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ABSTRACT

This study investigated associations between change in the food environment and change in measured body mass index (BMI) and waist circumference (WC) in the Christchurch Health and Development Study (CHDS) birth cohort. Our findings suggest that cohort members who experienced the greatest proportional change towards better access to fast food outlets had the slightly larger increases in BMI and WC. Contrastingly, cohort members who experienced the greatest proportional change towards shorter distance and better access to supermarkets had slightly smaller increases in BMI and WC. Our findings may help explain the changes in BMI and WC at a population level.

1. Introduction

Overweight and obesity are defined as excessive fat accumulations that present a risk to health (World Health Organisation, 2013, 2021a). Globally, the prevalence of people living with obesity is a significant and a persistent public health concern with an estimated 35% of adults overweight and 11% obese worldwide (World Health Organisation, 2021a; James et al., 2018; Bass and Eneli, 2015; Ng et al., 2014). Obesity lessens life expectancy markedly especially among younger adults (Fontaine et al., 2003; Lung et al., 2019). Moreover, contemporary evidence suggests that most of the world's population now reside in countries where overweight and obesity kills more people than underweight (World Health Organisation, 2021a). Aotearoa New Zealand (NZ) is part of this global trend, where approximately one in three adults lives with obesity (Glover et al., 2019; Ministry of Health, 2018a; Ministry of Health, 2018b). Moreover, there are large disparities by ethnicity and socioeconomic status globally, as well as in NZ, with approximately two in three Pacific adults and around half of Māori adults living with obesity (Ministry of Health, 2018a; Ministry of Health, 2018b). As living with obesity is associated with several short- and long-term adverse comorbidities (Must and Strauss, 1999; Must et al., 1999; Bhaskaran et al., 2014; Luppino et al., 2010; Allison et al., 2008; Cerhan et al., 2014; Kitahara et al., 2014), the high prevalence of people living with obesity is placing significant strain upon individuals and health systems (Ng et al., 2014; Scarborough et al., 2011; El-Sayed et al., 2012; GBoCollaborators, 2017).

Young to middle adulthood (i.e. age 18–40 years) represents an important life period where unhealthy behaviours and outcomes may accrue over time (Zheng et al., 2017). What happens during this period of adulthood has profound and long-lasting implications for future health and wellbeing, yet it remains an understudied population group (Zheng et al., 2017; National Research Council, 2015; Pinto Pereira

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et al., 2020; Lachman, 2004). There is increasing evidence that many chronic health conditions experienced by older people originate during middle adulthood (Avis et al., 2018; Gondek et al., 2021a, 2021b; Schubert et al., 2019). In addition, there is also emerging evidence that behavioural risk factors can increase during this period of life and that adverse health outcomes in later adulthood may be shaped by social, environmental and lifestyle risk factors in midlife (Bosnes et al., 2019; Lafortune et al., 2016; Lee-Bravatti et al., 2021; Canizares et al., 2018). Moreover, there remains a common misconception that psychosocial growth and development stagnates in midlife. However, evidence shows that many key developmental processes take place in this phase of life including parenting older dependants, career progression, a transition to caring for elderly parents, marital separation, and laying down financial security for late life (Lachman, 2004; Stone et al., 2010).

It is acknowledged that the global rise in obesity since 1980 occurred too rapidly for genetic or biological factors to be its root cause (Sallis and Glanz, 2009; Mason et al., 2020; Swinburn and Egger, 2002; Swinburn et al., 1999). While individual risk factors such as genetic makeup explain some variability between individuals, the rise in prevalence of obesity seems to be fuelled by the coincidental increased supply of cheap, palatable, energy-dense foods that are accessible, convenient and effectively marketed (Swinburn et al., 2011; Burgoine et al., 2021). The food environment, especially the ubiquitous access to healthier and unhealthier food outlets, has therefore become an important research topic in terms of the association with obesity or increases in population-level weight (Ministry of Health, 2018b; Sallis and Glanz, 2009; Mason et al., 2020; Swinburn et al., 1999; Swinburn et al., 2011). Despite this, the evidence base to date is hampered by the cross-sectional design of studies (Hobbs et al., 2019a; Mackenbach et al., 2016, 2018). This allows for an exploration of the extent to which variation in obesity levels or BMI are attributable to variations in food environments, but not for more complex research questions or inference over time (Wilkins et al., 2019).

