overall, we were not able to link our data to individual-level health behavior (e.g. walking) or outcome (e.g. cardiovascular diseases) data, which could give us a better understanding on the effects of our walkability measures; however, one of our next steps is to link these measures with physical activity and cardiovascular health data. In this research, we focused mainly in walking behavior and its environment determinants; however, as it is set in the introduction, many other environment determinants could be important for physical activity (e.g. sport facilities, public transportation) that we have only partially considered. It would be interesting to develop and compare GIS, direct and perceptions on the different domains of the physical activity environment. Regarding the walkability measures, the GIS-based walkability index contained indicators from residential and population density, destinations and street structure; on the other hand, M-SPACES audit tool was composed from 4 factors: function, safety, aesthetics and destinations. Despite some of these measures could be grouped within similar concepts (some function or safety elements are street structure; destinations in both measures), it is important to choose which walkability measure is the appropriate for your study, in terms of: (1) conceptual framework, (2) level of analysis (street, census section), (3) feasibility. In future analysis, we will try to capture street-level information to reproduce M-SPACES dimensions with secondary public sources.

There are specific limitations when using Google Street view. For instance, the availability and the updating of Google images could be a great limitation for some settings; in this study, 30.4 % of images were updated last time before 2010. There were ~10% of streets that were not able to measure with Google Street View, as images were not fully-available for streets where the vehicle that take the pictures was not physically able to photograph (e.g. pedestrian streets). However, Google Street View, as other virtual imagery sets (MS Visual Oblique) are expanding their images availability in the last years. We were not able to measure the intra-rater agreement for “Destinations”, as the question changed between the 2013 and 2014 auditing. In the statistical analysis, our ICC analysis might not be the best one for street features with low variability such as cycling infrastructure or some surface characteristics (Devellis, 2003).

In the third study, we have focused on the city of Madrid; we did not take into account the whole metropolitan area, which includes more than 100 small municipalities. This decision was made as data is provided by the city council of Madrid, and it is not available for other municipalities than Madrid. tTe marker of gentrification used is unspecific, as a change in education proportions may reflect both residential mobility phenomena (linked to gentrification) and other population changes in the non-moving population (linked to social mobility). Further research in Madrid with residential mobility data should explore the impact of these two phenomena on our inferences.

5.5.2. Strengths

Overall, in this research we were able to measure walkability with two different approaches: systematic observation checklist (M-SPACES) and GIS-based walkability index through publicly available datasets. Moreover, we tested how M-SPACES information can be integrated with other quantitative measures of the neighborhood (open spaces use, healthy food availability, tobacco and alcohol availability), and qualitative information through mixed methods analysis.

For both measures of walkability, we made an effort adapting and creating new measures and tools for our context. Firstly, we adapted the original SPACES audit tool in order to better capture the reality of the streets in Madrid. From the SPACES tool, some adjustments were made: summing the item weights for “negotiation of footpath”, and “type of footpath” into a single item called “type of footpath”; similarly, we aggregated “footpath smoothness” and “footpath smoothness/condition” into a variable called “footpath smoothness.” We also modified the “Destinations” item by adding the number of destinations present in the street segment, as most of Madrid’s segments presented many destinations, and we considered important to discriminate the number of destinations. These changes did not affect to the original weights. For the GIS-based walkability index has been adapted for one used in Canada (Creatore et al., 2016), but the changes followed some adaptations that could be needed for European context, using different measures for connectivity and land-use (Grasser et al., 2016).

Specifically, the Google Street View validity study is the largest one that has been published, as far as we know. We were able to test the validity in three different urban-form neighborhoods, instead of focusing on one area. Moreover, this is the first study to test the validity in a Mediterranean high-density city, where urban form patterns differ from the less-density cities in North-America or Australasia.

In the study of neighborhood dynamics, we took an original approach to look at the recent changes of the city. Most of the neighborhoods and health studies that use a temporal approach usually look at changes of the built environment; however, we looked at the neighborhood dynamics in terms of gentrification and neighborhood age, which reflect changes in terms of the built environment structure and in terms of population that live in the neighborhoods. We have also built a strong SES and walkability measures using GIS and an integrated composite index, which allow us to better measure SES by using information from several indicators and therefore reduce the degree of measurement error.

5.6. Challenges

5.6.1. Policy change and interdisciplinary collaboration

Health researchers have a growing range of different tools for finding answers to questions about how the neighborhood and the built environment affects health. This dynamic area of research continues developing innovative data and dissemination strategies to meet local needs. Yet even local efforts embedded in unique histories of a given place can be viewed with an eye to what lessons we can share with other communities. Building partnerships and multi-city collaborations shows promise for spreading widely the ideas and information that can make healthier lives possible for all.

Using evidence to inform policy and practice is challenging, especially in-built environment and health research, where policy changes are outside of the health sector and not necessarily “health-directed” (Lieberman, Golden, & Earp, 2013). Influencing public policy and practice is an explicit goal for applied built environment and health research. However, the gap between research and policy is in fact increased by a poor fit between academic research and the needs of policymakers and practitioners. To optimize “policy-relevant” research in built environment, Billie Giles-Corti et al (Giles-Corti et al., 2015) proposed 10 strategies: (1) understand the ‘policy world’ we are attempting to shift; (2) establish links with policymakers and practitioners; (3) work with knowledge brokers, advocates, and lobbyists; (4) establish research agendas jointly with policymakers and practitioners; (5) undertake interdisciplinary collaborative research; (6) study the health-economic impacts of active living infrastructure; (7) evaluate policy reform through natural experiments; (8) conduct research focusing on community needs and preferences; (9) highlight specific policy implications; and (10) create interdisciplinary built environment and health training programs.

5.6.2. Citizen participation and citizen science

Many of the neighborhood and health studies have looked for associations between objectively measured aspects of the neighborhood and health behaviors or outcomes, using mainly quantitative methodologies; others have looked for perceptions using qualitative methods. However, citizens have been mostly acting as "passive voices" of the research.

Participatory Action Research (PAR) might be a suitable approach for involving citizens in research and policy change. Specifically, Community-Based Participatory Research (CBPR) is an approach that acknowledges community as an equal partner throughout the research and action process (Caldwell, Reyes, Rowe, Weinert, & Israel, 2015). For example, Photovoice is a participatory method coming out of CBPR and PAR, defined as "a process by which people can identify, represent, and enhance their community through a specific photographic technique" (Wang & Burris, 1997). Photovoice has been used previously as a method for identifying key elements of the neighborhood that are important for physical activity (Belon et al., 2014); however, the potential of photovoice for translating the voice of the residents into policy change for active living is still in its first steps (Kramer et al., 2010).

5.6.3. Evaluation of natural experiments

Natural experiments are the methodological approaches to evaluating the impact on health or other outcomes of interventions or policies, which are not under the control of researchers but which are amenable to the research (P. Craig et al., 2012; Franco et al., 2015). For example, Franco et al (Franco et al., 2013) studied the changes in body weight in Cuba with the economic changes in the last 20 years. In urban health research, natural experiments research have been used in the last years to evaluate changes in some neighborhoods and to compare it to "control neighborhoods" where the policy intervention did not occur (Franco et al., 2015). As an example, from the neighborhood built environment literature, the evaluation of the Neighborhoods Law in Catalonia (Spain) evaluated the effects on health and health inequalities of a renewal project in Barcelona (Mehdipanah et al., 2014, 2015). The Neighborhoods Law in Catalonia (Spain) funded municipalities that presented urban renewal projects within disadvantaged neighborhoods focusing on physical, social and economic improvements; they found that The Neighborhoods Law had a positive effect on self-rated health and seems to prevent poor mental health increases in both sexes and especially among manual social classes (Mehdipanah et al., 2014). It is important to note that the effect of neighborhood built environment change might be stronger as more time passes; longer-term follow-up is required to fully capture the impact on residents (Giles-Corti et al., 2013). Despite this promising alternative, it has been argued that the methodological problems and risk of bias pose threats to natural experiments designs (Benton, Anderson, Hunter, & French, 2016).

5.6.4. Shaping from neighborhood effects to "city effects": the scale effect of research and policy

Within public health, the focus is often on how features of the neighborhood shape residents' health. However, the built environment may affect population health at both coarser and finer scales as well. Some characteristics of cities may be influenced by national or regional mass influences, and will therefore not be discoverable with studies comparing neighborhood characteristics within a single city (all under the same mass influence). For instance, transit systems facilitate mobility at the level of the metropolitan area. Following Geoffrey Rose's population approach, in order to uncover these mass influences, we must study and compare entire populations (e.g. cities) as well as variation within each population (Rose G, 1985).

Moreover, it is important to note that scale effect should be taken into account in research. The modifiable areal unit problem (MAUP) is a well-known issue in all studies involving spatial data (Fotheringham & Wong, 1991). This problem emerges when the inferences drawn from a study are not robust to the selection of a spatial level of analysis. For example, if we are to study phenomena occurring at the smallest geographical level, and instead we use data on larger city areas much larger than those neighborhoods (such as neighborhood clusters, police jurisdictions or other administrative boundaries), our inferences may be biased compared to using small areas.

5.7. Policy implications

The policy implications for this PhD dissertation require future studies with improved data and new analysis. However, there are some key factors that should be discussed for its policy implications.

In the last years, Madrid is passing through some changes in order to make the city more sustainable and friendly for active transportation. Nevertheless, these changes are focused on single characteristics of the urban environment, such as a new bike sharing system or new bike lanes in the inner center. As we saw in this dissertation, the different elements of a walkable environment interact and correlate with each other, and there is a need to see active transportation as a whole strategy, where there are different elements and policy strategies to follow in order to make a more sustainable and active transport friendly city. For example, when designing new bike lanes policy makers should take into account other strategies such as traffic restriction or the promotion of walking and cycling destinations that discourages car use for daily activities. Moreover, these decisions have to be considered taking into account residents' perspectives, as we saw that there might be a gap between quantitative data and residents' perceptions.

Following a similar approach, the second implication implies a holistic perspective of the city. Changes in one of the elements of a city might have implications in others. The abundance of research available as a foundation for understanding the built environment and behavior from beyond the health sciences provides a groundwork for interdisciplinary and cross-sectoral collaborations. Relationship between neighborhood characteristics and health might act by indirect pathways; for instance, changes in the food outlets regulation that implies better healthy food availability might imply also an increase in active transportation and reduce car dependence.

Lastly, this dissertation has implications in relation to residents' mobility and neighborhood dynamics. As we saw in the third study of this dissertation, newest built areas in Madrid and those that have been gentrified are designed with a different socio-spatial approach, where low-SES neighborhoods might be losing the "advantage" in walkability. If new neighborhoods in Madrid are built following a different socio-spatial distribution of walkability (more favorable for the wealthy, or with a loss of a walkability advantage for the poor), and the wealthy people are moving to the walkable neighbor- hoods (Koschinsky & Talen, 2015), there is a need to balance with safeguards to preserve affordability and avoid the displacement of low-SES populations, keeping the "right to the city" with adequate housing reforms (Kadi & Ronald, 2014). Therefore, continued attention needs to be paid to equity in urban policies to change the urban form to ensure changes do not have the unintended consequence of increased health inequities (Hirsch et al., 2016).

