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Apolline Saucy, Natalia Ortega, Cathryn Tonne

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Residential relocation to assess impact of changes in the living environment on cardio-respiratory health: a narrative literature review with considerations for exposome research

Authors: Apolline Saucy[1,2,3]*, Natalia Ortega[1,4,5]*, Cathryn Tonne[1,2,3]

[1] Barcelona Institute for Global Health (ISGlobal), Barcelona, Spain
[2] Universitat Pompeu Fabra, Barcelona, Spain
[3] CIBER Epidemiología y Salud Pública, Madrid, Spain
[4] Institute of Primary Health Care (BIHAM), University of Bern, Bern, Switzerland
[5] Population Health Laboratory (#PopHealthLab), University of Fribourg, Fribourg, Switzerland
* Equal contribution

Corresponding authors: Cathryn Tonne; Apolline Saucy
Emails: cathryn.tonne@isglobal.org; apolline.saucy@isglobal.org
Direction: C/ Doctor Aiguader, 88. 08003. BarcelonaPhone: +34 93 214 7300

Abstract

Residential relocation studies have become increasingly valuable tools for evaluating the effects of changing living environments on human health, but little is known about their application to multiple aspects of the living environment and the most appropriate methodology. This narrative review explores the utility of residential relocation as a natural experiment for studying the impact of changing urban exposures on cardio-metabolic health in high-income settings. It provides a comprehensive overview of the use of residential relocation studies, evaluates their methodological approaches, and synthesizes findings related to health behaviors and cardio-metabolic outcomes. Our search identified 43 relevant studies published between January 1995 and February 2023, from eight countries, predominantly the USA, Canada, and Australia. The majority of eligible studies were published between 2012 and 2021 and examined changes in various domains of the living environment, such as walkability, the built and social environments, but rarely combinations of exposures. Included studies displayed heterogeneity in design and outcomes, 25 involving only movers and 18 considering both movers and non-movers. To mitigate the issue of residential self-selection bias, most studies employed a "change-in-change" design and adjusted for baseline covariates but only a fraction of them accounted for time-varying confounding. Relocation causes simultaneous changes in various features of the living environment, which presents an opportunity for exposome research to establish causal relationships, using large datasets with increased statistical power and a wide range of health outcomes, behaviors and biomarkers. Residential relocation is not a random process. Thus, studies focusing on living environment characteristics need to carefully select time-varying covariates and reference group. Overall, this review informs future research by guiding choices in study design, data requirements, and statistical methodologies. Ultimately, it contributes to the advancement of the urban exposome field and enhances our understanding of the complex relationship between urban environments and human health.

Keywords: residential relocation; living environments; exposome; natural experiments; movers; cardiorespiratory health.

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1. Introduction

Despite a growing body of evidence supporting the impact of the living environment on human health (Buszkiewicz et al., 2021; Prochnow et al., 2023), most existing research still relies on observational study designs (Wing et al., 2018). Well-conducted randomized control trials provide the highest level of evidence to evaluate the health impact of environmental factors, but their application in the field of environmental exposures is often not feasible for practical and ethical reasons. Natural experiments or quasi-experimental designs appear particularly attractive to assess the effectiveness of environmental and urban planning interventions (Crane et al., 2020; Mayne et al., 2015). Such designs take advantage of changes in exposures due to phenomena outside of researchers' control (e.g., implementation of policies or urban plans, removal of pollution sources) to quantify associated changes in health behaviors or outcomes, while overcoming some common sources of bias in observational studies (Craig et al., 2012; Petticrew et al., 2005).

Among quasi-experimental study designs, so-called "relocation" or "movers" studies have recently gained popularity (Drewnowski et al., 2019). These studies exploit residential relocation – a frequent and naturally occurring event – as a source of exposure variation to assess the impact of changes in various aspects of the living environment on behavior and health, presenting several advantages. Compared to other studies focusing on naturally occurring changes over time at a given location (Kivimäki et al., 2021), relocation studies usually result in larger exposure changes (Craig et al., 2012). This study design also enables researchers to disentangle the impact of a change in living environment from socioeconomic and other spatial differences associated with environmental characteristics (Ding et al., 2018). As a result, well-designed relocation studies can better account for confounding due to residential self-selection compared to cross-sectional studies.

Despite a growing interest in relocation studies, the most appropriate methodological approaches, research questions, and application to multiple exposure changes remain unclear. Two previous literature reviews evaluating the use of relocation studies to assess the health impact of changes in air pollution (Edwards et al., 2022) and the built environment (Ding et al., 2018) highlighted frequent weakness in the study designs, with only a limited number of well-designed studies fitting their inclusion criteria. However, residential relocation usually implies a sudden change in multiple area-level environmental and social characteristics simultaneously, holding promise for exposome-based applications considering the totality of individual and environmental factors affecting health and well-being (Wild, 2012). Further, the recent increase in large cohort data with longitudinal designs, repeated outcome measurements and precise individual exposure assessment presents a unique opportunity to apply robust relocation studies to investigate multiple aspects of the living environment simultaneously using longitudinal data (Drewnowski et al., 2019; Hill, 1965).

The aim of this narrative review is to provide an overview of the application of residential relocation as a natural experiment to investigate the impact of changes in the built, physical-chemical and social environments on cardio-metabolic health behaviors and outcomes. Specifically, our three objectives were (i) to summarize the use of residential relocation as a natural experiment to evaluate change in urban environments; (ii) to evaluate the methodological approaches applied in the selected relocation studies; and (iii) to synthesize the findings of relocation studies focusing on health behaviors and cardio-metabolic health outcomes. This narrative review focuses on one particular study design – relocation studies – and is therefore not designed for assessing the level of evidence in each exposure-outcome pair. Instead, we extracted a range of indicators (e.g. study design, study population, statistical method, comparison groups, adjusting for time-varying variables) to understand the methodological requirements for conducting high-quality residential relocation studies. Our review aims to inform future studies on the choice of study design, data requirements, and statistical approaches to conduct robust residential relocation studies and their application to the urban exposome (Vlaanderen et al., 2021).

2. Methods

2.1. Eligibility criteria

As part of the EXPANSE project investigating the impact of the urban exposome on cardiorespiratory health, this review focuses on studies generalizable to the European population. We limited the review scope to studies focusing on behaviors and outcomes related to cardiorespiratory health. We included studies that: (i) used residential relocation as a natural experiment; (ii) were based on long-term and voluntary residential relocation; (iii) were carried out in a high-income country; (iv) assessed changes in environmental exposures and their effect on health behaviors or cardiometabolic health outcomes. In this review, we were interested in the application of relocation studies as a natural experiment, where moving is used as a proxy for a change in the urban exposome. Forced relocation is more likely to directly affect health, and less well suited to investigate changes in the urban exposome. We did not include studies where moving was randomized or happened after a natural disaster. We also excluded studies that considered moving alone as exposure of interest (i.e. did not consider environmental exposures) but did not set a limit on the magnitude of change in urbanization grade, environmental exposures or individual socioeconomic factors. If a study performed several analyses, we reported only those corresponding to our selection criteria. Details on inclusion and exclusion criteria are described in Table 1.

Table 1: Inclusion and exclusion criteria for the narrative literature review.

Criteria	*Inclusion*	*Exclusion*
Population	• *Human population of all ages in high-income countries*	• *Studies taking place in middle- and low-income countries*
Exposure	• *Changes in all aspects of the physio-chemical, built, and social environment*	• *Non-environmental exposures such as housing characteristics, medication etc.*
Outcome	• *Cardiometabolic health outcomes, including health indicators and biomarkers, as well as health-related behaviors such as physical activity and active transport.*	• *Studies focusing on all-cause mortality* • *Car ownership as principal outcome*
Comparison	• *Change in environmental exposures using within-person or between-persons comparison using moving and non-moving population*	• *Movers not included in the analysis* • *Studies focusing on effect of relocation as main explanatory variable*
Study type	• *Human epidemiological studies*	• *Book or book chapters* • *Abstracts and conference papers* • *Reviews*
Setting	• *Naturally occurring residential relocation* • *Relocation used as a natural experiment* • Long-term and voluntary relocation	• *Intervention studies* • *Relocation following a natural disaster* • *Studies focusing on exposure changes occurring over time at a given location* • Short stays or holidays (e.g. internships or short-term professional trips< 1 year) • Forced relocation (e.g. studies focusing on refugee populations)

2.2. Literature search

We conducted a search in OvidMEDLINE R, EBSCO and Scopus to identify relevant articles published from January 1995 until up to end of February 2023. Our search strategy included: (residential relocation or ((relocat* or mov* or chang*) adj3 (residen* or hous* or neighbo?rhood*)).mp. or (moving adj2 opportunity).tw. or (residen* adj3 mobil*).mp.) AND (Body Mass Index/ or Obesity/ or Overweight/ or Stroke Volume/ or Respiratory Function Tests/ or Chronic Obstructive Pulmonary Disease/ or Diabetes Mellitus, Type 2/ or Stroke/ or Myocardial Ischemia/ or Hypertension/ or Waist Circumference/ or Cardiovascular disease/ or Health behaviour/ or Smoking/ or Exercise/ or Sedentary behaviour/ or Diet/ or Feeding Behavior/ or Behavior and Behavior Mechanisms/ or Socioeconomic factor/ or Educational Status/ or Ethnic Groups/ or Health Status/ or Built environment/), which format was adapted for searching the different databases (**Appendix**). After performing a screening of the titles and abstracts to eliminate studies that did not fit our research questions, we reviewed the full text of the previously selected articles and removed irrelevant studies. Relevant citations in the selected articles were also included in the review. Finally, eligible publications addressing at least one of our research questions were included in the review. Screening and data extraction for articles published until end of 2021 were performed separately by the two first authors. One author additionally screened and extracted the data for the most recent publications. References were managed using Mendeley Desktop, version 1.19.8.