A number of longitudinal studies in adults have been conducted, but most are from the United States and have reported equivocal findings (Wilkins et al., 2019). For example, two studies (Lee et al., 2017; Li et al., 2009) related baseline access to food outlets to change in adiposity outcomes. One was a six-year follow-up concluding that a higher density of food stores, fast food restaurants and supermarkets was protective. The other had a one-year follow-up and the authors concluded that higher density of fast food restaurants was a risk factor for higher adiposity. Four studies (Rummo et al., 2017; Richardson et al., 2014; Gibson, 2011; Block et al., 2011) have linked changes in access to food outlets to changes in adiposity outcomes, again with mixed results. A study with a 26 year follow-up by Rummo et al. (2017) demonstrated that their instrumental variables approach, accounting for residual confounding, generated stronger associations between neighbourhood food outlets and BMI than ordinary least squares, random effects or fixed effects models (Rummo et al., 2017). Richardson et al. (2015) were the only ones to explore mediating pathways via fast food consumption, but while living near fast food outlets was associated with higher fast food consumption no associations with BMI were observed (Richardson et al., 2015). Two studies assessed the longitudinal associations between food outlets and diet, concluding that low-income respondents with higher fast food availability consumed more fast food across a 15 year period (Boone-Heinonen et al., 2011), and that increases in healthy food access was associated with increased diet quality scores during an eight year follow-up (Bivoltsis et al., 2020). While evidence overall is largely equivocal, more longitudinal research over an extended time frame may be required to detect associations between change in the food environment and change in adiposity.

While there are many advantages to longitudinal research, one particular advantage relates to the possibility of attempting to account for selective migration, where some individuals are more likely to move to certain areas (Wilding et al., 2020; van Lenthe et al., 2007). Differences in the associations between area characteristics and adiposity for individuals who moved and those who stayed at the same address have been highlighted in previous research (Wilding et al., 2020; Twaits and Alwan, 2020). This is especially important for longitudinal studies linking change in access to the food environment with change in adiposity, as change in access to the food environment may be due to either actual changes in the food environment in one area, or due to individuals moving to another area with different food environment characteristics. In addition, research often only uses one or two definitions of access such as within a radial buffer or distance to the nearest fast food outlet. While previous research has shown that different definitions of access are highly correlated (Hobbs et al., 2017; Burgoine et al., 2013) other research has suggested they capture different elements of access and multiple definitions of access and availability such as the density in a particular area should be explored (Christensen et al., 2021; Kwan and Schwanen, 2009; Kwan, 2009, 2012, 2018). Consistent associations across multiple definitions of access and availability would also increase confidence in study findings and may help explain the heterogeneity in previous evidence.

Recently, scholars, including those from Public Health and Health Geography, have called for more research to use geospatial longitudinal methods to better capture spatiotemporal dynamics of health and by building towards life course exposures (Desjardins et al., 2023; Timmermans et al., 2018). Using data from a birth cohort study, we aim to investigate whether changes in access to fast food outlets and supermarkets from 2005 to 2015 is associated with change in measured adiposity outcomes (BMI and WC) within a key period of adulthood from age 30–40 years. Second, we aim to examine if there are differences in associations between change in the food environment and change in adiposity over time for those who remained at the same address from age 30 to 40 compared to those who changed address from age 30 to 40.

2. Methods

2.1. Study design and participants

Participants were cohort members of the Christchurch Health and Development Study (CHDS). The CHDS is a birth cohort study of 1265 children born in the Christchurch, NZ urban region over a 4-month period during 1977. This birth cohort has been studied regularly from birth to age 40 years using a combination of interviews with parents and participants, standardised testing, teacher report, and medical record data (Fergusson and Horwood, 2001). The study sample was based on the NZ resident population of CHDS cohort members at age 30 (2007) and 40 (2017). Overall, n = 870 (68.8%) had valid data for change in BMI and n = 753 (59.5%) had data for change in WC. All phases of the CHDS were subject to ethical approval by the Regional Health and Disabilities Ethics Committee.