We believe that conducting this type of research in European cities with a longer historical trajectory, a presence of different urban form structures (like historical mixed-use downtown areas) provides a different mechanistic insight into the determinants of walkability and can help inform policies in European cities in a more appropriate way.

6.CONCLUSIONS

- The adapted Madrid Systematic Pedestrian and Cycling Environment Scan (M-SPACES) audit tool was able to discriminate between different population density areas.
- Google Street View provided a valid way of measuring most aspects of the residential environment in a European city like Madrid, especially neighborhood permeability walking infrastructure, traffic safety, streetscape aesthetics, and destinations. However, for some features (e.g., street lane), the audits may need to be completed with other secondary spatial databases. Characteristics of the streets that may inhibit or promote cycling had lower correlation between on-field and virtual audits.
- Inter-rater agreement of the M-SPACES audit tool was, in general, weak ($ICC<0.4$); therefore, intensive observer training and the use of complementary objective techniques may be required. Intra-auditor agreement was substantially better when measuring urban environments virtually.
- Quantitative epidemiological and geographical methodologies showed to be complementary and relevant when describing the specific features of the urban environment and walkability. This experience allowed testing and refining measuring tools to understand walkability.
- The inclusion of qualitative methodologies provided important insights adding emergent categories to the characterization of neighborhoods such as: subjective neighborhood boundaries, the use of open spaces and streets, and the importance of destinations for walking.
- The combination of walkability with other urban environment measurements, quantitative and qualitative, and universal electronic health records from the primary care health system, will provide useful data to examine the relationship of neighborhood characteristics and cardiovascular health shedding important light to develop sound population preventive approaches.
- Higher SES areas of Madrid showed lower walkability compared with lower SES areas.
- Neighborhood dynamics in terms of social (gentrification) an urban form (neighborhood age) modified this association; newest and gentrified neighborhoods had a flat curve between area-SES and walkability. A deeper

understanding of the dynamic relationship between urban form and neighborhood composition would provide further insights into mobility and health behaviors and outcomes, and inform urban planning policy in European cities to preserve health equities

7. NEXT STEPS

The work developed in this dissertation doesn't end here. As explained in the introduction, this dissertation is set in the Heart Healthy Hoods Project (hhhproject.eu), specifically developing new tools and methods for measuring the built environment. Thus, there is future research that I will work on after this dissertation. This further analysis and publications will complete the work that I have been doing in the last years.

The first one is the most obvious and derived from one of the limitations of this dissertation, the availability of health data. At this moment, we have access to an Electronic Health Records dataset with data from 1.5 million residents 40-75 years old of Madrid, and we are starting the recruitment of a cohort of ~2500 people. Thus, one of the objectives that I would like to achieve in the following months is the relationship between the measures used for this dissertation and cardiovascular health and cardiovascular risk factors. Specifically, I would like to study what is the role of the different characteristics of the neighborhoods in shaping health inequalities, and to study in-depth the role of the neighborhood dynamics.

One of the challenges that has been discussed in this dissertation is the need of cross-country comparisons. As part of the time that I spent at Drexel's Urban Health Collaborative in Philadelphia, we have walkability data from Madrid and this US city using M-SPACES and Google Street View. With this cross-country comparison, we would like to study the difference in the Median Neighborhood of both cities as well as the intra-city inequalities in walkability using a street-sample strategy in both cities. Preliminary results of this article have been presented in the International Conference on Urban Health and the Spanish Epidemiology Association meeting; in this conference, it was awarded as one of the best scientific communications presented by young researchers.

Moreover, other challenge in urban health research is citizen's participation in research. I designed and participated in a Photovoice project in 2 different-SES neighborhoods in Madrid. In this Photovoice project, 4 groups of people in Chamberí (high-SES area) and Villaverde (low-SES area), have been studying and conceptualizing the relationship between their neighborhoods and physical activity. Currently, we are working with the citizens in the design of policy recommendations, that they would present to policy-makers in Madrid. Besides, using the photovoice data and the quantitative data from the cohort and the EHR, I would like to design a mixed methods approach for a better understanding of the complex relationships between SES, walkability and health. Preliminary results have been presented in the Spanish Epidemiology Association meeting of 2017.

8.BIBLIOGRAPHY

Adams, M. a, Frank, L. D., Schipperijn, J., Smith, G., Chapman, J., Christiansen, L. B., … Sallis, J. F. (2014). International variation in neighborhood walkability, transit, and recreation environments using geographic information systems: the IPEN adult study. *International Journal of Health Geographics*, *13*(43), 17. https://doi.org/10.1186/1476-072X-13-43

Alonso-Blanco, C., Palacios-Ceña, D., Hernández-Barrera, V., Carrasco-Garrido, P., Jiménez-García, R., & Fernández-de-Las-Peñas, C. (2012). Trends in leisure time and work-related physical activity in the Spanish working population, 1987-2006. *Gaceta Sanitaria*, *26*(3), 223–30. https://doi.org/10.1016/j.gaceta.2011.07.027

Arnott, B., Rehackova, L., Errington, L., Sniehotta, F. F., Roberts, J., & Araujo-Soares, V. (2014). Efficacy of behavioural interventions for transport behaviour change: systematic review, meta-analysis and intervention coding. *International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 133. https://doi.org/10.1186/s12966-014-0133-9

Badland, H. M., Opit, S., Witten, K., Kearns, R. A., & Mavoa, S. (2010). Can Virtual Streetscape Audits Reliably Replace Physical Streetscape Audits? *Journal of Urban Health*, *87*(6), 1007–1016. https://doi.org/10.1007/s11524-010-9505-x

Badland, H., & Schofield, G. (2005). Transport, urban design, and physical activity: An evidence-based update. *Transportation Research Part D: Transport and Environment*, *10*(3), 177–196. https://doi.org/10.1016/j.trd.2004.12.001

Barnett, D. W., Barnett, A., Nathan, A., Van Cauwenberg, J., & Cerin, E. (2017). Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1), 103. https://doi.org/10.1186/s12966-017-0558-z

Beenackers, M. A., Kamphuis, C. B. M., Giskes, K., Brug, J., Kunst, A. E., Burdorf, A., & van Lenthe, F. J. (2012). Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: a systematic review. *The International Journal of Behavioral Nutrition and Physical Activity*, *9*, 116. https://doi.org/10.1186/1479-5868-9-116

Belon, A. P., Nieuwendyk, L. M., Vallianatos, H., & Nykiforuk, C. I. J. (2014). How community environment shapes physical activity: Perceptions revealed through the PhotoVoice method. *Social Science and Medicine*, *116*, 10–21. https://doi.org/10.1016/j.socscimed.2014.06.027

Benton, J. S., Anderson, J., Hunter, R. F., & French, D. P. (2016). The effect of changing the built environment on physical activity: a quantitative review of the risk of bias in natural experiments. *International Journal of Behavioral Nutrition and Physical Activity*, *13*(1), 107. https://doi.org/10.1186/s12966-016-0433-3

Berg, B. K., Warner, S., & Das, B. M. (2015). What about sport? A public health perspective on leisure-time physical activity. *Sport Management Review*, *18*(1), 20–31. https://doi.org/10.1016/j.smr.2014.09.005

Bethlehem, J. R., Mackenbach, J. D., Ben-rebah, M., Compernolle, S., Glonti, K., Bárdos, H., … Lakerveld, J. (2014). The SPOTLIGHT virtual audit tool: a valid and reliable tool to assess obesogenic characteristics of the built environment. *International Journal of Health Geographics*, *13*(1), 52. https://doi.org/10.1186/1476-072X-13-52

Bhatnagar, A. (2017). Environmental Determinants of Cardiovascular Disease. *Circulation Research*, *121*(2), 162–180. https://doi.org/10.1161/CIRCRESAHA.117.306458

Blacksher, E., & Lovasi, G. S. (2012). Place-focused physical activity research, human agency, and social justice in public health: Taking agency seriously in studies of the built environment. *Health and Place*, *18*(2), 172–179. https://doi.org/10.1016/j.healthplace.2011.08.019

Boehmer, T. K., Hoehner, C. M., Deshpande, a D., Brennan Ramirez, L. K., & Brownson, R. C. (2007). Perceived and observed neighborhood indicators of obesity among urban adults. *International Journal of Obesity*, *31*(6), 968–977. https://doi.org/10.1038/sj.ijo.0803531

Booth, M. (2000). Assessment of Physical Activity: An International Perspective. *Research Quarterly for Exercise and Sport*, *71*(sup2), 114–120. https://doi.org/10.1080/02701367.2000.11082794

Borrell, C., Malmusi, D., & Muntaner, C. (2017). Introduction to the "Evaluating the Impact of Structural Policies on Health Inequalities and Their Social Determinants and Fostering Change" (SOPHIE) Project. *International Journal of Health Services*, *47*(1), 10–17. https://doi.org/10.1177/0020731416681891

Burchell, R. W., & Mukherji, S. (2003). Conventional Development Versus Managed Growth: The Costs of Sprawl. *American Journal of Public Health*, *93*(9), 1534–1540. https://doi.org/10.2105/AJPH.93.9.1534

Caldwell, W. B., Reyes, A. G., Rowe, Z., Weinert, J., & Israel, B. A. (2015). Community Partner Perspectives on Benefits, Challenges, Facilitating Factors, and Lessons Learned from Community-Based Participatory Research Partnerships in Detroit. *Progress in Community Health Partnerships: Research, Education, and Action*, *9*(2), 299–311. https://doi.org/10.1353/cpr.2015.0031

Carpenter, A., & Peponis, J. (2010). Poverty and Connectitvity. *The Journal of Space Syntax*, *1*(July), 108–120. Retrieved from http://128.40.150.106/joss/index.php/joss/article/viewFile/23/pdf_10

Carreño, V., Franco, M., Gullón, P., & Carreño, V. (2015). Studying city life, improving population health. *International Journal of Epidemiology*, dyv207. https://doi.org/10.1093/ije/dyv207

Caspersen, C. J., & Christenson, G. M. (1985). Physical Activity , Exercise , and Physical Fitness : Definitions and Distinctions for Health-Related Research. *Public Health Reports*, *100(2)*(Mar-Apr), 126–131.