2.3. Data extraction

We developed tools to extract data from studies using residential relocation to assess the impact of aspects of the external exposome on cardiorespiratory health relative to our three research objectives. To assess the general use of residential relocation as a natural experiment in the context of our review (objective 1) we collected information on the publication year, the country where the study was conducted and whether the specific study was part of a larger research project, exposures and outcomes of interest, relocation rates, moving distances, cohort type, temporal extent of the study, and the study population. As part of objective 2, we collected information on the study design, including the number of repeated measurements, the choice of comparison group(s), and the modelling approach including statistical models and selected covariates to assess the methodological approaches used in the selected studies. We also reported whether studies focused on single exposures or included multiple-exposures or exposome frameworks. Finally (objective 3), we collected information on the magnitude of changes in exposures due to residential relocation and reported the main findings for each exposure-outcome pair. Findings were considered “conclusive” if the study observed a statistically significant association of interest. Papers with suggestive associations or conclusive results on some but not all associations of interest were considered “partially conclusive”. This evaluation was not based on the quality of the study but was useful to compare findings of studies with different designs, strengths and limitations.

Our primary search led to 1,160 non-duplicated article entries, of which 22 were identified through citations in other papers and 1,110 were excluded after the first abstract and title screening, leading to 50 records for full text assessment. We excluded 2 randomized experiments as residential relocation is controlled by the design, and 5 further studies that did not use relocation as a natural experiment or focused on car ownership, to end up with 43 included articles (**Figure 1**).

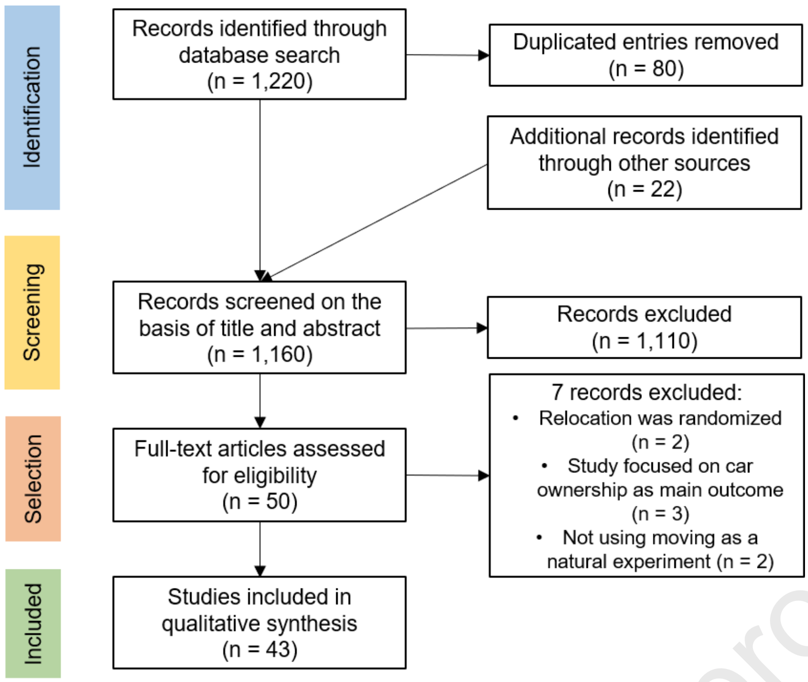

Figure 1. Flow diagram of the search strategy and selection process. The identification phase refers to the search of 3 databases and additional records identified through references and other sources. Screening was based on title and abstract only. Selection was based on 50 full-text articles, from which 30 were included in this review.

3. Results

3.1. Study characteristics

Selected studies originated from populations in eight countries, including the USA (n=14), Canada (n=9), and Australia (n=7). We found more studies fitting our inclusion criteria in the second half of the temporal extent of our search (2012-2021) compared to earlier years (**Table 2**). **Figure 2** shows the geographical and temporal distributions of included studies. Some specific research projects or datasets contributed to several of the studies included in this review. Notably, 6 included studies originated from the RESIDE (RESIDential Environment Project, Australia, published between 2012 and 2020); 4 from a survey to residents of eight neighborhoods in Northern California (USA, 2005-2008); 3 from Alberta's Tomorrow Project (Canada, 2021-2023); and 2 from the Dallas Heart Study (USA, 2105-2017) (Supplementary Table 1).

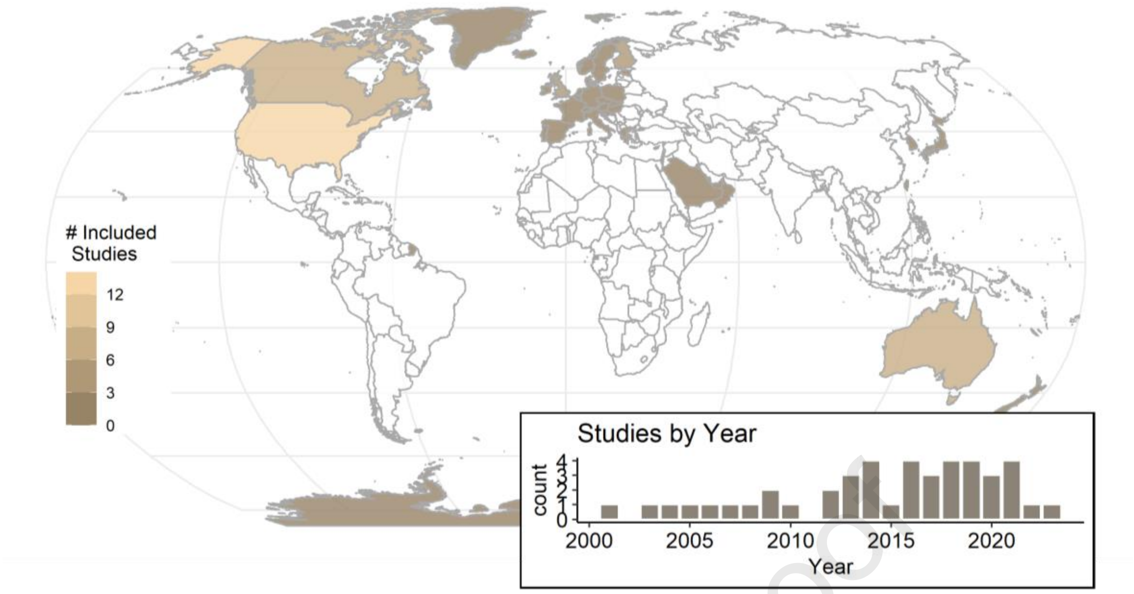

Figure 2. Overview of the spatial distribution and publication years of the selected studies. Lighter shading represents a higher number of studies. Countries excluded from the review are transparent.

Twenty-five studies focused exclusively on movers and 18 included both movers and non-movers. Thirty-two studies investigated health behaviors, 12 investigated health outcomes, and two included both outcome types. Most studies on health behaviors (n=28) focused on physical activity and transport behaviors; two focused on diet. Health outcomes included cardiometabolic health, mortality, and respiratory health (**Figure 3**). One study (Kivimäki et al., 2021) investigated the impact of changes in neighborhood characteristics on 79 health outcomes. Thirty-two studies used a prospective study design, while 12 were retrospective. All studies using a retrospective design focused on physical activity or transport behavior as main outcome, while the outcomes were more varied in prospective studies (Supplementary Figure 1).