2.2. Outcome

2.2.1. Body mass index and waist circumference

At age 30 years, measures of participants' height (cm), weight (kg) and WC (cm) were obtained and at age 40, measures of weight and WC were again obtained. These were taken in respondents' homes by trained staff using standardized instruments; Seca 214 portable stadiometers to measure height; Tanita HD-351 scales to measure body-weight and a measuring tape to measure WC. Direct assessment was not always possible because the interview had been conducted with the cohort member on Skype or the telephone. In these cases, the cohort member self-reported their measurements. Validity of assessing BMI on the basis of self-report as opposed to measured data was previously examined on a subsample of the cohort at age 30. This showed a correlation of r = 0.96 between assessments of BMI based on self-report and standardized measurements (Fergusson et al., 2014a; McLeod et al., 2016). Using this information, body mass index (BMI: kg/m^2) scores were calculated for respondents at ages 30 and 40.

2.3. The food environment

Obtaining data on the food environment in NZ that is comparable over time is difficult and has seldom been done before. To our knowledge, for one of the first times, we sourced valid and accurate data from 2005 to 2015 for major chain fast food outlets and large supermarkets. Fast food outlets were defined as multinational and included large outlets such as McDonald's, Burger King and Pizza Hut. Large supermarkets were defined as the major chain supermarkets of NZ and included New World, Pak'nSave, Countdown, Fresh Choice, and Four Square.

Data in 2005 was sourced from all Territorial Authorities (TAs) across New Zealand who have a responsibility to maintain a list of all premises in their respective region used in the manufacturing, preparation and/or storage of food for sale (Hobbs et al., 2021). As outlined previously (Hobbs et al., 2021; Wiki et al., 2018), data were verified using an online telephone directory and, in the case of missing data, were supplemented with additional address information and all outlets were geocoded to provide precise geographic coordinates of its location. Data in 2015 were again sourced from all TAs across New Zealand and were supplemented with additional searches from the Ministry for Primary Industries (MPI) website (Wiki et al., 2018). Closed premises were removed and if duplicate entries for one premise were given only the latest registration was kept, however, duplicate business names at different locations were kept as unique records. Data were geocoded using Google Maps Geocoding Application Programming Interface (API), at the address level of precision, and the geographic coordinates for any un-matched records were manually looked up.

Distance and access to food outlets was calculated along the road network (Beere, 2016) as driving distance (metres) for all areas of NZ (Hobbs et al., 2021). We estimated the driving distance by car via the road network from residential areas of individuals within the CHDS to the closest food outlet. Residential areas from 2005 were defined using meshblock population weighted centroids from the Census 2006, and in 2015 were defined using meshblock population weighted centroids from the Census 2018, thus providing an estimate of distance and access to fast food outlets and supermarkets in both 2005 and 2015 across the country.

2.4. Other relevant Christchurch Health and Development Study (CHDS) data

Other potentially relevant variables were extracted from the CHDS birth cohort database based on previous research reporting on the associations with BMI and the food environment as well as expert author knowledge on the associations that exist within current evidence and evidence reviews (Fergusson and Horwood, 2001; Fergusson et al., 2014a; McLeod et al., 2018). These included: adult age (years), sex (male or female), ethnicity (Māori/Pacific vs. other at birth), historical family socioeconomic status at the birth of the cohort member which was represented by father's occupation (1 = unskilled/semiskilled; 2 = technical/trades; 3 = managerial/professional) (Elley and Irving, 1976), paternal BMI at the time of the cohort member's birth, maternal BMI prior to pregnancy with cohort member and recorded at the cohort member's birth, maternal age at birth of the cohort member (years), and birthweight (g) of the cohort member. Such historical covariates are seldom available for food environment research.