Cavill, N., Kahlmeier, S., & Racioppi, F. (2006). *Physical Activity and Health in Europe: Evidence for Action*. Retrieved from http://books.google.dk/books?id=ANPNh-oiIggC

Cebrecos, A., Díez, J., Gullón, P., Bilal, U., Franco, M., & Escobar, F. (2016). Characterizing physical activity and food urban environments: a GIS-based multicomponent proposal. *International Journal of Health Geographics*, *15*, 35. https://doi.org/10.1186/s12942-016-0065-5

Cerin, E., & Leslie, E. (2008). How socio-economic status contributes to participation in leisure-time physical activity. *Social Science and Medicine*, *66*(12), 2596–2609.

https://doi.org/10.1016/j.socscimed.2008.02.012

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, *2*(3), 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6

Charreire, H., Mackenbach, J. D., Ouasti, M., Lakerveld, J., Compernolle, S., Ben-Rebah, M., … Oppert, J. M. (2014). Using remote sensing to define environmental characteristics related to physical activity and dietary behaviours: A systematic review (the SPOTLIGHT project). *Health and Place*, *25*, 1–9. https://doi.org/10.1016/j.healthplace.2013.09.017

Chau, J., Chey, T., Burks-Young, S., Engelen, L., & Bauman, A. (2017). Trends in prevalence of leisure time physical activity and inactivity: results from Australian National Health Surveys 1989 to 2011. *Australian and New Zealand Journal of Public Health*, 1–8. https://doi.org/10.1111/1753-6405.12699

Chiang, Y. C., Sullivan, W., & Larsen, L. (2017). Measuring neighborhood walkable environments: A comparison of three approaches. *International Journal of Environmental Research and Public Health*, *14*(6), 1–12. https://doi.org/10.3390/ijerph14060593

Chow, C. K., Lock, K., Teo, K., Subramanian, S., McKee, M., & Yusuf, S. (2009). Environmental and societal influences acting on cardiovascular risk factors and disease at a population level: A review. *International Journal of Epidemiology*, *38*(6), 1580–1594. https://doi.org/10.1093/ije/dyn258

Cimarras-Otal, C., Calderón-Larrañaga, A., Poblador-Plou, B., González-Rubio, F., Gimeno-Feliu, L. A., Arjol-Serrano, J. L., & Prados-Torres, A. (2014). Association between physical activity, multimorbidity, self-rated health and functional limitation in the Spanish population. *BMC Public Health*, *14*(1), 1170. https://doi.org/10.1186/1471-2458-14-1170

Cole, H. V. S., Garcia Lamarca, M., Connolly, J. J. T., & Anguelovski, I. (2017). Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. *Journal of Epidemiology and Community Health*, jech-2017-209201. https://doi.org/10.1136/jech-2017-209201

Council of Europe. (1992). *The European Sport Charter*.

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., … Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381–95. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Craig, P., Cooper, C., Gunnell, D., Haw, S., Lawson, K., Macintyre, S., … Thompson, S. (2012). Using natural experiments to evaluate population health interventions: new Medical Research Council guidance. *Journal of Epidemiology and Community Health*, *66*(12), 1182–1186. https://doi.org/10.1136/jech-2011-200375

Creatore, M. I., Glazier, R. H., Moineddin, R., Fazli, G. S., Johns, A., Gozdyra, P., … Booth, G. L. (2016). Association of Neighborhood Walkability With Change in Overweight, Obesity, and Diabetes. *Jama*, *315*(20), 2211. https://doi.org/10.1001/jama.2016.5898

Creswell, J., Klassen, A. C., Plano, V., & Smith, K. C. (2011). Best Practices for Mixed Methods Research in the Health Sciences, *29*, 1–39.

Cummins, S., Curtis, S., Diez-Roux, A. V., & Macintyre, S. (2007). Understanding and representing “place” in health research: A relational approach. *Social Science and Medicine*, *65*(9), 1825–1838. https://doi.org/10.1016/j.socscimed.2007.05.036

Curtis, J. W., Curtis, A., Mapes, J., Szell, A. B., & Cinderich, A. (2013). Using google street view for systematic observation of the built environment: analysis of spatio-temporal instability of imagery dates. *International Journal of Health Geographics*, *12*(1), 53. https://doi.org/10.1186/1476-072X-12-53

Das, P., & Horton, R. (2012). Rethinking our approach to physical activity. *Lancet (London, England)*, *380*(9838), 189–90. https://doi.org/10.1016/S0140-6736(12)61024-1

Devellis, R. F. (2003). *Scale Development: Theory and Applications*. Thousand Oaks, CA: SAGE Publications.

Díez, J., Conde, P., Sandin, M., Urtasun, M., López, R., Carrero, J. L., … Franco, M. (2017). Understanding the local food environment: A participatory photovoice project in a low-income area in Madrid, Spain. *Health and Place*, *43*(October

2016), 95–103. https://doi.org/10.1016/j.healthplace.2016.11.012

Diez Roux, A.-V. (2007). Neighborhoods and health: where are we and were do we go from here? *Revue d'Épidémiologie et de Santé Publique*, *55*(1), 13–21. https://doi.org/10.1016/j.respe.2006.12.003

Ding, D., Lawson, K. D., Kolbe-Alexander, T. L., Finkelstein, E. A., Katzmarzyk, P. T., van Mechelen, W., & Pratt, M. (2016). The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *The Lancet*, *388*(10051), 1311–1324. https://doi.org/10.1016/S0140-6736(16)30383-X

Dunton, G. F., Liao, Y., Intille, S. S., Spruijt-Metz, D., & Pentz, M. (2011). Investigating children's physical activity and sedentary behavior using ecological momentary assessment with mobile phones. *Obesity (Silver Spring, Md.)*, *19*(6), 1205–1212. https://doi.org/10.1038/oby.2010.302

Dyck, D. Van, Cardon, G., Deforche, B., & De Bourdeaudhuij, I. (2011). Do adults like living in high-walkable neighborhoods? Associations of walkability parameters with neighborhood satisfaction and possible mediators. *Health and Place*, *17*(4), 971–977. https://doi.org/10.1016/j.healthplace.2011.04.001

Escobar, F., Green, J., Waters, E., & Williamson, I. (2000). Enabling Geographic Information Systems for the Public Health Sector. A proposal for the research agenda. In *GEOMED'99, Second International Workshop on Geography and Medicine, Paris, France* (pp. 1–12).

Evenson, K. R., Wen, F., & Herring, A. H. (2016). Associations of Accelerometry-Assessed and Self-Reported Physical Activity and Sedentary Behavior With All-Cause and Cardiovascular Mortality Among US Adults. *American Journal of Epidemiology*, *184*(9), 621–632. https://doi.org/10.1093/aje/kww070

Ewing, R., Handy, S., Brownson, R. C., Clemente, O., & Winston, E. (2006). Identifying and Measuring Urban Design Qualities Related to Walkability. *Journal of Physical Activity and Health*, *3*(Suppl 1), 223–240. https://doi.org/10.13072/midss.126

Farrell, L., Hollingsworth, B., Propper, C., & Shields, M. A. (2014). The socioeconomic gradient in physical inactivity: Evidence from one million adults in England.

Social Science and Medicine, *123*, 55–63. https://doi.org/10.1016/j.socscimed.2014.10.039

Fotheringham, A. S., & Wong, D. W. S. (1991). The Modifiable Areal Unit Problem in Multivariate Statistical Analysis. *Environment and Planning A*, *23*(7), 1025–1044. https://doi.org/10.1068/a231025

Franco, M., Bilal, U., & Diez-Roux, A. V. (2015). Preventing non-communicable diseases through structural changes in urban environments. *Journal of Epidemiology and Community Health*, *69*(6), 509–11. https://doi.org/10.1136/jech-2014-203865

Franco, M., Bilal, U., Orduñez, P., Benet, M., Morejón, A., Caballero, B., … Cooper, R. S. (2013). Population-wide weight loss and regain in relation to diabetes burden and cardiovascular mortality in Cuba 1980-2010: repeated cross sectional surveys and ecological comparison of secular trends. *BMJ (Clinical Research Ed.)*, *346*(apr09 2), f1515. https://doi.org/10.1136/bmj.f1515

Frank, L. D., Andresen, M. A., & Schmid, T. L. (2004). Obesity relationships with community design, physical activity, and time spent in cars. *American Journal of Preventive Medicine*, *27*(2), 87–96. https://doi.org/10.1016/j.amepre.2004.04.011

Frank, L. D., Schmid, T. L., Sallis, J. F., Chapman, J., & Saelens, B. E. (2005). Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *American Journal of Preventive Medicine*, *28*(2 SUPPL. 2), 117–125. https://doi.org/10.1016/j.amepre.2004.11.001

Frohlich, K. L. (2014). Commentary: What is a population-based intervention? Returning to geoffrey rose. *International Journal of Epidemiology*, *43*(4), 1292–1293. https://doi.org/10.1093/ije/dyu111

Gerovasili, V., Agaku, I. T., Vardavas, C. I., & Filippidis, F. T. (2015). Levels of physical activity among adults 18-64 years old in 28 European countries. *Preventive Medicine*, *81*, 87–91. https://doi.org/10.1016/j.ypmed.2015.08.005

Giles-Corti, B., Bull, F., Knuiman, M., McCormack, G., Van Niel, K., Timperio, A., … Boruff, B. (2013). The influence of urban design on neighbourhood walking following residential relocation: Longitudinal results from the RESIDE study. *Social Science and Medicine*, *77*(1), 20–30.

https://doi.org/10.1016/j.socscimed.2012.10.016

Giles-Corti, B., Sallis, J. F., Sugiyama, T., Frank, L. D., Lowe, M., & Owen, N. (2015). Translating active living research into policy and practice: One important pathway to chronic disease prevention. *Journal of Public Health Policy*, *36*(2), 231–243. https://doi.org/10.1057/jphp.2014.53

Grasser, G., Van Dyck, D., Titze, S., & Stronegger, W. (2013). Objectively measured walkability and active transport and weight-related outcomes in adults: A systematic review. *International Journal of Public Health*, *58*(4), 615–625. https://doi.org/10.1007/s00038-012-0435-0

Grasser, G., van Dyck, D., Titze, S., & Stronegger, W. J. (2016). A European perspective on GIS-based walkability and active modes of transport. *The European Journal of Public Health*, ckw118. https://doi.org/10.1093/eurpub/ckw118

Gullón, P., Bilal, U., & Franco, M. (2014). Physical activity environment measurement and same source bias. *Gaceta Sanitaria / S.E.S.P.A.S*, *28*(4), 344–5. https://doi.org/10.1016/j.gaceta.2013.12.011

Gullon, P., & Lovasi, G. S. (2017). Designing healthier built environments. In D. T. Duncan & I. Kawachi (Eds.), *Neighborhoods and health*. Oxford University Press.