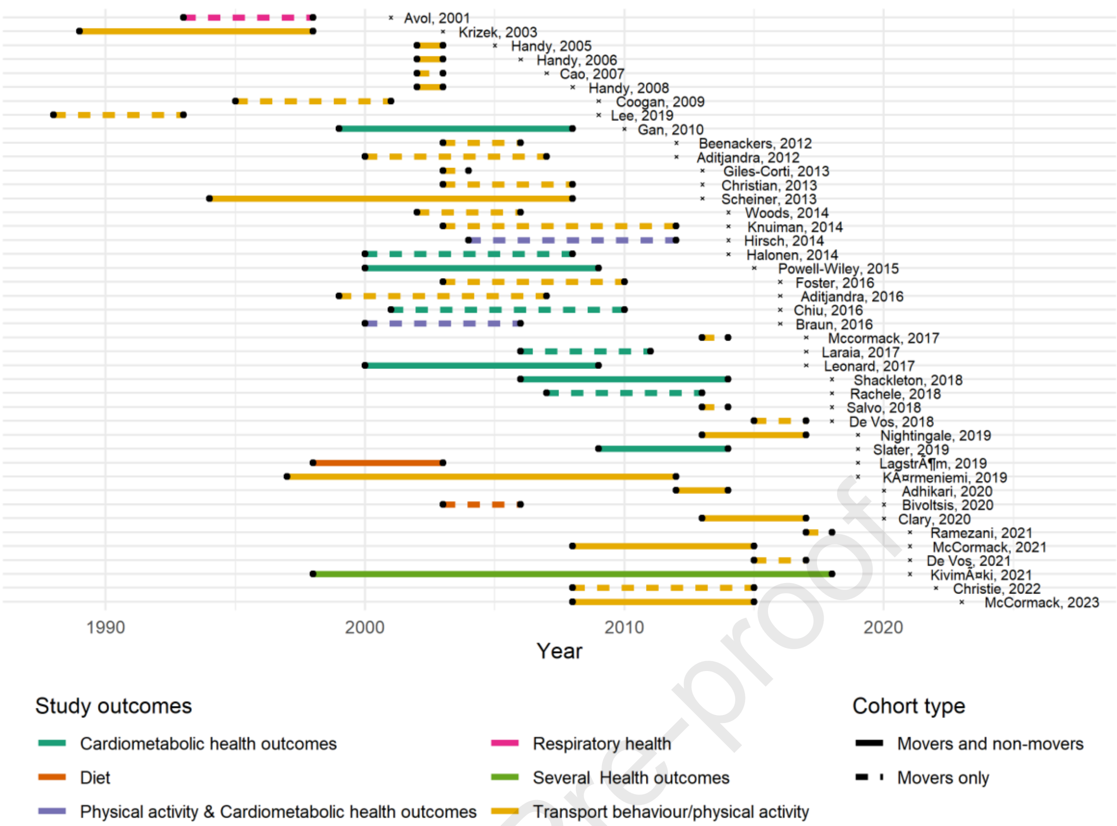

Figure **3:** Overview of the included studies by publication year (cross), temporal extent of the data used in the analyses (horizontal lines), cohort type and study outcomes. References include the first author and year of publication.

Studies covered multiple aspects of the living environment. Most studies focused on walkability and neighborhood accessibility (43%) and various aspects of the built and social environments (18%). Other studies investigated neighborhood deprivation (11%) and urbanization grade (11%) while few concentrated on specific elements of the built environment, including safety, food environment and road traffic and pollution (5% each) and 1 study focused on green and blue space **(Figure 4)**.

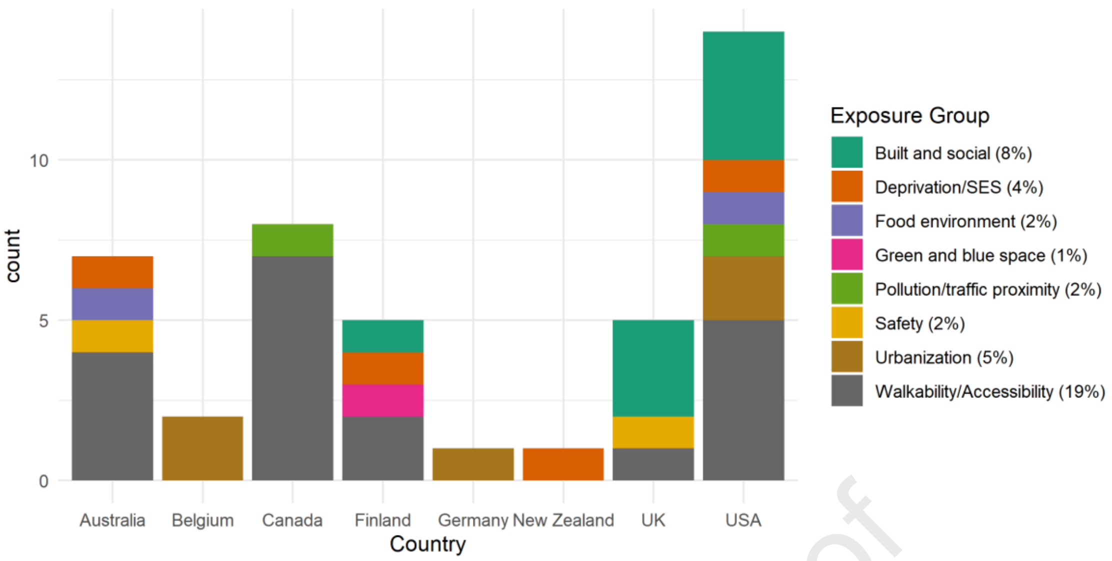

Figure 4: Dimensions of the living environment explored in the included studies by country.

Studies assessed residential relocation during follow-up periods ranging from 10 months (Adhikari et al., 2020) to 15 years (Kärmeniemi et al., 2019). Overall, follow-up times were longer for studies focusing on health outcomes compared to those investigating changes in health behaviors (Supplementary Table 2). Among the studies including movers and non-movers in their design, relocation rates ranged between 5% (Gavin R McCormack et al., 2021, 2023) and 53% (Lagström et al., 2019), with an average relocation rate of 5.7% per year. The large variation in relocation rates can be explained by differences in follow-up periods, but also the study design, given that some studies used representative samples of the general population while others focused on specific groups or explicitly selected the study population to contain a large percentage of movers. For example, one study specifically recruited non-movers for matching with the included movers, based on a range of individual and geographical characteristics (Adhikari et al., 2020). Only a single study reported distance of relocation (Krizek, 2003): 20% of the study population relocated within 2.5 miles. However, most studies included only participants that moved within a defined study area; participants moving outside of the study area were considered as lost to follow-up (Ramezani et al., 2021).

Table 2. Included studies characteristics (n=43)

Reference	Country	Project/Dataset	N	Exposure(s)	Outcome (s)	Assoc. Found	Cohort/Data collection
McCormack, 2023	Canada	Alberta's Tomorrow Project	5977	neighborhood walkability	walking: weekly minutes of leisure, transportation, and total walking at follow-up (International Physical Activity Questionnaire (IPAQ) captured self-reported walking)	Partially	prospective
Christie, 2022	Canada	Alberta's Tomorrow Project	703	neighborhood walkability	walking (International Physical Activity Questionnaire (IPAQ), minutes walked per week)	Partially	prospective
De Vos, 2021	Belgium	Online survey	1650	residential neighbourhood (level of urbanization)	travel mode (frequency of car, public transport, cycling and walking)	Yes	retrospective
Ramezani, 2021	Finland	Online map-based survey	1321	changes in the built environment (land use mix, population density, job density, and distance from home to work and non-work places)	changes in the use of different modes of transport	Yes	retrospective
McCormack, 2021	Canada	Alberta's Tomorrow Project	5944	street layout integration	physical activity from the International Physical Activity Questionnaire (IPAQ)	Yes	prospective
Kivimäki, 2021	Finland	Health and Social Support study & Finnish Public Sector study	114786	changes in neighbourhood characteristics (neighbourhood socioeconomic composition (education, income, and unemployment) and an index of green space)	79 common health condition	Yes	prospective
Adhikari, 2020	Canada	CHANGE study (Changes in Health, Activity, and Nutrition across Geographic Environments)	223	urban form (walkability & regional accessibility)	travel behaviour (trip frequency by different modes (auto, transit, and walk))	Yes	prospective
Bivoltsis, 2020	Australia	RESIDE (RESIDential Environment Project)	1200	local food environment	changes in dietary outcomes	Yes	prospective
Clary, 2020	UK	ENABLE London study (Examining Neighbourhood Activities in Built Living Environments in London)	1278	change in built environment (walkability, park proximity and public transport accessibility)	Daily steps	Partially	prospective
Slater, 2019	USA	WAVES (Weight and Veterans' Environments Study)	1700000	Recreational facilities	BMI	No	prospective
Lagström, 2019	Finland	HeSSup (Health and Social Support)	8818	neighborhood SES	adherence to dietary recommendations	Yes	prospective
Kärmeniemi, 2019	Finland	Northern Finland Birth Cohort	5947	density, mixed land use and access networks (DMA)	walking and cycling and objectively measured physical activity	Yes	prospective