2.5. Nationwide geospatial analyses

To examine the distance to food outlets from a cohort members residence we used a road network (Beere, 2016) to measure driving distance from meshblock centroid to the nearest food outlet and create a dataset for the whole of New Zealand in 2005 and 2015. From this we calculated three change in the food environment metrics: i) distance to the nearest outlet, ii) average distance to the nearest five outlets, and iii) access based on an enhanced two-step floating catchment area model (E2SFCA) (Hobbs et al., 2021; Beere, 2016). First, the driving distance (metres) by car to the nearest food outlet along the road network was calculated using the GIS network analysis functionality, specifically the closest facility analysis in ArcGIS Pro 2.4. All calculations performed were calculated separately for 2005 and 2015 data as well as by fast food outlet and supermarket. Second, the average driving distance to the five closest food outlets was also calculated using an origin-destination matrix. Origins in this case were again meshblock population-weighted centroids and destinations were the food outlets in 2005 and 2015. Finally, an enhanced two-step floating catchment area (E2SFCA) model that takes into account both the accessibility of population and service providers was modelled (Luo and Qi, 2009). The E2SFCA method simply combines a chosen distance decay function with the 2SFCA method. More specifically, the spatial decomposition method, a type of floating catchment area method, was first introduced by Radke and Mu (2000). This method defines the service area by a threshold travel time or distance, accounting for service availability by the surrounding demand. This is a special case of the gravity-based method first introduced by Weibull (1976) (Weibull, 1976) and later developed further by Joseph and Bantock (1982) (Joseph and Bantock, 1982), whereby a nearby service is considered more accessible than a remote service and service availability is discounted by gravity-based potential. These methods were synthesized into one framework by Luo and Wang (2003), the two-step floating catchment area (2SFCA) method. Luo and Qi (2009) (Luo and Qi, 2009) provide a further enhancement to this, accounting for distance decay by applying weights to differentiate travel time/distance zones. These zones are assigned with different weights according to the Gaussian function, and the method is termed the enhanced two-step floating catchment area (E2SFCA) method (Luo and Qi, 2009). We applied a 30 km catchment area, with supply points being equal to one and demand points being population-weighted centroids. Demand volume was equal to the usual resident population and a Butterworth distance decay was applied (power function 6, passband as 50% of threshold). Finally, we calculated the relative percentage change in distance to food outlets and to the nearest five food outlets to allow a standardised difference for all outlets (e.g. ((Distance 2015 - Distance 2005)/Distance 2005) *100). In terms of interpretation, for the distance to nearest, and the distance to nearest five food outlets, negative values mean relative percentage reduction in distance (e.g., −50% means 2x closer in 2015 than in 2005). When split into quintiles, Quintile 1 (Q1) represents the greatest proportional change towards shorter distance over time from 2005 to 2015. In contrast, for access, in the E2SFCA, the coefficients reflect access rather than distance. Therefore, in contrast to the distance measures, Q5 represents the greatest proportional change towards better access over time. For our statistical models we used continuous distance to maximise statistical power and for descriptive statistics we used Quintiles of access.

2.6. Statistical analyses

Descriptive statistics are presented as mean (standard deviation (sd)), median (interquartile range) and n (%) of sample where appropriate. Mixed effects linear regression models producing unstandardised betas and 95% confidence intervals with individuals nested within meshblock 2018 utilising the robust or sandwich estimator of variance were used to investigate the association between the food environment and the two outcomes of: i) change in BMI and ii) change in WC. Unadjusted and adjusted models tested for the association between relative percentage change in distance and access to fast food outlets and supermarkets and change in adiposity outcomes. We adjusted for gender, ethnicity, socioeconomic circumstances at birth based on Elley and Irving 1979 scale (Elley and Irving, 1976), maternal BMI at birth, paternal BMI at birth of participant, and participant birthweight (kg)).

The present analyses were from a possible 987 cohort members at age 30 and 902 at age 40. To examine the effects of sample loss on the representativeness of the sample, the obtained samples with complete data at each age were compared with the remaining sample members on sociodemographic measures collected at birth. Supplementary materials (Table S4) show a comparison of the analysis sample with surviving members of the CHDS cohort who have measures of BMI and distance and access to the food environment, and those who were not assessed at age 30 and 40 years. This analysis suggested statistically significant tendencies for the obtained samples to underrepresent males, and individuals from socially disadvantaged backgrounds (low socioeconomic status, younger mother, maternal smoking in pregnancy. More specifically, data from the CHDS had complete data on change in BMI (n = 870) and change in WC (n = 753) between ages 30 and 40. Once residential address locations were obtained (that were required at both ages 30 and 40 years to calculate change in the food environment). This resulted in a final analytical sample of n = 691 cohort members with complete data for BMI and n = 621 with complete data for WC and all covariates including change in the food environment. Due to very few missing values on covariates we conducted complete case analyses and data were analysed using Stata SE version 16.0 (StataCorp, College Station, TX, USA), and two-tailed α of 0.05 defined significance. To address the issue of obtained samples to underrepresent individuals from socially disadvantaged backgrounds, data-weighting methods (Carlin et al., 1999) were used to examine possible implications of selection effects arising from the pattern of missing data. These analyses produced essentially the same pattern of results as those reported here for associations between change in food environment metrics and change in adiposity. This suggests that the conclusions of this study were unlikely to have been influenced by selection bias (Table S6). All our data analyses completed were pre-planned in October 2021 and completed in November 2021 in accordance with this plan; no analyses were data-driven. This study is reported as per the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline (S1 Checklist).