Hajna, S., Ross, N. A., Brazeau, A.-S., Bélisle, P., Joseph, L., & Dasgupta, K. (2015). Associations between neighbourhood walkability and daily steps in adults: a systematic review and meta-analysis. *BMC Public Health*, *15*(1), 768. https://doi.org/10.1186/s12889-015-2082-x

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U., … Wells, J. C. (2012). Global physical activity levels: Surveillance progress, pitfalls, and prospects. *The Lancet*, *380*(9838), 247–257. https://doi.org/10.1016/S0140-6736(12)60646-1

Hamer, M., & Chida, Y. (2008). Walking and primary prevention: a meta-analysis of prospective cohort studies. *British Journal of Sports Medicine*, *42*(4), 238–243. https://doi.org/10.1136/bjsm.2007.039974

Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity: Views from urban planning. *American*

Journal of Preventive Medicine, *23*(2 SUPPL. 1), 64–73. https://doi.org/10.1016/S0749-3797(02)00475-0

Hirsch, J. A., Grengs, J., Schulz, A., Adar, S. D., Rodriguez, D. A., Brines, S. J., & Roux, A. V. D. (2016). How much are built environments changing, and where?: Patterns of change by neighborhood sociodemographic characteristics across seven U.S. metropolitan areas. *Social Science & Medicine*, *169*, 97–105. https://doi.org/10.1016/j.socscimed.2016.09.032

Hoehner, C. M., Ivy, A., Brennan Ramirez, L., Meriwether, B., & Brownson, R. C. (2006). How Reliably Do Community Members Audit the Neighborhood Environment for Its Support of Physical Activity? Implications for Participatory Research. *Journal of Public Health Management and Practice*, *12*(3), 270–277. https://doi.org/10.1097/00124784-200605000-00008

Hu, F. B., Sigal, R. J., Rich-Edwards, J. W., Colditz, G. A., Solomon, C. G., Willett, W. C., … Manson, J. E. (1999). Walking compared with vigorous physical activity and risk of type 2 diabetes in women: a prospective study. *JAMA : The Journal of the American Medical Association*, *282*(15), 1433–1439. https://doi.org/joc90446 [pii]

Jacobs, J. (1961). *The death and life of great american cities*. Random House.

Kadi, J., & Ronald, R. (2014). Market-based housing reforms and the “right to the city”: the variegated experiences of New York, Amsterdam and Tokyo. *International Journal of Housing Policy*, *14*(3), 268–292. https://doi.org/10.1080/14616718.2014.928098

Kasanko, M., Barredo, J. I., Lavalle, C., McCormick, N., Demicheli, L., Sagris, V., & Brezger, A. (2006). Are European cities becoming dispersed?. A comparative analysis of 15 European urban areas. *Landscape and Urban Planning*, *77*(1–2), 111–130. https://doi.org/10.1016/j.landurbplan.2005.02.003

Kazepov, Y. (2005). *Cities of Europe: Changing Contexts, Local Arrangement and the Challenge to Urban Cohesion*. Oxford: Wiley.

King, K. E., & Clarke, P. J. (2015). A disadvantaged advantage in walkability: Findings from socioeconomic and geographical analysis of national built environment data in the United States. *American Journal of Epidemiology*, *181*(1), 17–25.

https://doi.org/10.1093/aje/kwu310

Knell, G., Gabriel, K. P., Businelle, M. S., Shuval, K., Wetter, D. W., & Kendzor, D. E. (2017). Ecological Momentary Assessment of Physical Activity: Validation Study. *Journal of Medical Internet Research*, *19*(7), e253. https://doi.org/10.2196/jmir.7602

Knuth, A., & Hallal, P. (2009). Temporal trends in physical activity: a systematic review. *Journal of Physical Activity and Health*, *6*(c), 548–559.

Kohl, H. W., Craig, C. L., Lambert, E. V., Inoue, S., Alkandari, J. R., Leetongin, G., … Lancet Physical Activity Series Working Group. (2012). The pandemic of physical inactivity: global action for public health. *Lancet (London, England)*, *380*(9838), 294–305. https://doi.org/10.1016/S0140-6736(12)60898-8

Koschinsky, J., & Talen, E. (2015). Affordable housing and walkable neighborhoods: A national urban analysis. *Cityscape: A Journal of Policy Development and Research*, *17*(2), 13–56.

Kramer, L., Schwartz, P., Cheadle, A., Borton, J. E., Wright, M., Chase, C., & Lindley, C. (2010). Promoting policy and environmental change using photovoice in the Kaiser Permanente Community Health Initiative. *Health Promotion Practice*, *11*(3), 332–9. https://doi.org/10.1177/1524839909341555

Krieger, N. (2001). Historical roots of social epidemiology: socioeconomic gradients in health and contextual analysis. *International Journal of Epidemiology*, *30*(4), 899–900. https://doi.org/10.1097/gme.0b013e3181967b88

Larsen, K., Gilliland, J., Hess, P., Tucker, P., Irwin, J., & He, M. (2009). The influence of the physical environment and sociodemographic characteristics on children's mode of travel to and from school. *American Journal of Public Health*, *99*(3), 520–526. https://doi.org/10.2105/AJPH.2008.135319

Laverty, A. a, Palladino, R., Lee, J. T., & Millett, C. (2015). Associations between active travel and weight, blood pressure and diabetes in six middle income countries: a cross-sectional study in older adults. *The International Journal of Behavioral Nutrition and Physical Activity*, *12*(1), 65. https://doi.org/10.1186/s12966-015-0223-3

Leal, C., & Chaix, B. (2011). The influence of geographic life environments on cardiometabolic risk factors: A systematic review, a methodological assessment and a research agenda. *Obesity Reviews*, *12*(3), 217–230. https://doi.org/10.1111/j.1467-789X.2010.00726.x

Leal, J., & Sorando, D. (2016). Economic crisis, social change and segregation processes in Madrid. *Socio-Economic Segregation in European Capital Cities: East Meets West*, 214–237.

Lee, I., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., Katzmarzyk, P. T., … Group, W. (2012). Effect of physical inactivity on major non-communicable diseases worldwide : an analysis of burden of disease and. *The Lancet*, *380*(9838), 219–229. https://doi.org/10.1016/S0140-6736(12)61031-9

Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A., & Hugo, G. (2007). Walkability of local communities: Using geographic information systems to objectively assess relevant environmental attributes. *Health and Place*, *13*(1), 111–122. https://doi.org/10.1016/j.healthplace.2005.11.001

Lieberman, L., Golden, S. D., & Earp, J. A. L. (2013). Structural approaches to health promotion: what do we need to know about policy and environmental change? *Health Education & Behavior : The Official Publication of the Society for Public Health Education*, *40*(5), 520–5. https://doi.org/10.1177/1090198113503342

Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., … Memish, Z. A. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet (London, England)*, *380*(9859), 2224–60. https://doi.org/10.1016/S0140-6736(12)61766-8

Loprinzi, P. D. (2015). Physical activity is the best buy in medicine, but perhaps for less obvious reasons. *Preventive Medicine*, *75*, 23–24. https://doi.org/10.1016/j.ypmed.2015.01.033

Lovasi, G. S. (2012). Built environment and health. In J. M. Rippe (Ed.), *Encyclopedia of Lifestyle Medicine and Health*. SAGE Publications.

Maestre-Miquel, C., Regidor, E., Cuthill, F., & Martínez, D. (2015). Desigualdad en la prevalencia de sedentarismo durante el tiempo libre en población adulta española según su nivel de educación. Diferencias entre 2002 y 2021. *Rev Esp Salud Publica*, *89*(3), 259–269. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4443597&tool=pmcentrez&rendertype=abstract

Malambo, P., Kengne, A. P., De Villiers, A., Lambert, E. V., & Puoane, T. (2016). Built environment, selected risk factors and major cardiovascular disease outcomes: A systematic review. *PLoS ONE*, *11*(11), 1–13. https://doi.org/10.1371/journal.pone.0166846

Marco, M., Gracia, E., Martín-Fernández, M., & López-Quílez, A. (2017). Validation of a Google Street View-Based Neighborhood Disorder Observational Scale. *Journal of Urban Health*, *94*(2), 190–198. https://doi.org/10.1007/s11524-017-0134-5

Marques, A., Martins, J., Peralta, M., Catunda, R., & Nunes, L. S. (2016). European adults' physical activity socio-demographic correlates: a cross-sectional study from the European Social Survey. *PeerJ*, *4*, e2066. https://doi.org/10.7717/peerj.2066

Marques, A., Sarmento, H., Martins, J., & Saboga Nunes, L. (2015). Prevalence of physical activity in European adults - Compliance with the World Health Organization's physical activity guidelines, *81*, 333–338. https://doi.org/10.1016/j.ypmed.2015.09.018

McCartney, G., Hearty, W., Taulbut, M., Mitchell, R., Dryden, R., & Collins, C. (2017). Regeneration and health: a structured, rapid literature review. *Public Health*, *148*, 69–87. https://doi.org/10.1016/j.puhe.2017.02.022

McKenzie, T. L., Cohen, D. A., Sehgal, A., Williamson, S., & Golionelli, D. (2006). System for Observing Play and Recreation in Communities (SOPARC): Reliability and Feasibility Measures. *J Phys Act Health*, *3*(Suppl 1), 208–222. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2957838/pdf/nihms28342.pdf

Mehdipanah, R., Manzano, A., Borrell, C., Malmusi, D., Rodriguez-Sanz, M., Greenhalgh, J., … Pawson, R. (2015). Exploring complex causal pathways between urban renewal, health and health inequality using a theory-driven realist approach. *Social Science & Medicine*, *124*, 266–274. https://doi.org/10.1016/j.socscimed.2014.11.050

Mehdipanah, R., Rodríguez-Sanz, M., Malmusi, D., Muntaner, C., Díez, E., Bartoll, X., & Borrell, C. (2014). The effects of an urban renewal project on health and health inequalities: a quasi-experimental study in Barcelona. *Journal of Epidemiology and Community Health*, *68*(9), 811–817. https://doi.org/10.1136/jech-2013-203434

Mertens, L., Van Holle, V., De Bourdeaudhuij, I., Deforche, B., Salmon, J., Nasar, J., … Van Cauwenberg, J. (2014). The effect of changing micro-scale physical environmental factors on an environment's invitingness for transportation cycling in adults: an exploratory study using manipulated photographs. *The International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 88. https://doi.org/10.1186/s12966-014-0088-x

Molnar, B. E., Gortmaker, S. L., Bull, F. C., & Buka, S. L. (2004). Unsafe to Play? Neighborhood Disorder and Lack of Safety Predict Reduced Physical Activity among Urban Children and Adolescents. *American Journal of Health Promotion*, *18*(5), 378–386. https://doi.org/10.4278/0890-1171-18.5.378

Mooney, S. J., Bader, M. D. M., Lovasi, G. S., Neckerman, K. M., Teitler, J. O., & Rundle, A. G. (2014). Validity of an Ecometric Neighborhood Physical Disorder Measure Constructed by Virtual Street Audit. *American Journal of Epidemiology*, *180*(6), 626–635. https://doi.org/10.1093/aje/kwu180

Moran, M., Van Cauwenberg, J., Hercky-Linnewiel, R., Cerin, E., Deforche, B., & Plaut, P. (2014). Understanding the relationships between the physical environment and physical activity in older adults: a systematic review of qualitative studies. *The International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 79. https://doi.org/10.1186/1479-5868-11-79