Nightingale, 2019	UK	ENABLE London study (Examining Neighbourhood Activities in Built Living Environments in London)	877	Moving to East Village	walking (average daily steps)	No	prospective
De Vos, 2018	Belgium	Existing Internet survey on travel behaviour of recently relocated people within the city of Ghent, Belgium	1539	change in urbanization on a scale from 1 (far less urbanized) to 5 (far more urbanised)	mode frequency and travel attitudes	Yes	retrospective
Salvo, 2018	Canada	Existing random sample of Calgary households	97	Walkability	changes in transportation walking, transportation cycling, and overall physical activity	No	retrospective
Shackleton, 2018	New Zealand	Cohort based on data from using Primary Health Organisation	2418397	neighborhood socioeconomic deprivation	Cardiovascular Disease (hospitalization or death)	Yes	prospective
Rachele, 2018	Australia	HABITAT Study (How Areas in Brisbane Influence Health and Activity)	928	neighborhood disadvantage	BMI	No	prospective
Laraia, 2017	USA	Kaiser Permanente Diabetes Registry	35108	food environment	BMI	No	prospective
Mccormack, 2017	Canada	Pathways to Health (cross-sectional survey)	915	Walkability	transportation mode (walking, cycling, overall physical activity)	Yes	retrospective
Leonard, 2017	USA	Dallas Heart Study (DHS)	1253	change in neighborhood condition	BMI	Yes	prospective
Foster, 2016	Australia	RESIDE (RESIDential Environment Project)	1813	neighborhood crime-related safety	walking	Yes	prospective
Braun, 2016	USA	CARDIA study, a population-based prospective epidemiologic study of the determinants and evolution of cardiovascular risk factors in young adults	1079	Walkability	walking, BMI, waist circumference, blood pressure, insulin resistance, triglycerides, cholesterol, atherogenic dyslipidemia, and C-reactive protein	Yes	prospective
Chiu, 2016	Canada	Canadian Community Health Survey	2114	Walkability	hypertension	Yes	prospective
Aditjandra, 2016	UK	Cohort with data derived from British Census data	219	neighborhood design characteristics	travel mode choice (public transport and walking)	Yes	retrospective
Powell-Wiley, 2015	USA	Dallas Heart Study (DHS)	1835	neighborhood deprivation	body weight	Yes	prospective
Knuiman, 2014	Australia	RESIDE (RESIDential Environment Project)	1703	neighborhood walkability and destination accessibility	walking for transportation	Yes	prospective
Woods, 2014	UK	Current and retrospective recall survey of households in Glasgow and Edinburgh	281	changes in urban form (residential population density, land use mix, distance to city center)	change in car use	Yes	retrospective
Hirsch, 2014	USA	MESA (Multi-Ethnic Study of Atherosclerosis study)	701	neighborhood walkability	walking & BMI	Partially	prospective

Halonen, 2014	Finland	Finnish Public Sector study	3302	proximity of urban green or blue areas	BMI	Yes	prospective
Giles-Corti, 2013	Australia	RESIDE (RESIDential Environment Project)	1420	neighborhood characteristics	walking	Yes	prospective
Scheiner, 2013	Germany	German Mobility Panel (GMP)	6932	changes in urbanity and public transport	changes in travel mode	Partially	prospective
Christian, 2013	Australia	RESIDE (RESIDential Environment Project)	1047	type of development	walking	No	prospective
Aditjandra, 2012	UK	Survey to inhabitants from ten neighbourhoods selected to represent five Districts of Tyne and Wear metropolitan area in the North East of England.	219	neighbourhood characteristics	travel choice	Yes	retrospective
Beenackers, 2012	Australia	RESIDE (RESIDential Environment Project)	1427	neighborhood environment	transport and recreational cycling	Yes	prospective
Gan, 2010	Canada	Cohort derived from administrative databases from British Columbia's universal health insurance system	414793	Residential proximity to traffic	coronary heart disease	Yes	prospective
Coogan, 2009	USA	Black Women's Health Study	2435	Housing density	physical activity	Yes	prospective
Lee, 2019	USA	Harvard Alumni Health Study	3448	changes in exposure to urban sprawl	physical activity	No	prospective
Handy, 2008	USA	Survey on transport behavior change among residents of 4 traditional and 4 suburban neighborhoods in Northern California	1352	Neighborhood design	physical activity	Yes	retrospective
Cao, 2007	USA	Survey on transport behavior change among residents of 4 traditional and 4 suburban neighborhoods in Northern California	547	change in built environment	change in travel behaviour	Yes	retrospective
Handy, 2006	USA	Survey on transport behavior change among residents of 4 traditional and 4 suburban neighborhoods in Northern California	1328	change in built environment	change in physical activity (walking and biking)	Yes	retrospective
Handy, 2005	USA	Survey on transport behavior change among residents of 4 traditional and 4 suburban neighborhoods in Northern California	1490	change in built environment	change in travel behaviour	Yes	retrospective
Krizek, 2003	USA	PSTP (Puget Sound Transportation Panel)	6144	changes in urban form (neighborhood and regional accessibility)	changes in household travel	Partially	prospective

Avol, 2001	USA	CHS (The Children's Health Study)	110	Annual average daily ambient pollution (NO_2, PM_{10}, O_3)	lung function	Yes	prospective

3.2. Analytical approaches used in residential relocation studies

3.2.1. Design and target populations

We found a large variety of methodological approaches, which could be categorized into two main groups: studies including only movers (**Table 3**) and those who include both movers and non-movers in their analyses (**Table 4**). Studies focusing on movers and non-movers tended to have larger sample sizes. In both groups, most studies included two or few repeated exposure and outcome measurements. Two studies included up to 6 repeated measurements (Lagström et al., 2019; Slater et al., 2019), and three studies included continuous outcomes (Chiu et al., 2016; Kivimäki et al., 2021) and/or exposures (Kärmeniemi et al., 2019; Shackleton et al., 2018) to investigate trajectories in the living environment upon relocation (repeated exposures) or time to events (repeated outcomes).

3.2.2. Statistical methods

Overall, standard regression models were the most common approach in both studies restricted to movers and those including movers and non-movers and three further studies used Cox proportional hazard models to investigate the impact of changes in the living environment on the risk of one or several health outcomes (Chiu et al., 2016; Kivimäki et al., 2021; Shackleton et al., 2018). Among the studies focusing on movers only, five used structural equation modeling (SEM), all of which explored the effect of changes in the built environment on travel behavior (P T Aditjandra et al., 2012; Paulus Teguh Aditjandra et al., 2016; Cao et al., 2007; J De Vos et al., 2021; Ramezani et al., 2021). Five other studies focused on movers used fixed-effects models (Braun et al., 2016; Christie et al., 2022; Hirsch et al., 2014; Knuiman et al., 2014; Laraia et al., 2017), one used a marginal repeated measures model (Foster et al., 2016), one used t-tests (Salvo et al., 2018) and one used a combination of multilevel regression analysis and hybrid models (Rachele et al., 2018). Among studies including both movers and non-movers, methods included difference-in-differences analyses to investigate changes in body weight (Leonard et al., 2017; Powell-Wiley et al., 2015), Fisher's exact test (Kärmeniemi et al., 2019), and generalized estimating equations (Scheiner & Holz-Rau, 2013).

Most studies focused on one or few aspects of the living environment. Few included both the built and social environment in their analyses, either investigating each environmental characteristic separately (Kivimäki et al., 2021), using a composite indicator (Leonard et al., 2017), including several environment characteristics in multivariable models with variable selection (Woods & Ferguson, 2014) or dimension reduction (S. L. Handy et al., 2008). None was conducted within an exposome framework.

3.2.3. Comparison groups & adjustment methods

Irrespective of the overall study design, most included studies conducted some type of "change in change" analyses, based on different modelling approaches:

- Calculating changes in exposures and outcomes between given timepoints: this is the most common approach, especially in studies focusing on 2 time-points or those with a retrospective study design;
- Creating exposures or outcomes trajectories (Kärmeniemi et al., 2019; Lagström et al., 2019; Shackleton et al., 2018);
- Assessing the impact of relocating to specific neighborhoods: (Nightingale et al., 2019) investigated the impact of moving to East Village on physical activity compared to non-movers;
- Regressing the outcome at follow-up on the baseline outcome and change in exposure (Clary et al., 2020);

- Using fixed-effects models: these models consider solely within-individual variability over time (Gunasekara et al., 2014) and therefore also fall under the broader category of "change in change" approaches.

Exceptions were studies focusing on the time to event, which focused on the risk of disease in association with change in the living environment.

Studies including both movers and non-movers usually use outcomes in non-movers as the comparator. In contrast, studies focusing on movers often use movers with little or no change in exposure upon moving as the reference group. Few studies used a combination of non-movers and movers with stable relocation trajectories as comparison group. Further methods were used to make the exposure and control groups more comparable, including baseline covariate adjustment (most studies) or further weighting (Gavin R McCormack et al., 2023) or matching methods (Adhikari et al., 2020; Chiu et al., 2016; Christian et al., 2013). Only a fraction of included studies adjusted for some time-varying confounding (**Tables 3 and 4**).

Table 3: Description of studies including only movers

Reference	Statistical approach	Analysis[1]	Comparison groups	Comparison groups simplified	Covariates	Include time-varying covariates
Christie, 2022	fixed-effects linear regression models to estimate associations between changes in built characteristics and minutes walked per week	FE	Within individuals with varying changes in built environment	Within-individual comparison	Changes in relationship status, presence of children at home, season of survey completion, follow-up IPAQ survey type	Yes, all
De Vos, 2021	structural equation modelling	SEM	Across individuals with varying changes in residential neighborhood upon relocation	Change in change	sociodemographics, change in car ownership and travel distance	Yes, car ownership and travel distance
Ramezani, 2021	Structural equation modelling used to investigate the interrelationships between changes in the built environment, activity space dispersion, car and bike ownership, travel attitudes, and travel behavior	SEM	Across individuals with varying changes in built environment upon relocation	Change in change	sociodemographics, change in: job, transport mode availability, household composition, physical limitations.	Yes, job, transport mode availability, household composition, and physical limitations
Bivoltsis, 2020	mixed models to examine each change variable (i.e. spatial exposures, individual behaviours and perceptions) for associations with change in each dietary outcome variable	ME	Across individuals with varying changes in dietary outcomes (change in change)	Change in change	age, gender, education level, marital status, hours of work per week, household income, children <18 years at home, access to a motor vehicle, physical activity, BMI	No
De Vos, 2018	multinomial logistic regressions to estimate the association between change in mode use and change in the level of urbanization	Multinomial logistic	Across individuals with varying urbanization relocation trajectories	Change in change	age, gender, educational, household income, children younger than eighteen living at home, driving license, household car possession	No
Salvo, 2018	independent t-tests to assess the relations between perceived change in transportation walking, transportation cycling, and overall physical activity and changes in walkability (“improvers” vs “decliners”)	T-tests	Improvers VS decliners	Change in change	none	No
Rachele, 2018	The association between changes in neighborhood disadvantage and changes in BMI was examined using 3-level mixed-effects linear regression models. multilevel, hybrid linear models	ME and hybrid models	Within individuals with varying changes in neighborhood disadvantage	between and within-person effects	age, education, occupation, household income, neighborhood self-selection	Yes, occupation and household income
Laraia, 2017	Fixed-effects models with a 1-year-lagged BMI	FE	Within individuals with varying changes in food environment	Within-individual comparison	age, Medicaid enrollment, Charlson comorbidity index, indicators of medication use, area-level characteristics (population density, proportion white, proportion black, proportion poor)	yes, all
Mccormack, 2017	propensity score covariate-adjusted Firth logistic regression Firth Binary Logistic Regression to estimate the likelihood of (1)	Logistic	Within individuals with varying changes in walkability	Change in change	propensity scores for walkability groups based on residential self-selection,	No, but propensity scores for relocation trajectories

[1] Abbreviations used for the simplified statistical analysis: Fixed-effects (FE); Structural Equation Models (SEM); Mixed-effects (ME).

	perceived increase versus no perceived change in physical activity and (2) perceived decrease versus no perceived change in physical activity for walkability improvers and walkability decliners relative to walkability maintainers (reference group).				sociodemographic, and health-related characteristics	
Braun, 2016	fixed-effects models to estimate the associations between within-person change in walkability resulting from residential relocation and within-person change in each health outcome of interest.	FE	Within individuals with varying changes in walkability	Within-individual comparison	Income, household size, marital status, employment status, smoking status, and general health status	yes, all
Chiu, 2016	(1) weighted logistic regression model to calculate propensity score for the probability of moving from a low- to a high-walkability postal code and match individuals from both groups (matched cohort) (2) Cox proportional hazards model to estimate the effect of moving to a high-walkability neighborhood on the hazard of incident hypertension.	Cox	Individuals who moved from low to high walkability VS those who moved from low to low (propensity score matching)	Change in exposure, risk of hypertension (matched cohort)	age; sex; education; marital status; immigrant status; race/ethnicity; current smoking; diabetes; BMI; psychosocial stress; inadequate leisure physical activity; alcohol consumption; inadequate fruit and vegetable consumption; area-based income urbanicity	yes, area-based income and urbanicity
Aditjandra, 2016	structural equations model methodology to investigate links between change in neighborhood design and chante in travel behavior	SEM	Across individuals with varying changes in neighborhood design characteristics	Change in change	gender, age, economic status, educational background, household in-come, household size, and number of children, as well as changes in household income, household size, and number of children, before and after household relocation, neighborhood characteristics, neighborhood preferences, travel attitudes	yes, household income, size and number of children
Foster, 2016	marginal repeated measures model with an unrestricted variance pattern across time points. Additional models were run that decomposed the safety from crime measure into between-person and within-person measures to separately estimate the cross-sectional and longitudinal effect.	marginal repeated measures model	Within and between individuals with varying levels of crime safety	Between and within-person effects	Demographics (gender, age, marital status, education, household income), time, self-selection (importance of safety from crime as a reason for neighbourhood selection at baseline), built and social environment, neighborhood perceptions	Yes, objective physical environmental measures
Halonen, 2014	Multilevel regression to examine the mean changes in BMI (continuous) between baseline and follow- up in relation to change in distance to green/blue area	ME	Across individuals with varying changes in distance to green and blue space (categorical)	Change in change	age, sex, level of education, chronic disease, neighborhood socioeconomic disadvantage, baseline BMI, smoking status, heavy alcohol use, physical inactivity	yes, unclear
Hirsch, 2014	fixed-effects models to estimate associations of within-person change in Walk Score with within-person changes in walking or BMI	FE	Within individuals with varying changes in neighborhood walkability	Within-individual comparison	age, income, working status, marital status, self-reported health, arthritis, cancer diagnosis, season	yes,all

Knuiman, 2014	Compared three models: (1) Marginal population-average model; (2) Conditional subject-level mixed model; (3) Conditional subject-level fixed-effect model; to examine the relationship of neighborhood walkability and destination accessibility with walking for transportation	FE	Across AND within individuals with varying neighborhood environment characteristics	Within-individual comparison	age, sex, marital status, educational level, occupation, hours of work per week, annual household income, number of adults in the household, children in the home, access to a motor vehicle	yes, all
Woods, 2014	Ordinal regression model to estimate the association between changes in urban form and in self-reported distance driven. Reported change in driving, measured on a Likert scale from "a lot less" to "a lot more," was entered as the dependent variable.	Ordinal regression	Across individuals with varying changes in urban form	Change in change	previous urban rural class, and changes in: accommodation type, driving license status, employment status, household income	yes, accommodation type, driving license status, employment status, household income
Christian, 2013	General linear models to examine the association between type of development and change in mean weekly minutes of neighborhood transportation, recreational, and total walking between time points (T1 - T2, T2 - T3, and T1 -T3). Conventional developments were matched to livable and hybrid developments using 3 criteria: stage of development (percentage vacant land), block value (which is an indicator of socioeconomic status), and proximity to the ocean.	ME	Across individuals with different types of housing developments (matched cohort)	Change in change (matched cohort)	baseline age; gender; education level; marital status; children at home; baseline minutes of recreational, transportation, or total walking; self-selection factors for choice of new neighborhood; and clustering within development	No
Giles-Corti, 2013	Generalized Linear Mixed Models (that included a random cluster effect to allow for clustering by (new) developments) to examine associations with changes in neighbourhood recreational and transport-related walking.	ME	Across individuals with varying changes in neighborhood environment	Change in change	Age, gender, marital status, children at home, education	yes, marital status, work status, level of education, children at home, hours worked and minutes travelled to work
Aditjandra, 2012	Structural equation modelling (change in change)	SEM	Across individuals with varying changes in neighborhood characteristics	Change in change	gender, age, economic status, educational background, household income, household size and number of children	Yes, household income, household size and number of children
Beenackers, 2012	Logistic regression models (with generalized estimating equations) were used to estimate the ORs for taking up cycling while accounting for clustering within neighborhoods (restricted to non-cycling at baseline)	Logistic	Across individuals with varying changes in the neighborhood environment	Change in change	age, gender, educational level, marital status, children aged <18, years living at home, access to a car	yes, but not changes in covariates not associated with changes in cycling and not included in the final models
Lee, 2019	Linear regression estimated the mean change in energy expended on all activities from 1988 to 1993. Parallel analyses examined changes in distance walked and BMI.	Linear	Men moving to higher or lower sprawl level, VS those movers who remained in the same sprawl level	Change in change	age, smoking, and baseline (1988) energy expenditure	Yes, age and smoking

Coogan, 2009	multinomial logistic regression generalized estimating equation models to estimate the odds that a woman changed her level of utilitarian walking or exercise walking among women who moved once during the follow-up period. Women who remained in the same quintile of housing density were used as a reference group.	ME	Women who moved to increased or decreased housing density VS those who moved to a similar housing density	Change in change	age, region, year, BMI, smoking status, alcohol intake, marital status, caregiver responsibilities, years of education, chronic disease, history of cancer at baseline (yes, no), energy intake, hours of TV viewing per day, percentage of vacant housing units, neighborhood socioeconomic status, crime index (quintiles).	Yes, all time-varying individual and census-block variables
Cao, 2007	Srtuctural equation modelling to investigate the relationships among changes in the built environment, changes in auto ownership, and changes in travel behavior. The	SEM	Across individuals with varying levels of change in built environment	Change in change	sex, age, income, household and family characteristics, preferred neighborhood characteristics	No
Avol, 2001	linear regression (annual average changes in lung function VS average changes in pollution)	Linear	Across individuals with varying levels of change in air pollution	Change in change	sex, race, CHS entry year, annual average change in height, weight and body mass index (BMI), and the interaction of sex with annual average change in height.	Yes, annual average change in height, weight and BMI