Morseth, B., Jacobsen, B. K., Emaus, N., Wilsgaard, T., & Jorgensen, L. (2016). Secular trends and correlates of physical activity: The Tromso Study 1979-2008. *Bmc Public Health*, *16*, 1–12. https://doi.org/10.1186/s12889-016-3886-z

Moudon, A. V., Lee, C., Cheadle, A. D., Garvin, C., Johnson, D., Schmid, T. L., … Lin, L. (2006). Operational definitions of walkable neighborhood: Theoretical and empirical insights. *Journal of Physical Activity and Health*, *3*(Supplement 1), S99–S117. https://doi.org/10.1080/13574800802452658

Mujahid, M. S., Diez Roux, A. V., Morenoff, J. D., & Raghunathan, T. (2007). Assessing the measurement properties of neighborhood scales: From psychometrics to ecometrics. *American Journal of Epidemiology*, *165*(8), 858–867. https://doi.org/10.1093/aje/kwm040

Northridge, M. E., Sclar, E. D., & Biswas, P. (2003). Sorting Out the Connections between the Built Environment and Health: A Conceptual Framework for Navigating Pathways and Planning Healthy Cities. *Journal of Urban Health*, *80*(4), 556–568. https://doi.org/10.1093/jurban/jtg064

O'Cathain, A., Nicholl, J., & Murphy, E. (2009). Structural issues affecting mixed methods studies in health research: a qualitative study. *BMC Medical Research Methodology*, *9*, 82. https://doi.org/10.1186/1471-2288-9-82

Ottoson, J. M., Green, L. W., Beery, W. L., Senter, S. K., Cahill, C. L., Pearson, D. C., … Leviton, L. (2009). Policy-Contribution Assessment and Field-Building Analysis of the Robert Wood Johnson Foundation's Active Living Research Program. *American Journal of Preventive Medicine*, *36*(2 SUPPL.), S34–S43. https://doi.org/10.1016/j.amepre.2008.10.010

Oueslati, W., Alvanides, S., & Garrod, G. (2015). Determinants of urban sprawl in European cities. *Urban Studies*, *52*(9), 1594–1614. https://doi.org/10.1177/0042098015577773

Peiró-Pérez, R., Salas, D., Vallés, G., Abad-Fernandez, M. S., Vidal, C., Sanchez-Contador Escudero, C., … Pollán, M. (2015). Walking, biking or sport: How Spanish women attending breast cancer screening meet physical activity recommendations? *European Journal of Public Health*, *25*(5), 857–863. https://doi.org/10.1093/eurpub/cku248

Pikora, T., Giles-Corti, B., Bull, F., Jamrozik, K., & Donovan, R. (2003). Developing a framework for assessment of the environmental determinants of walking and cycling. *Soc Sci Med*, *56*(8), 1693–1703. https://doi.org/S0277953602001636 [pii]

Pikora, T. J., Giles-Corti, B., Knuiman, M. W., Bull, F. C., Jamrozik, K., & Donovan, R.

J. (2006). Neighborhood environmental factors correlated with walking near home: Using SPACES. *Medicine and Science in Sports and Exercise*, *38*(4), 708–714. https://doi.org/10.1249/01.mss.0000210189.64458.f3

Pollard, T. M., & Wagnild, J. M. (2017). Gender differences in walking (for leisure, transport and in total) across adult life: a systematic review. *BMC Public Health*, *17*(1), 341. https://doi.org/10.1186/s12889-017-4253-4

Prasad, A., Gray, C. B., Ross, A., & Kano, M. (2016). Metrics in Urban Health: Current Developments and Future Prospects. *Annual Review of Public Health*, *37*, 113–133. https://doi.org/10.1146/annurev-publhealth-032315-021749

Rose G. (1985). Sick Individuals and Sick Populations GEOFFREY ROSE. *Internationa! Journal of Epidemiology © International Epidemiological Association*, *14*(1), 32–38. https://doi.org/10.1093/ije/14.1.32

Rundle, A. G., Bader, M. D. M., Richards, C. A., Neckerman, K. M., & Teitler, J. O. (2011). Using Google Street View to Audit Neighborhood Environments. *American Journal of Preventive Medicine*, *40*(1), 94–100. https://doi.org/10.1016/j.amepre.2010.09.034

Saelens, B. E., & Handy, S. L. (2008). Built environment correlates of walking: a review. *Medicine and Science in Sports and Exercise*, *40*(7 Suppl), S550-66. https://doi.org/10.1249/MSS.0b013e31817c67a4

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental Correlates of Walking and Cycling: Findings From the Transportation, Urban Design, and Planning Literatures. *Ann Behav Med*, *25*(2), 80–91. https://doi.org/10.1207/S15324796ABM2502_03

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., … Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: A cross-sectional study. *The Lancet*, *387*(10034), 2207–2217. https://doi.org/10.1016/S0140-6736(15)01284-2

Sallis, J. F., Linton, L. S., Kraft, M. K., Cutter, C. L., Kerr, J., Weitzel, J., … Pratt, M. (2009). The Active Living Research Program. Six Years of Grantmaking. *American Journal of Preventive Medicine*, *36*(2 SUPPL.), S10–S21.

https://doi.org/10.1016/j.amepre.2008.10.007

Sallis, J. F., Slymen, D. J., Conway, T. L., Frank, L. D., Saelens, B. E., Cain, K., & Chapman, J. E. (2011). Income disparities in perceived neighborhood built and social environment attributes. *Health and Place*, *17*(6), 1274–1283. https://doi.org/10.1016/j.healthplace.2011.02.006

Samitz, G., Egger, M., & Zwahlen, M. (2011). Domains of physical activity and all-cause mortality: Systematic review and dose-response meta-analysis of cohort studies. *International Journal of Epidemiology*, *40*(5), 1382–1400. https://doi.org/10.1093/ije/dyr112

Schwarz, N. (2010). Urban form revisited-Selecting indicators for characterising European cities. *Landscape and Urban Planning*, *96*(1), 29–47. https://doi.org/10.1016/j.landurbplan.2010.01.007

Shenassa, E. D., Liebhaber, A., & Ezeamama, A. (2006). Perceived safety of area of residence and exercise: A pan-European study. *American Journal of Epidemiology*, *163*(11), 1012–1017. https://doi.org/10.1093/aje/kwj142

Sorando, D., & Ardura, Á. (2016). *First we take Manhattan: la destrucción creativa de las ciudades*. La Catarata.

Stamatakis, E., Ekelund, U., & Wareham, N. J. (2007). Temporal trends in physical activity in England: The Health Survey for England 1991 to 2004. *Preventive Medicine*, *45*(6), 416–423. https://doi.org/10.1016/j.ypmed.2006.12.014

Stewart, M., Makwarimba, E., Barnfather, A., Letourneau, N., & Neufeld, A. (2008). Researching reducing health disparities: Mixed-methods approaches. *Social Science and Medicine*, *66*(6), 1406–1417. https://doi.org/10.1016/j.socscimed.2007.11.021

Stokols, D. (1996). Translating social ecological theory into guidelines for community health promotion. *American Journal of Health Promotion*, *10*(4), 282–298. https://doi.org/10.4278/0890-1171-10.4.282

Sugiyama, T., Howard, N. J., Paquet, C., Coffee, N. T., Taylor, A. W., & Daniel, M. (2015). Do Relationships Between Environmental Attributes and Recreational Walking Vary According to Area-Level Socioeconomic Status? *Journal of Urban Health*, *92*(2), 253–264. https://doi.org/10.1007/s11524-014-9932-1

van Ham, M., Manley, D., Bailey, N., Simpson, L., & Maclennan, D. (Eds.). (2013). *Understanding Neighbourhood Dynamics*. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-4854-5

Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., & De Bourdeaudhuij, I. (2012). Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *BMC Public Health*, *12*(1), 807. https://doi.org/10.1186/1471-2458-12-807

Wang, C., & Burris, M. A. (1997). Photovoice: concept, methodology, and use for participatory needs assessment. *Health Education & Behavior : The Official Publication of the Society for Public Health Education*, *24*(3), 369–87. https://doi.org/10.1177/109019819702400309

Wen, C. P., & Wu, X. (2012). Stressing harms of physical inactivity to promote exercise. *The Lancet*, *380*(9838), 192–193. https://doi.org/10.1016/S0140-6736(12)60954-4

WHO. (2010a). Global Health Observatory Data. Retrieved August 5, 2017, from http://www.who.int/gho/ncd/risk_factors/physical_activity/en/

WHO. (2010b). *Global recommendations on physical activity for health*. *World Health Organization*. https://doi.org/10.1080/11026480410034349

Wood, M. S., Wasfi, R., Parker, G., Bornstein, L., Caron, J., & Kestens, Y. (2017). Is gentrification all bad ? Positive association between gentrification and individual's perceived neighborhood collective efficacy in Montreal , Canada. *International Journal of Health Geographics*, *16*(24), 1–8. https://doi.org/10.1186/s12942-017-0096-6

Xu, C.-X., Zhu, H.-H., Fang, L., Hu, R.-Y., Wang, H., Liang, M.-B., … Zhong, J.-M. (2017). Gender disparity in the associations of overweight/obesity with occupational activity, transport to/from work, leisure-time physical activity, and leisure-time spent sitting in working adults: A cross-sectional study. *Journal of Epidemiology*, 1–7. https://doi.org/10.1016/j.je.2016.08.019

APPENDIX

ANNEX 1. Pedro Gullón international visits in research centers and courses

Geographic Information Systems course at Columbia

Center: Epidemiology and Population Health Summer Institute at Columbia University

Place: New York City, NY, USA.

Date: June 2015 (20 h)

Topic: Introduction to GIS course at EPIC summer courses.

28th Residential Summer Course in Epidemiology

Center: European Education Programme in Epidemiology

Place: Florence, Italy

Date: June-July 2015 (3 weeks)

Topic: 3-weeks course in Epidemiology and Biostatistics.

International research visit at the Urban Health Collaborative.

Center: Urban Health Collaborative. Drexel Dornsife School of Public Health

Place: Philadelphia, PA, USA.

Date: October to December 2016

Topic: Research visit with the Urban Health Collaborative at Drexel. Built environment and walkability measures, international comparisons of walkability, use of parks for physical activity, Geographic Information Systems.