Table 4: Description of studies including movers and non-movers

Reference	**Statistical approach**	**Analysis**[2]	**Comparison groups**	**Comparison groups simplified**	**Covariates**	**Include time-varying covariates**
McCormack, 2023	Inverse-Probability-Weighted Regression to estimate differences [i.e., average treatment effects in the treated (ATET)] in weekly minutes of leisure, transportation, and total walking at follow-up between residential relocation groups	Inverse-probability-weighted regression	Individuals who moved to more or less walkability VS non-movers	Change in change (IPW to estimate ATET)	baseline walking, sociodemographic characteristics, season	No
Kivimäki, 2021	Cox proportional hazard regression models to compute adjusted hazard ratios (HRs) of incident disease associated with neighbourhood characteristics and changes in neighbourhood characteristics over time	Cox	Individuals who experienced favourable and defavourable neighborhood deprivation (movers and in-situ changes combined) VS individuals with stable disadvantaged or stable advantaged neighbourhoods	Change in neighborhood characteristics, risk of various conditions	age, sex, education, marital status, population density in the neighbourhood, place of residence (urban vs rural), and being in employment during the 5-year exposure period	No, but exclusion of individuals not fully employed during the 5-years exposure period
McCormack, 2021	(1) multivariable linear regression to regress follow-up minutes on baseline minutes of physical activity adjusted for elapsed time between surveys; (2) covariate-adjusted linear regression models to estimate the mean differences and 95 per cent confidence intervals	Linear	2 approaches: 1) Movers to more and less street integration VS non-movers & 2) across movers with different changes in street integration	Change in change	Baseline sociodemographic variables (sex, age, number of children < 18 years, education, annual gross household income, marital status, employment status)	No

[2] Abbreviations used for the simplified statistical analysis: Fixed-effects (FE); Structural Equation Models (SEM); Mixed-effects (ME); Difference-in-Differences (DiD); Ordinary Least Squares (OLS); Generalized Estimating Equations (GEE).

	(95CI) in residualized follow-up physical activity minutes (from [1]) between the three residential relocation groups using non-movers as the reference group; (3) estimated beta slope coefficients and 95CIs between absolute and relative street integration exposures and residualized follow-up physical activity minutes.					
Clary, 2020	multilevel linear regression models were used to examine the effect of changes in exposure on physical activity levels. Daily steps at follow-up were regressed on daily steps at baseline, change in built environment exposures and confounding variables using multilevel linear regression to assess if changes in neighbourhood walkability, park proximity and public transport accessibility were associated with changes in daily steps. We	ME (outcome at follow-up regressed against outcome at baseline, change in exposure and covariates)	Across individuals with varying changes in residential built environment without distinction on moving status (movers to East village, movers elsewhere and non-movers)	Change in change	sex, age group, ethnic group, aspirational housing tenure	No
Adhikari, 2020	ordinary least square (OLS) regression analyses to examine the effects of changes in neighborhood walkability on travel behaviors	OLS	Individuals who had a change in urban form VS those with no change (movers and non-movers combined). Movers were matched to non-movers on individual and baseline neighborhood characteristics.	Change in change (movers matched to non-movers)	baseline travel behavior and other socio-demographic factors. Further, movers and non-movers were matched on gender, age, income, and walkability index. The effect of “moving” on travel behavior was examined by the dummy variable created to identify residential movers from non-movers.	marking life events (retrospective at follow-up)
Kärmeniemi, 2019	1) sequence analysis using TraMineR to identify DMA trajectories; (2) stratified the study population into ten clusters according to similarity of residential relocation history.; (3)Fisher’s exact test with odds ratio to test whether the number of study participants who started regular walking or cycling during the follow-up differed across clusters.	Fischer's exact test	Across individuals with varying DMA trajectories	Change in change	/	/
Lagström, 2019	(1) latent class growth analysis with censored normal model to identify subgroups that are following a similar pattern of annual change in the neighborhood SES. (2) General linear models to investigate the associations between each neighborhood SES trajectory and dietary index.	ME	Across individuals with varying levels of change in neighborhood SES trajectories. Changes in neighborhood SES provides both from relocation and changes over time at given locations.	SES trajectories, dietary scores & change in change	age, sex, marital status, education, chronic cardio-metabolic diseases, severe financial difficulties, death of spouse and/or divorce over the last five years, hypertension, diabetes, atrial fibrillation, ischemic heart disease and cerebrovascular disease, urbanicity in the last residential neighborhood	yes, time-varying covariates
Slater, 2019	multilevel linear regression models in- cluding a random effect to examine the effect of changes in exposure to residential built environment	Multilevel linear	Across individuals with varying differences in recreational facilities (resulting from moving AND	Change in change	marital status, ten chronic health conditions, census division, urbanicity, census tract demographic, and	yes, all

	features on changes in total daily steps and total daily MVPA (min)		happening over time at given locations)		walkability, access to supermarkets, grocery stores, convenience stores, and fast food restaurants	
Nightingale, 2019	multilevel linear regression models to examine the effect of moving to East Village on the amount of physical activity (change in daily steps)and on adiposity compared with controls who did not live in East Village	Multilevel linear	Movers to East Village VS non-movers	Change in change	average daily steps at baseline, sex, age group, ethnic group, and household as random effect	No, but stratified models by housing tenure
Shackleton, 2018	1) identify deprivartion trajectories in movers (STATA "traj"). 2) Cox proportional hazard model to examine the relationship between residential-deprivation mobility groups (trajectory groups for movers, deprivation quintiles for churners and stayers) and risk of CVD event. Stayers in deprivation quintile 1 (least deprived) were the reference category	Cox	Movers with different deprivation relocation trajectories VS stayers in least deprived group	Deprivation trajectory and risk of CVD	age, age squared, sex, ethnicity, number of quarters observed (prior to event), number of moves	No
Leonard, 2017	difference-in-differences, using multilevel linear regression models with block group random effects to examine the relationship between change in standardized neighborhood condition and weight change. Separate models for (1) the full sample; (2) movers and non-movers separately.	DID	Across individuals with varying changes of standardized neighborhood condition, for the whole population and movers and non-movers separated	Change in change	age, sex, race, education, household income, physical activity, total years in Dallas County neighborhood at baseline, home ownership, employment status, marital status, number of children, mover status, neighborhood self-selection	No
Powell-Wiley, 2015	Multilevel difference-in-difference models with random effects and a Heckman correction factor (HCF) determined weight change relative to NDI change.	Multilevel DID	Individuals who moved to a higher-NDI neighborhood VS those moving to an equal/lower-NDI neighborhood or who remained in the same-NDI neighborhood	Change in change	age, sex, ethnicity, education, income, smoking, physical activity, neighborhood environment perceptions, neighborhood physical environment perceptions	yes, education, income, smoking, and physical activity, neighborhood environment perceptions, neighborhood physical environment perceptions
Scheiner, 2013	GEE regression modelling to detect the effects of a comprehensive set of life course events, cohort and period effects on travel mode use	GEE	Across individuals with varying relocation trajectories (1) and different levels of change in urbanity (2). (2) can be due both to relocation and changes over time at home location	Change in change	Gender, household, family biography, education, employment status	Yes, several including education level and employment status
Gan, 2010	logistic regression analysis to determine the association between residential proximity to traffic and the risk of CHD mortality using the nonexposed group as the reference category. Analyses were repeated for different	logistic	People who constantly lived close to traffic VS those who moved away and those who moved from far to close, respectively. There is no	change in exposure, risk of CHD mortality	baseline age, sex, pre-existing comorbidities (diabetes, chronic obstructive pulmonary disease, hypertensive heart disease), and neighborhood socioeconomic status.	No

	combinations of road types (highway or major road) and distances		distinction between movers and non-movers in the reference group.			
Handy, 2008	ordered probit model to estimate the relationship between changes in the built environment and changes in physical activity	ordered probit	Across individuals with varying levels of change in neighborhood design. Non-movers are assumed to have no change in neighborhood design.	Change in change	neighborhood preferences, pro-bike/walk attitudes, sociodemographic characteristics.	Yes, sociodemographic characteristics
Handy, 2006	ordered probit model to estimate the relationships between changes in the built environment and changes in walking, while controlling for attitudes	ordered probit	Across individuals with varying levels of change in built environment. Built environment assumed to be constant for non-movers.	Change in change	age, household size, presence of children, income, travel attitudes, residential preferences.	Yes, age, household size, presence of children, income
Handy, 2005	ordered probit model to estimate the relationship between changes in the built environment and changes in driving while con-trolling for attitudes and changes in socio-demographics	ordered probit	Across individuals with varying levels of change in built environment. Built environment assumed to be constant for non-movers.	Change in change	age, household size, presence of children, income, travel attitudes, residential preferences.	Yes, sociodemographic characteristics
Krizek, 2003	4 regression models, one per travel outcome (change in travel behavior as a function of change in neighborhood accessibility)	OLS	Individuals who had changes in various aspects of urban form upon moving VS non-movers	Change in change	household income, number of vehicles, household composition, change in household commute distance, base values of travel behaviours	Yes, household commute distance

3.3. Impacts of relocation on changes in various aspects of the living environment and cardiorespiratory health

3.3.1. Relocation as a source of changes in the living environment

Magnitude of exposure change due to moving was not systematically reported in all studies; when reported, movers tended to relocate to similar environments to those of the previous address. Some studies included change in exposure as continuous variables, while most categorized changes (e.g. improvers VS decliners (Salvo et al., 2018)) or trajectories (Kärmeniemi et al., 2019; Lagström et al., 2019; Shackleton et al., 2018). Others considered the overall change in exposure between consecutive time points, irrespective of the moving status. Such changes thus reflect both changes due to relocation and changes that naturally happen over time at given locations and limited our ability to assess the exact magnitude of change in various aspects of the living environment in relation to relocation. Below, we summarize changes in the living environment in relocation studies for the most frequently investigated exposures.