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ANNEX 3. Pedro Gullón scientific production directly related with this PhD dissertation

Peer-review publications

Gullón P., Bilal U., Cebrecos A., Badland HM., Galán I., Franco M. Intersection of neighborhood dynamics and socioeconomic status in small-area walkability: the Heart Healhty Hoods project. Int J Health Geogr 2017 Jun 6;16(1):21. doi: 10.1186/s12942-017-0095-7

Cebrecos A., Díez J., **Gullón P**., Bilal U., Franco M., Escobar F. Characterizing physical activity and food urban environments: a GIS-based multicomponent proposal. Int J Health Geogr. 2016 Oct 4;15:35. doi: 10.1186/s12942-016-0065-5

Bilal U., Díez J., Alfayate S., **Gullón P**., del Cura I., Escobar F., Sandín M., Franco M. Population cardiovascular health and urban environments: The Heart Healthy Hoods exploratory study in Madrid, Spain. BMC Med Res Methodol. 2016 Aug 22;16:104. doi: 10.1186/s12874-016-0213-4

Gullon P, Badland HM, Alfayate S, Bilal U, Escobar F, Cebrecos A, et al. Assessing Walking and Cycling Environments in the Streets of Madrid: Comparing On-Field and Virtual Audits. J Urban Health 2015 Oct;92(5):923-39. doi: 10.1007/s11524-015-9982-z

Editorial, letters and invited papers

Franco M., **Gullón P**., Carreño V. Studying city life, improving population health. International Journal of Epidemiology 2015 Nov 24. doi: 10.1093/ije/dyv207

Gullon P, Bilal U, Franco M. Physical activity environment measurement and same source bias. Gac Sanit. 2014 Jul-Aug;28(4):344-5. doi: 10.1016/j.gaceta.2013.12.011

Book chapters

Gullón P., Lovasi GS. Chapter: Built environment and health. In: Neighborhoods and health 2nd Edition. Oxford University Press. Accepted for publication

Communications in scientific conferences

Gullón P., Díez J., Conde P., Pérez-de-Arenza C., Franco M., Entorno urbano y actividad física: un proyecto participativo a través de la fotografía en Madrid. XXXV Reunión anual de la Sociedad Española de Epidemiología, Barcelona, September 2017

Gullón P., Lovasi GS., Bilal U., Escobar F., Badlan HM., Galán I., Franco M. Caminabilidad y ciclabilidad en diferentes contextos: el caso de Madrid y Filadelfia. Reunión anual de la Sociedad Española de Epidemiología, Barcelona, September 2017

Gullón P., Bilal U., Cebrecos A., Díez J., Sureda X., Franco M. Comparación de la caminabilidad medida por sistemas de información geográfica y con instrumento de medición directa. XXXIV Reunión anual de la Sociedad Española de Epidemiología, Sevilla. September 2016

Gullón P., Cebrecos A., Sureda X., Bilal U., Díez J., Escobar F., Franco M. Variación de la caminabilidad en áreas de diferente nivel sociodemográfico en Madrid. II congreso iberoamericano de epidemiología y salud pública, Santiago de Compostela. September 2015.

Sureda, X., Cebrecos, A., Bilal, U., **Gullón, P.,** Díez, J., Fuentes, S., Franco, M.. Densidad de estancos y características sociodemográficas en los barrios de madrid. II congreso iberoamericano de epidemiología y salud pública, Santiago de Compostela. September 2015.

Gullón P., Alfayate S., Escobar F., Bilal U., Díez J., Franco M. Validación de una herramienta para medir el entorno de las calles para andar y usar la bicicleta: medición directa y con Google Street View. XXXII Reunión científica de la Sociedad Española de Epidemiología (SEE). Alicante, September 2014.

Gullón P., Alfayate S., Bilal U., Díez J., Franco M. Validation of a Walking and Cycling Audit Tool in the Streets of Madrid using On-Field and Google Street View Audits. Epidemiology and Prevention. Nutrition, Physical Activity and Metabolism 2014 Scientific Sessions. San Francisco, USA, March 2014.

Bilal U., Díez J., **Gullón P**., Alfayate S., del Cura I., Franco M. Measuring the Food, Tobacco, Alcohol and Physical Activity Urban Environments in Relation to Cardiovascular Health: The Heart Healthy Hoods Pilot Study in Madrid, Spain Epidemiology and Prevention. Nutrition, Physical Activity and Metabolism 2014 Scientific Sessions. San Francisco, USA, March 2014.

ANNEX 4. Pedro Gullón scientific production not-directly related with this PhD dissertation

Peer-review publications

Gullón P., Varela C., Martínez EV., Gómez-Barroso D. Association between meteorological factors and Hepatitis A in Spain 2010-214. Environ Int. 2017 May;102:230-235. doi: 10.1016/j.envint.2017.03.008

Latasa P., Gil-Borreli C., Aguilera JA., Reques L., Barreales S., Ojeda E., Alemán G., Iniesta C., **Gullón P.** [Impact of the Core Training Law on preventive medicine and public health training and other common medical specialties]. Gac Sanit. 2016 Jul-Aug;30(4):296-9. doi: 10.1016/j.gaceta.2016.04.004

Cimas M*., **Gullón P**.*, Aguilera E., Meyer E., Freire JM., Pérez-Gómez B. The effect of healthcare decentralization on healthcare coverage for undocumented migrants in the Spanish National Health System: Regional dfiferences after RDL 16/2012. Health Policy. 2016 Apr;120(4):384-95. doi: 10.1016/j.healthpol.2016.02.005 (*both first authors)

Communications in scientific conferences

González-Rubio R., **Gullón P.,** Latasa P., Aginagalde AH., Peremiquel-Trillas P., Iniesta C., Pantoja PE., Reques L. Competencias de la especialidad de Medicina Preventiva y Salud Pública: Una nueva visión. XXXV Reunión anual de la Sociedad Española de Epidemiología, Barcelona, September 2017

Aginagalde AH., Gutiérrez E., **Gullón P**., Rodríguez S., Arroyo V., Ruiz R., Mori F., Quiroga A., Ojeda E. Herramienta para evaluar la empleabilidad de egresados de Medicina Preventiva y Salud Pública. XXXV Reunión anual de la Sociedad Española de Epidemiología, Barcelona, September 2017

Gullón P., Varela C., Martínez EV., Gómez D. Asociación entre fenómenos meteorológicos y hepatitis A en España 2010-2013. XXXIV Reunión anual de la Sociedad Española de Epidemiología, Sevilla. September 2016

Quintas S., García-Soto D., Reig G., Rogado J., Pacheco V., **Gullón P.,** Vivancos J. Predictores de cáncer oculto en pacientes con infarto cerebral. LXVIII Reunión anual de la Sociedad Española de Neurología, Valencia. November 2016

Monreal E., **Gullón P**., Escobar A., Martínez P., Querda C., Hernández I., Masjuan J., Pérez MJ., Corral I. Aumento de la frecuencia de ictus isquémicos y hemorrágicos en pacientes con infección por VIH en España. LXVIII Reunión anual de la Sociedad Española de Neurología, Valencia. November 2016

Latasa P., Gil-Borreli C., Aguilera JA., Reques L., Barreales L., Ojeda E., Alemán G., Iniesta C., **Gullón P**. Impacto del Real Decreto de Troncalidad en la formación especializada en Medicina Preventiva y Salud Pública. II congreso iberoamericano de epidemiología y salud pública, Santiago de Compostela. September 2015.

Iniesta C., **Gullón P.,** Ojeda E., Barreales S., Gil-Borrelli CC. Representa. Creando redes de representantes de residentes de Medicina Preventiva y Salud Pública. XXXII Reunión científica de la Sociedad Española de Epidemiología (SEE). Alicante, September 2014.

Gullón P., Velasco C., Gil-Borrelli CC., Latasa P., Iniesta C., Ojeda E., Barreales S., Aguilera JA. Proyecto INCIDO: Registro de incidencias en docencia en la formación de residentes de Medicina Preventiva y Salud Pública. XXXII Reunión científica de la Sociedad Española de Epidemiología (SEE). Alicante, September 2014.

Gil-Borrelli CC, Latasa P, Reques L, Prieto L, Barreales S, Ojeda E, Iniesta C, **Gullón P**. Reivindicad: Residentes implicados en la vigilancia de indicadores de calidad en la docencia. XXXII Reunión científica de la Sociedad Española de Epidemiología (SEE). Alicante, September 2014.

Cimas M., **Gullón P**., Aguilera E., Meyer S., Freire JM., Pérez-Gómez B. Exclusion of undocumented migrants in the Spanish National Health System: differences in Regions after RDL 16/2012. EUPHA’s 5th European Conference on Migrant and Ethnic Minority Health. Granada. April 2014

Gullón P., Asúnsolo Á., Ojeda E., Tébar A. Ayudas y apoyos recibidos por las personas con discapacidad en España. Congreso Iberoamericano de Salud Pública. Granada, September 2013.

Ojeda E., Cereijo L., **Gullón P.,** Tébar A., Asúnsolo Á., Valadés D. Percepción del estado de salud y ejercicio físico en personas con discapacidad en España. Congreso Iberoamericano de Salud Pública. Granada, September 2013.

ANNEX 5. Madrid Systematic Pedestrian and Cycling Scan (M-SPACES) audit tool adapted by Gullon et al

Auditor ID ____________ Date ____________
Hood ____Street ____________________
Seg ID____________________________
Hour ____________ Time ____________

1a. Type of buildings/ features: (*tick all applicable*):

	Side 1		Side 2
Transport infrastructure	☐	0	☐
Housing	☐	1	☐
Office	☐	2	☐
Convenience stores	☐	3	☐
Other retail	☐	4	☐
Industrial	☐	5	☐
Educational	☐	6	☐
Service	☐	7	☐
Natural features	☐	8	☐

1b. Predominant buildings/features (*tick ONE per side only*):

	Side 1		Side 2
Transport infrastructure	☐	0	☐
Housing	☐	1	☐
Office	☐	2	☐
Convenience stores	☐	3	☐
Other retail	☐	4	☐
Industrial	☐	5	☐
Educational	☐	6	☐
Service	☐	7	☐
Natural features	☐	8	☐

1c. Are the predominant buildings/features the same for both sides?