3.3.1.1. **Walkability/Accessibility**

Overall, the evidence suggests most movers stay in a neighborhood with similar walkability as their previous address (Braun et al., 2016; Chiu et al., 2016; Hirsch et al., 2014; Gavin R McCormack et al., 2017) or reported balanced changes into more and less walkable neighborhoods (Adhikari et al., 2020; Christie et al., 2022; Gavin R McCormack et al., 2023; Salvo et al., 2018). One study concentrating on adults seeking to move into East Village, London, reported an overall increase in walkability (1.4 unit [95%CI 1.2,1.6]) (Clary et al., 2020) while three studies found more frequent relocation to areas with less accessibility (e.g. street integration (Gavin R McCormack et al., 2021), density, mixed land use and access networks (Kärmeniemi et al., 2019), transport destinations (Giles-Corti et al., 2013).

3.3.1.2. **Social environment**

An inconsistent pattern of moving to either more or less deprived neighborhoods was found across studies, some reporting that most individuals tended to relocate into neighborhoods with similar deprivation level as their previous address (Lagström et al., 2019; Rachele et al., 2018) and others finding frequent relocation into less deprived (Powell-Wiley et al., 2015), or a balance between directions (Shackleton et al., 2018). Most studies investigating the built and social environment did not report the exact dimensions of exposure change upon moving (P T Aditjandra et al., 2012; Paulus Teguh Aditjandra et al., 2016; S. Handy et al., 2005, 2006; S. L. Handy et al., 2008; Kivimäki et al., 2021). (Leonard et al., 2017) reported a very limited change in standardized neighborhood score after residential relocation (mean change = -0.03 [SD = 9.97]). Similarly, (Woods & Ferguson, 2014) reported only minimal change in jobs/population (mean change = -2,46 [16.5]). The two studies focusing on crime-related safety observed an improvement upon relocation (Foster et al., 2016; Nightingale et al., 2019).

3.3.1.3. **Other aspects of the built and physio-chemical environment**

Distance to green and blue areas decreased for 20.3% and 20.6% and increased for 21.2% and 17.9% of participants, respectively (Halonen et al., 2014). Clary and colleagues reported an increase in walkability and a decrease in the distance to the nearest park (Clary et al., 2020). A large Canadian cohort reported that among the 15% who changed their exposure to road traffic through residential relocation, equal percentages became more or less exposed after the move (Gan et al., 2010). Two studies assessing the change in the food environment point to opposite exposure change, one cohort increasing the number of food outlets in one mile (Laraia et al., 2017) and the other decreasing the number after moving (Bivoltsis et al., 2020). Studies focusing on urbanization levels also reported balanced changes towards more and less urban areas (J De Vos et al., 2021; Jonas De Vos et al., 2018; Scheiner & Holz-Rau, 2013) and a large proportion of people relocating into similar levels of housing density (Coogan et al., 2009) and sprawl (Lee et al., 2009).

3.3.2. Main findings

Transport behavior and physical activity were among the most frequently investigated outcomes and were investigated in association with several exposures, including the built and social environment, safety, urbanization and walkability/accessibility (**Table 5**). There was consistent evidence of the association with different aspects of the built and social environments, and mixed evidence in relation to safety.

On average, studies using a retrospective design were more likely to confirm the association of interest (92% conclusive findings VS 63% conclusive and 18% partially conclusive in prospective designs). When restricting to prospective studies focusing on physical activity and transport behaviors, the probability of confirming the association of interest dropped to 50% conclusive results and 31% partially conclusive (Supplementary Tables 3 and 4).

Table 5: Number of studies that confirmed the association of interest (totally or partially) relative to the number of studies including an exposure-outcome pair. Studies focusing on health behaviors are displayed in yellow, those focusing on health outcomes in red, and those including both behaviors and outcomes are displayed in green.

	Built and social	Deprivation/ SEP	Food environment	Green and blue space	Pollution/ Traffic proximity	Safety	Urbanization	Walkability/ Accessibility	**N. Total**
Transport behavior/ Physical activity	6/6					1/2	4/5	13/15	**28**
Diet		1/1	1/1						**2**
Physical activity & Cardiometabolic health outcomes								2/2	**2**
Cardiometabolic health outcomes	1/1	2/3	0/1	1/1	0/1			1/2	**9**
Respiratory health					1/1				**1**
Several health outcomes	1/1								**1**
N. Total	**8**	**4**	**2**	**1**	**2**	**2**	**5**	**19**	**43**

4. Discussion

4.1. Relocation studies to assess the impact of changes in the living environment on cardiorespiratory health: current state of the literature and research gaps

We identified an extensive, but heterogenous body of literature using residential relocation as a natural experiment to investigate the impact of changes in the living environment on cardiorespiratory health and behaviors, with a rapid increase in studies over the past 10 years. Studies covered different domains of the living environment including the built, social, physiochemical, and food environment. The most commonly investigated outcomes were in relation to transport behavior and physical activity, with relatively fewer focused on cardiometabolic disease outcomes such as BMI. Overall, there was consistent evidence regarding changing built environment characteristics and transport mode use after relocation.

In the absence of general guidelines to leverage residential relocation as a quasi-experimental design in health research, the included studies covered a large variety in design and methodological approaches and could be separated into two main groups: those who focused on movers only, and those that included both movers and non-movers. A common characteristic of most studies was the use of "change-in-change" design, where the longitudinal design of the data is leveraged to calculate changes in the outcome within individuals over time. This approach limits the risk bias from residential self-selection, which is one of the most important issues in observational studies focusing on the living environment.

Several gaps were identified, including limited geographical representativeness and lack of comprehensiveness of the exposure-outcome pairs. Even though we restricted the search to high income countries, the results only include studies from 8 countries, where the European Union is under-represented and several studies were issued from the same research project. This lack of heterogeneity can be explained by the specific data requirement needed for conducting relocation studies, including large cohort or panel data with accurate address history, and precise exposure evaluation, as well as – in most cases – repeated outcome and covariate measurements. Studies were mainly conducted in North America, potentially limiting generalizability of findings related to individual behavior (e.g. transport, diet) and living environment (e.g. sprawl, walkability) which differ considerably from those in European context. Further, we found a lack of relocation studies focusing on intermediate health factors such as biomarkers or considering vulnerable groups. Only one study included health biomarkers like C-reactive protein, cholesterol and other variables routinely assessed in blood samples (Braun et al., 2016). Only few studies systematically investigated the joint impact of several aspects of the living environment or mutually adjusted for simultaneous changes in various exposures and none considered environmental noise. Further, most studies only considered relocation events within specific areas or countries, since larger distance moves are more likely to lead to loss to follow-up or new addresses not to be available in residential registries. No study investigated the possible reversibility of adverse health outcomes.

We found large heterogeneity in the clarity of the stated research question, the reporting of study designs, statistical approaches, and covariates included in adjustment. Studies should provide more detailed information about their study design and methodological approaches and reflect more thoroughly the type of bias that may affect their results. Similarly, we found that studies did not systematically report information on moving distances and the extent of exposure change due to moving which is the relevant source of exposure variability and determines statistical power. Whenever possible, relocation studies should also use prospective study designs and rely on objective measures of the living environment and associated health outcomes and behaviors to avoid recall bias.

4.2. Applications for exposome research: opportunities and challenges

Even though most studies focused on one or few aspects of the living environment, relocation was found to cause changes in multiple exposures simultaneously, making it a unique opportunity for exposome research to leverage residential relocation to investigate the joint effect of multiple dimensions of the living environment on health. Such applications can address mutual confounding from different dimensions of the living environment, something which has rarely been done in the previous literature (**Supplementary Figure 2**). Large-scale exposome research projects offer access to a wide range of exposure metrics and health data, including datasets combining both intermediate health markers and long-term health outcomes. Using health biomarkers is particularly useful because they typically appear faster than long-term health outcomes and make it possible to observe the short-term impacts of various changes in the living environment. Intermediate health indicators are also important to establish causal relationships (Hill, 1965). Large datasets are needed to conduct relocation studies, which are particularly sensitive to power limitations, especially in situations where the within-individual change in exposure is limited. Residential relocation studies are a relevant tool to understand 1) the interplay between spatial and temporal changes in living environments and 2) urban exposome interventions focused on changes in neighborhood characteristics or due to small-scale urban policies (Andrianou & Makris, 2018).