Yes	1	☐
No	2	☐

A. Path for walking &/or cycling (*only if a path present*)

2. Type of path:

	Side 1		Side 2
Go to section B ⟵ No path	☐	1	☐
Footpath	☐	2	☐
Shared path – with markings	☐	3	☐
Shared path – no markings	☐	4	☐

3. Path location:

	Side 1		Side 2
Next to road	☐	1	☐
Within 1m of kerb	☐	2	☐
Between 1 & 2m of kerb	☐	3	☐
Between 2 & 3m of kerb	☐	4	☐
More than 3m from kerb	☐	5	☐

4. Path material:

	Side 1		Side 2
Continuous concrete	☐	1	☐
Concrete slabs	☐	2	☐
Paving bricks	☐	3	☐
Gravel	☐	4	☐
Bitumen	☐	5	☐
Grass or sand	☐	6	☐
Under repair	☐	7	☐

5. Slope:

	Side 1		Side 2
Flat or gentle	☐	1	☐
Moderate slope	☐	2	☐
Steep slope	☐	3	☐

6. Path condition & smoothness:

	Side 1		Side 2
Poor (a lot of bumps, cracks, holes & weeds)	☐	1	☐
Moderate (some bumps, cracks, holes & weeds)	☐	2	☐
Good (very few bumps, cracks, holes & weeds)	☐	3	☐
Under repair	☐	4	☐

7. Permanent path obstructions:

	Side 1		Side 2
Poles	☐	1	☐
Signs	☐	2	☐
Tables & chairs	☐	3	☐
Trees	☐	4	☐
None	☐	5	☐

B. On-road (*all segments*)

8. Path type:

On-road cycle lane – marked	1	☐
On-road – no lane marked	2	☐

9. Slope: (*only assess on-road if no path is present*):

Flat or gentle slope	1	☐
Moderate slope	2	☐
Steep slope	3	☐

10. Condition of road:

Poor (a lot of bumps, cracks, holes)	1	☐
Moderate (some bumps, cracks, holes)	2	☐
Good (very few bumps, cracks, holes)	3	☐
Under repair	4	☐

11. Number of lanes on road (in total):

1 lane	1	☐
2 or 3 lanes	2	☐
4 or 5 lanes	3	☐
6 or more lanes	4	☐

12. Vehicle parking restriction signs present:

	Side 1		Side 2
Yes	☐	1	☐
No	☐	2	☐

13. Kerb type:

	Side 1		Side 2
Mountable	☐	1	☐
Non-mountable	☐	2	☐
No kerb	☐	3	☐

14. Traffic control devices: (tick all applicable):

Roundabouts	1	☐
Speed humps or ramps	2	☐
Chicanes, chokers, kerb extensions or lane narrowing	3	☐
Traffic signals	4	☐
None	5	☐

15. Other routes available:

Lane	1	☐
Access through cul-de-sac/no through road	2	☐
Path through park	3	☐
None	4	☐

16. Type of crossings:

Zebra or children	1	☐
Traffic signals	2	☐
Bridge/overpass	3	☐
Underpass	4	☐
None	5	☐

17. Crossing aids: (*tick all applicable*)

Median refuge or traffic island	1	☐
Kerb extension	2	☐
None	3	☐

18. Streetlights present?

	Side 1		Side 2
Yes	☐	1	☐
Go to Q20 ⟵ No	☐	2	☐

19. Does lighting cover the path area?

	Side 1		Side 2
Yes	☐	1	☐
No	☐	2	☐

20. Are destinations present in segment?

Yes	1	☐
Go toQ24 ⟵ No	2	☐

21. Number of destinations:

0-5	1	☐
5-10	2	☐
10-15	3	☐

22. Number car parking facilities at destinations: (*approx.*)

	0 (1)	1-20 (2)	21-50 (3)	51-70 (4)	71-100 (5)	101+ (6)	
Shops	☐	☐	☐	☐	☐	☐	1
School	☐	☐	☐	☐	☐	☐	2
Other	☐	☐	☐	☐	☐	☐	3

23. Bike parking facilities:

Bike locker or enclosure	1	☐
Bike parking or U rails	2	☐
Rack or stand	3	☐
None	4	☐

24. Driveway crossovers:

Most buildings have one driveway	1	☐
Approx. ½ buildings have one driveway	2	☐
Approx. ¼ buildings have one driveway	3	☐
No driveways	4	☐

25. Surveillance: (can be observed from a window, verandah, porch, garden)

Can be observed from more than 75% of buildings	1	☐
Can be observed from between 50%-74% of buildings	2	☐
Can be observed from less than 50% of buildings	3	☐
No applicable	4	☐

26. Garden maintenance: (well maintained = looks trim & clean, looks kept)

More than 75% well maintained	1	☐
Between 50-74% well maintained	2	☐
Less than 50% well maintained	3	☐
Not applicable	4	☐

27. Verge maintenance: (well = looks trim & clean, looks kept)

More than 75% well maintained	1	☐
Between 50-74% well maintained	2	☐
Less than 50% well maintained	3	☐
Not applicable	4	☐

28. Number of verge trees:

	Side 1		Side 2
1 or more per house block	☐	1	☐
Approx. 1 tree for every 2 house blocks	☐	2	☐
Approx. 1 tree for every 3 or more house blocks	☐	3	☐
Go to Q30 ⟵ No trees at all	☐	4	☐

29. Average height of trees:

	Side 1		Side 2
Small (head high)	☐	1	☐
Medium (between head & ceiling high)	☐	2	☐
Large (higher than a ceiling)	☐	3	☐

30. Cleanliness: (can you see any litter, rubbish, graffiti, broken glass, discarded items)

Yes lots	1	☐
Yes some	2	☐
None or almost none	3	☐

31. Graffiti present?

Yes 1 ☐
No 2 ☐

32. Type of views: (*tick all applicable)*

Urban (houses & households gardens) 1 ☐
Commercial (shops, light industrial, offices, schools) 2 ☐
Water (such as river, ocean, lake) 3 ☐
Tended nature (parks, community gardens tended, well maintained) 4 ☐
Nature (parks, community gardens where level of care differs) 5 ☐

33. How alike are the building designs?

All of similar designs 1 ☐
Range of different designs 2 ☐
Not applicable (no buildings) 3 ☐

34. How attractive would you rate this segment for walking?

Very attractive 1 ☐
Attractive 2 ☐
Not attractive at all 3 ☐

35. How physically difficult would you rate this segment for walking?

Easy 1 ☐
Moderately difficult 2 ☐
Very difficult 3 ☐

36. How attractive would you rate this segment for cycling?

Very attractive 1 ☐
Attractive 2 ☐
Not attractive at all 3 ☐

37. How physically difficult would you rate this segment for cycling?

Easy 1 ☐
Moderately difficult 2 ☐
Very difficult 3 ☐

C. Overall assessment

38. Continuity of path:

Path forms useful & direct route 1 ☐
Path is disjointed 2 ☐

39. Neighbourhood legibility – ease of finding your way around the neighbourhood:

Very easy 1 ☐
Fairly easy 2 ☐
Not easy at all 3 ☐

Streetview

Yes ☐
No ☐

ANNEX 6. The Median Neighborhood Index Methodological Details

The Median Neighborhood Index (MNI) is the average Euclidean rank distance of each spatial unit of analysis to the median neighborhood in a series of variables. More specifically, this index uses four variables to represent the demographic and socioeconomic structure, segregation phenomena and urban form. The Euclidean rank distance in each variable is calculated by sorting all units of analysis (census sections) and computing how far in rank each unit is from the median neighborhood. The four distances are then averaged to the Median Neighborhood Index. A low value in this index represents a more average neighborhood in the four variables, while a higher value represents more extreme neighborhoods. Importantly, and since rank distances are all positive, these extreme neighborhoods may be on either tail of the distribution of social factors.

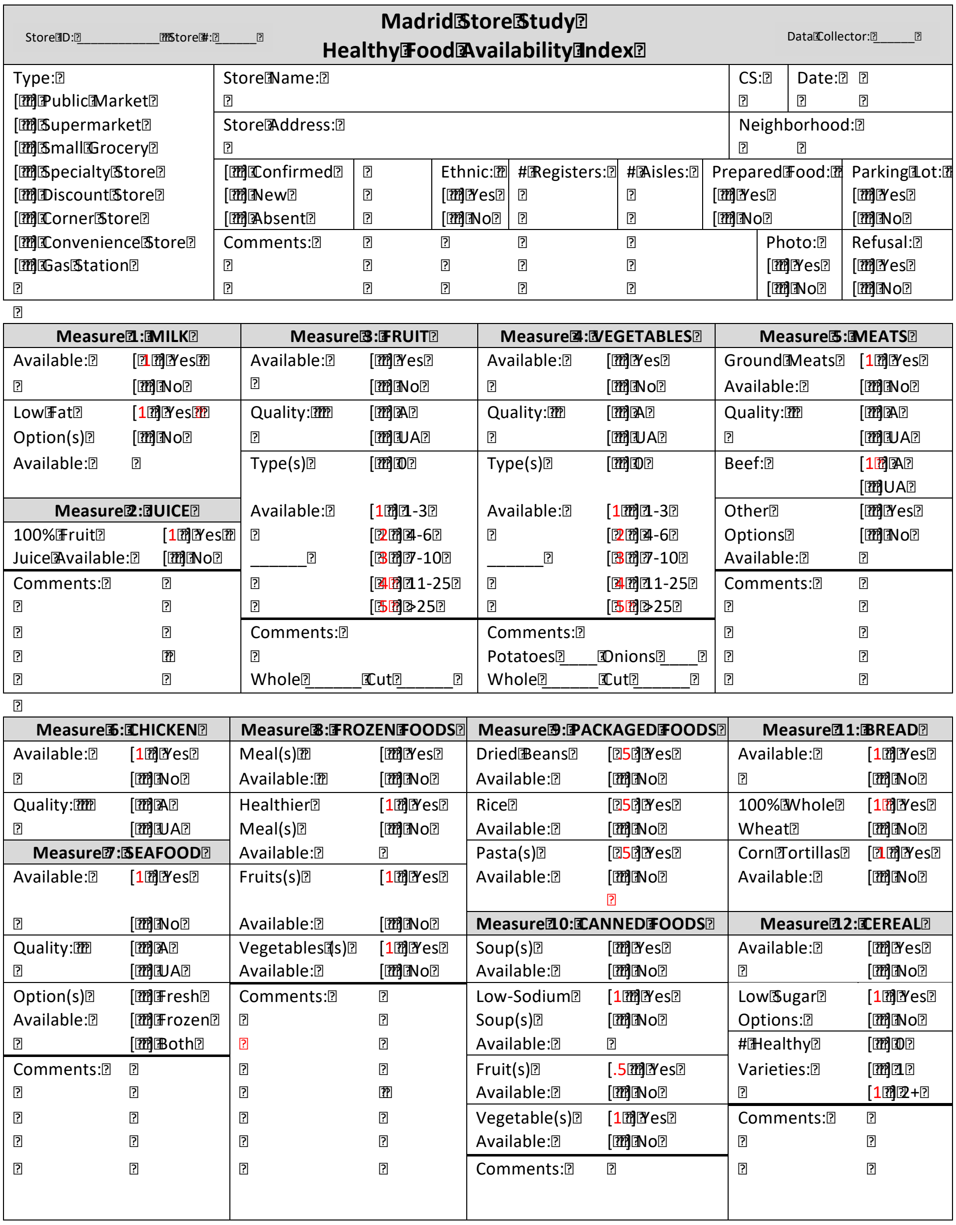
Variables

For the four variables, we used % population aged 65 or above as the demographic indicator, % people with college education or above as the socioeconomic indicator, % foreign-born as the segregation indicator, and population density (in sq. km) as the urban form indicator. The unit of analysis was the census section (around 1500 people).

Selecting Average Neighborhoods

To select average neighborhoods, we look for clusters of spatial units of analysis of the desired size. For example, if the unit of analysis is the census sections and we seek an area of 15,000 people, we must seek clusters of a maximum of 12 census sections. We use Kulldorf's Spatial Scan Statistic (Kuldorff 1997). This method allows for the search of clusters of cases, normally distributed variables or other distributions. Given the normally distributed nature of the MNI, we looked for clusters of low MNI values. The Kulldorf's Spatial Scan Statistic also allows for the setting of a maximum cluster size. Given that this statistic requires for spatial point data to be used, we calculated the centroids of each spatial unit of analysis prior to the cluster search.