A major challenge of relocation studies is to adequately account for time-varying confounders such as change in occupation, family status, important life events, etc. This represents a particular challenge when applying residential relocation as a natural experiment in large cohort data that has not been specifically design with this intention – as it is often the case in exposome projects – where this type of repeated information is not always collected or available at the time-points of interest. In this context, smaller-scale panel data including more detailed and repeated information at the individual scale are useful to interpret and validate the results, but have more limited statistical power.

4.3. Limiting bias in relocation studies focusing on multiple aspects of the living environment

Similar to other natural experiments, a careful choice of the study design and the most appropriate counterfactual population is critical to reducing the risk of bias in relocation studies (Craig et al., 2012; Heinen et al., 2018; Mayne et al., 2015; Wing et al., 2018). The "Moving to Opportunity" study, has been one of the only studies where relocation could effectively be randomized. Participants were randomly allocated vouchers to relocate into low-poverty areas, which led to reduced obesity and diabetes in the intervention group (Ludwig et al., 2011). However, unlike this study and other types of natural experiments focusing on new regulations or other external interventions, moving inherently depends on the personal situation and preferences of the individuals who relocate, and the investigator has no control over the "time, location or nature, or dose of the intervention" (Ding et al., 2018). When recently assessing the impact of natural experiments in obesity prevention, Crane et al. reported that "few studies applied rigorous research designs to establish stronger causal inference, such as multiple pre/post measures, time series designs or comparison of change against an unexposed group" (Crane et al., 2020). Another review on naturally occurring experiments in relation to the built environment and obesity found that studies with a weaker design were more likely to find positive associations compared to studies that were rated higher (Mayne et al., 2015). A recent review on the use of relocation in air pollution studies, (Edwards et al., 2022) assessed the quality of most studies as "poor", although two studies were reported to use designs that incorporated effective randomization of the exposure. Both focused on changes in $PM_{2.5}$ due to moving, arguing that people are unaware of the $PM_{2.5}$ levels at their original and new residence. While this argument may hold for this specific pollutant, it is unlikely to apply to other aspects of the living environment (including air pollutants like NO_2 which is traffic-related, road distance, noise, green space, urbanization level and further area-level SEP). For example, one study compared findings from fixed-effects with those from random effects models, and reported that random effects estimates were most biased from the null or in the opposite direction compared to the fixed-effects estimates (Braun et al., 2016; Firebaugh et al., 2013). Therefore, relocation studies relying on between-individual comparison instead of within-individual changes (change-in-change approach) require the previous identification and adequate adjustment for the drivers of residential self-selection (Lamb et al., 2020).

4.4. Selecting the most appropriate methodology

The most appropriate methodology relies on: the research question, data structure, and exposure-outcome pairs of interest. When interested in the average intra-individual change in the outcome, "change-in-change" approaches should be prioritized, as they take full advantage of the longitudinal study design by focusing solely on within-individual variability, thus limiting confounding by measured and non-measured individual characteristics that are stable over time, such as age, sex, education, etc. Since these methods eliminate between-individual variability, the advantage of bias reduction can be accompanied by a loss of power or affected by intra-individual variability in the outcome and possible regression-to-the-mean phenomenon (Barnett et al., 2005).

Analytical approaches for designs targeting intra-individual changes included fixed-effects models, standard regression based on previously calculated changes in exposure and outcome, and difference-in-difference analyses. Fixed-effects models present several advantages: they are flexible and can easily accommodate multiple exposures and time points in the same model, making them ideal for relocation studies focusing on multiple exposures. They can also be applied to long follow-up periods with several relocation events, offering the advantage to reduce bias (Gunasekara et al., 2014), gain power from repeated measurements, and limit the risk of reverse causality. Difference-in-differences have been designed to investigate the impact of external interventions (Bernal et al., 2019; Strumpf et al., 2017) and are particularly easy to implement and interpret. The DiD approach implicitly targets the Average Treatment Effect on the Treated, comparing the outcome in movers that changed their exposure had it remained unchanged (Rothbard et al., 2023). This characteristic makes this design particularly attractive to establish causal relationships. However, it does not take advantage of repeated measurements at the individual level and are less flexible to adapt to multiple time points and exposures. While it remains a good approach to assess the impact of a specific intervention and data including two or few time points − Powell-Wiley et al. used a DiD approach to compare weight gain in movers to a higher deprivation neighborhood compared to movers to an equal/lower deprivation neighborhood or who remained in the same neighborhood (Powell-Wiley et al., 2015) – these models are less flexible to accommodate multiple exposure changes and different relocation timings.

When "change-in-change" approaches cannot be implemented (e.g. investigating exposure-outcome pairs with long lag periods or disease incidence (Kivimäki et al., 2021; Shackleton et al., 2018)), investigators can compare the "intervention" arm with a control group which was typically non-movers or movers with different relocation trajectories. In this case, the analyses are based on between-individuals variability, and additional methods were need to ensure interchangeability (Hernán & Robins, 2020), such as appropriate adjusting, analyses weighting, or propensity-matching using the probability of belonging to a given intervention arm (e.g. (Chiu et al., 2016; G R McCormack et al., 2023)). Further, the use of a "non-movers" comparison group may be necessary when the study design is not sufficient to avoid bias due to time-trends (e.g. parallel temporal trends in changes in exposure(s) and changes in outcome). Identifying a-priori predictors of moving and exposure change that are also susceptible risk factors for the outcome of interest is therefore essential in selecting both the study design and appropriate covariates.

Finally, all types of relocation studies are susceptible to confounding due to changes in individual characteristics over time or any other important time-varying factor that may affect both relocation trajectories and the outcome of interest (e.g. change in occupation, childbirth, retirement) if not measured and accounted for (Zeldow & Hatfield, 2019). Time-varying confounding is the most important source of bias due to residential self-selection in relocation studies using a change-in-change study design (**supplementary Figure 2**).

4.4.1. Relocation studies are useful but not perfect

Relocation studies are becoming increasingly popular and are particularly useful because they provide the opportunity for comparing exposures and outcomes within an individual instead of comparing people living in different areas (Ding et al., 2018). When adequately designed, relocation studies can help: (i) reduce the risk of bias from residential self-selection and individual and social differences, which is the most important factor limiting evidence in previous observational studies focusing on the living environment; (ii) identify relevant public health interventions and estimate their potential impact at the population level; (iii) investigate the reversibility of health behaviors and short-term health outcomes; and (iv) help build causality by triangulating the evidence with other study designs based on different identification assumptions. Complementary methods can be traditional observational studies looking at the impact of changes in the living environment over time at given locations.

4.5. Strengths and limitations

Our narrative literature review offers a comprehensive, summary of studies that have used relocation as a natural experiment, with particular focus on their applicability in exposome research. We incorporated the PRISMA guidelines where applicable to have a silver-standard and reproducible narrative review. To our knowledge, only two previous studies reviewed the literature using relocation studies as a natural experiment, one focusing on air pollution only (Edwards et al., 2022), the second restricting their findings on travel behavior as main outcome (Ding et al., 2018). This is the first study to consider multiple pairs of exposure and outcomes and to propose applications for the exposome framework. This review is also unique in reporting and evaluating statistical approaches and their applications in relocation studies. The diversity of methodological and statistical approaches and lack of standard reporting of methods and results made it challenging to objectively describe the effect estimates and compare findings. Our focus was on evidence regarding changes in the urban exposome that could be generalized to European settings. We therefore excluded studies conducted in low- and middle-income countries and those focused on forced relocation, to which our findings are likely to have limited generalizability.

Conclusion

We provided a comprehensive overview of the use of relocation studies to understand how the living environment shapes cardio-respiratory health, as well as the methodological and statistical methods used and their applications in different contexts. This information is crucial to understand when relocation studies can be useful and how they can be implemented. Well-designed relocation studies can leverage rapid changes in exposure within individuals to limit bias due to residential self-selection observed in traditional observational studies. Together with other natural and experimental designs, they contribute to establishing causality and help identify possible public health interventions. Relocation studies also hold promise for exposome research as they can include and mutually adjust for various aspects of the living environment. We provided practical advice on the use, strengths and limitations of different methodological approaches in relocation studies with specific considerations for multiple-exposure frameworks and exposome research.

Recommendations

- Relocation studies are valuable designs to build causality and assess impact of interventions but particular care must be given to the choice of the control group and time-varying confounding to avoid bias due to residential self-selection;
- Relocation studies are an opportunity for exposome research to address mutual confounding due to various aspects of the living environment and leverage large databases, precise address and exposure data, as well as biomarkers and intermediate health indicators;
- More studies are required in the European region, as the structure and health impacts of living environments may vary regionally;
- Clearly describe the research question, design, study population, methods and comparison group.
- Retrospective cohort studies are subject to reverse causality and recall bias. Use objective measures as much as possible, selecting those that allow for greatest comparability or pooled analyses.

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Declaration of interests

☐ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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