ANNEX 7. Adapted NEMS-S audit tool



Store ID: ____________ Store #: ______	Madrid Store Study Healthy Food Availability Index	Data Collector: ______

Type:	Store Name:					CS:	Date:
[ ] Public Market [ ] Supermarket [ ] Small Grocery	Store Address:					Neighborhood:	
[ ] Specialty Store [ ] Discount Store [ ] Corner Store	[ ] Confirmed [ ] New [ ] Absent	Ethnic: [ ] Yes [ ] No	# Registers:	# Aisles:	Prepared Food: [ ] Yes [ ] No	Parking Lot: [ ] Yes [ ] No	
[ ] Convenience Store [ ] Gas Station	Comments:					Photo: [ ] Yes [ ] No	Refusal: [ ] Yes [ ] No

Measure 1: MILK	Measure 3: FRUIT	Measure 4: VEGETABLES	Measure 5: MEATS
Available: [1] Yes [ ] No	Available: [ ] Yes [ ] No	Available: [ ] Yes [ ] No	Ground Meats Available: [1] Yes [ ] No
Low Fat Option(s) Available: [1] Yes [ ] No	Quality: [ ] A [ ] UA	Quality: [ ] A [ ] UA	Quality: [ ] A [ ] UA
	Type(s) [ ] 0	Type(s) [ ] 0	Beef: [1] A [ ] UA
Measure 2: JUICE	Available: ______ [1] 1-3 [2] 4-6 [3] 7-10 [4] 11-25 [5] >25	Available: ______ [1] 1-3 [2] 4-6 [3] 7-10 [4] 11-25 [5] >25	Other Options Available: [ ] Yes [ ] No
100% Fruit Juice Available: [1] Yes [ ] No			
Comments:	Comments: Whole ______ Cut ______	Comments: Potatoes ____ Onions ____ Whole ______ Cut ______	Comments:

Measure 6: CHICKEN	Measure 8: FROZEN FOODS	Measure 9: PACKAGED FOODS	Measure 11: BREAD
Available: [1] Yes [ ] No	Meal(s) Available: [ ] Yes [ ] No	Dried Beans Available: [5] Yes [ ] No	Available: [1] Yes [ ] No
Quality: [ ] A [ ] UA	Healthier Meal(s) Available: [1] Yes [ ] No	Rice Available: [5] Yes [ ] No	100% Whole Wheat [1] Yes [ ] No
Measure 7: SEAFOOD		Pasta(s) Available: [5] Yes [ ] No	Corn Tortillas Available: [1] Yes [ ] No
Available: [1] Yes [ ] No	Fruits(s) Available: [1] Yes [ ] No		
Quality: [ ] A [ ] UA	Vegetables(s) Available: [1] Yes [ ] No	**Measure 10: CANNED FOODS**	**Measure 12: CEREAL**
		Soup(s) Available: [ ] Yes [ ] No	Available: [ ] Yes [ ] No
Option(s) Available: [ ] Fresh [ ] Frozen [ ] Both	Comments:	Low-Sodium Soup(s) Available: [1] Yes [ ] No	Low Sugar Options: [1] Yes [ ] No
Comments:		Fruit(s) Available: [.5] Yes [ ] No	# Healthy Varieties: [ ] 0 [ ] 1 [1] 2+
		Vegetable(s) Available: [1] Yes [ ] No	Comments:
		Comments:	

Adaptations (from the Abridged NEMS version produced by the CLF [available at http://mdfoodsystemmap.org/):

- +1 For Ground beef available changed to +1 For any ground meat
- +1 for Lean ground beef changed to +1 for beef
- .5 for frozen fruits or vegetables changed to +1 for each
- +1 if any of dried beans, rice or pasta available, changed to +0.5 for each

ANNEX 8. Additional information on the operationalization of variables in study 3 (Intersection of neighborhood dynamics and socioeconomic status in small-area walkability: The Heart Healthy Hoods project)

SES indicators

The two education indicators were obtained from the Padron, a continuous census of the entire population used for administrative purposes. The three occupation indicators (part time jobs, temporal jobs, and manual occupation class) were obtained from the Social Security data; the denominator was the total number of workers. Property value was obtained from the Idealista Report, a yearly study of neighborhood-level sale prices of all housing sold through the biggest real state corporation in Spain (Idealista). Property value data from the IDEALISTA Report contains data for all houses listed for sale in their website on the first day of each year. The report contains data at the neighborhood level (n=128 each year). To translate this to the census section level, we obtained data from the IDEALISTA API (http://developers.idealista.com/access-request) on April 18th 2016. We collected all housing units for sale on that day, including their price, size and geocoded location. We overlayed a census section polygon file and assigned each housing unit to a census section. With this, we constructed a measure of average property value per census section for 2016. We then used a weighted linear mixed model with property value at the census section as the dependent variable, and property value at the neighborhood level (from the IDEALISTA Report 2016 data) as a fixed and random coefficient (at the neighborhood level ,with an unstructured covariance structure), and the following fixed effects for each census section: % low education, % high education, % immigration from non-oecd countries, % people below age 25, % people above age 25, and a quadratic fixed term for each indicator. Each observation was weighted by the number of housing units on sale on each census section. We then predicted the property value in each census section in 2014 by replacing the data above with the respective data from 2014. To diagnose this imputation we correlated the predicted values for 2016 with the observed values in 2016, finding a pearson correlation coefficient of 0.93. Registered unemployment was obtained from the statistics of the Employment Service (SEPE); the denominator was, given the lack of a better measure for the active population at this level, the amount of people between 16 and 64 years of age in the neighborhood, obtained from the Padron. All data was downloaded from the statistics website of the City Government of Madrid.

Neighborhood dynamics indicators

Gentrification was obtained by ranking all census sections in 2005 and in 2014 in terms of % residents with high education (university education or above) and computing the change in rank from 2005 to 2014, where we defined a gentrified neighborhood as those in the top 95% percentile of rank change. Education data for this calculation was obtained from Padron. Median year of construction of all housing units in the census section was obtained from the Cadastre (*Catastro*, a universal tax registry of all housing units). We created three categories: up to 1985, from 1985 to 1997, from 1997 onwards.

Walkability indicators

Residential Density was operationalized as occupied dwellings by km^2; occupied dwellings were obtained from housing census. Total residents' data for the Population Density indicator (Residents/km^2) was obtained from Padron. Retail and Service Destinations were obtained from the Retail Spaces Census at the Madrid Council Open Database, that includes data on economic activities of all occupied commercial spaces; from this dataset, we select the categories for Retail and Services (47, 53, 56, 85, 90,91, 92, 93, 96 categories). For street connectivity, we calculated a Kernel Density Estimation (KDE) in 3mx3m pixels of the density of street intersections, resulting on a pixel-based surface. KDE fits a mathematical surface (composed of pixels) with a normal distribution over each point based on (a) the value empirically collected for each point, and (b) the distance from each location in the surface to all points in the area within defined radius or bandwidth. Essentially, the value of each point is smoothed over the study area producing a density value that will be the highest at the location of every point, and decaying from there with distance using a defined bandwidth. We used de KDE integrated in ArcGis 10.1 software which employs the quadratic Kernel function of Silverman:

$$f(x) = \frac{1}{nh} + \sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right)$$

where K is the quadratic Kernel function defined by $K(x) = \frac{3}{4}(1 - x^2)$, x ≤ 1, “x” is the point at which density is estimated, “xi” is the value of the variable in the case “i”, “n” is the number of cases and “h” is the bandwidth. The basic idea consists calculated for specific points, the averaged sum (hence the estimator involves summing over “n” and then divide by this value) of Kernels centered on the observations.

ANNEX 9. Additional descriptive table Madrid Census section sociodemographic and walkability indicators according to socioeconomic status (SES) tertiles (N = 2415)

Census section sociodemographic and walkability indicators according to SES tertiles (N=2415)

Census section characteristic	Census section Socioeconomic Status			
	Tertile 1 (Low SES)	Tertile 2 (Mid SES)	Tertile 3 (High SES)	Overall
N	805	805	805	2415
Population	1186.0(967.0;1447.0)	1211.0(948.0;1544.0)	1269.0(1013.0;1628.0)	1216.0(973.0;1544.0)
SES indicators				
% of low Education	70.2(64.9;75.9)	49.7(41.1;57.2)	24.9(19.2;31.5)	49.5(30.0;66.1)
% of high Education	11.5(8.1;15.0)	27.0(21.0;34.6)	52.4(45.7;59.5)	27.0(14.2;46.9)
% of part time Jobs	28.1(27.1;30.8)	24.0(20.8;26.7)	16.6(14.9;17.8)	22.9(17.6;27.7)
% of temporal Jobs	22.3(21.2;23.1)	20.6(19.2;21.6)	17.5(15.4;18.7)	20.3(17.8;21.8)
% of manual Occupation Class	42.0(39.5;47.0)	35.9(30.5;37.4)	23.0(19.0;24.9)	35.9(24.9;40.0)
Housing Prices 10^3 €/m^2	1.6(1.4;1.8)	2.3(2.1;2.6)	3.6(3.3;4.2)	2.3(1.8;3.3)
Unemployment Rate	14.7(13.5;16.1)	12.1(10.9;12.8)	8.1(6.9;9.1)	12.1(9.1;13.9)
SES Index	-0.9(-1.2;-0.7)	-0.1(-0.3;0.2)	1.0(0.8;1.3)	-0.1(-0.7;0.8)
Walkability indicators				
Residential Density (10^3 res/km^2)	12.7(8.6;18.1)	13.2(7.7;19.9)	12.2(5.8;20.4)	12.8(7.5;19.4)
Population Density (10^3 pop/km^2)	33.8(23.3;45.4)	30.8(19.6;45.0)	29.6(15.3;46.5)	31.8(19.4;45.5)
Retail Destinations Density (retail/km^2)	419.6(159.9;879.5)	474.8(186.7;1259.5)	669.6(189.5;1440.7)	484.6(175.7;1169.7)
Street Connectivity (Kernel Density)	0.2(0.1;0.3)	0.2(0.1;0.3)	0.1(0.1;0.2)	0.2(0.1;0.3)
Walkability Index	0.6(-1.1;2.1)	0.4(-1.7;2.2)	0.1(-2.3;2.1)	0.4(-1.8;2.1)
Neighborhood Dynamics				
% Gentrified in the last 10 years	2.90%	8.20%	3.90%	5.00%
% Median Year of Construction < 1985	87.80%	80.20%	80.40%	82.80%
% Median Year of Construction 1985-1997	8.90%	8.60%	9.90%	9.20%
% Median Year of Construction > 1997	3.20%	11.20%	9.70%	8.00%

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