3. Results

3.1. Study sample descriptive statistics

Table 1 displays the sociodemographic characteristics by outcome at age 30 years and change in BMI and WC. At age 30 years, mean (standard deviation) BMI and WC was 25.84 kg/m^2 (±4.82) and 87.01 cm (±12.15) respectively. There were clear differences in BMI and WC by sociodemographic characteristics including ethnicity, family socioeconomic status at birth, maternal and paternal BMI and cohort member's birthweight. Finally, there was a clear increase in both BMI and WC over time, which was broadly consistent across levels of demographic factors.

3.2. Characterising nationwide change in the food environment

We calculated nationwide metrics of change in food environment across NZ. We calculated distance to nearest food outlet, distance to nearest five fast food outlets and then access to food outlets using the Enhanced Two-Step Floating Catchment Area (E2SFCA) model. For ease of interpretation, Figs. 1–3 highlight change in the food environment metrics for the urban area of Christchurch city where the birth cohort was established in 1977. The supplementary online materials highlight change in food environment metrics for two other major urban areas of Auckland and Wellington (Figs. S3–S8).

Fig. 1 shows the distance to the nearest fast food outlet (Panel 1A: top left) and supermarket (Panel 1C: bottom left) in 2015. The relative percentage change over time is shown within Fig. 1 for the nearest fast food outlet (Panel 1B: top right) and supermarket (Panel 1D: bottom right). The relative percentage change in Fig. 1 shows that the residents and areas in the west of Christchurch had the greatest proportional change in terms of shorter distance to supermarkets over time and the

Table 1
Study sample key individual characteristics (mean (standard deviation) BMI and WC) at age 30 and change over time (30–40 years).

	30 years				Change from 30 to 40 years			
	BMI (kg/m^2)		WC (cm)		BMI change (kg/m^2)		WC change (cm)	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Total	870	25.84 (4.82)	753	87.01 (12.15)	870	2.19 (3.11)	753	5.87 (9.76)
Sex								
Male	412	26.39 (4.25)	390	91.23 (10.93)	412	1.86 (2.66)	390	5.63 (9.24)
Female	458	25.36 (5.25)	363	82.46 (11.75)	458	2.49 (3.45)	363	6.13 (10.30)
Ethnicity								
Māori/Pacific	107	27.38 (5.30)	87	90.31 (11.87)	107	2.34 (3.10)	87	5.66 (11.50)
Other	753	25.64 (4.72)	656	86.60 (12.14)	753	2.14 (3.10)	656	5.81 (9.48)
Maternal BMI (kg/m^2)								
Q1 (<19.8)	175	24.09 (3.89)	144	83.39 (10.10)	175	2.07 (2.57)	144	6.04 (8.40)
Q2 (19.8–21.0)	174	25.49 (4.60)	147	86.42 (11.24)	174	1.68 (3.01)	147	4.61 (9.82)
Q3 (21.1–22.1)	185	25.96 (4.62)	158	86.50 (10.72)	185	2.33 (3.11)	158	6.62 (10.12)
Q4 (22.2–23.9)	167	25.50 (4.18)	149	86.25 (10.52)	167	2.48 (3.01)	149	6.32 (8.96)
Q5 (>23.9)	159	28.46 (5.75)	145	92.67 (15.72)	159	2.32 (3.70)	145	5.33 (11.09)
Paternal BMI (kg/m^2)								
Q1 (<21.6)	184	24.58 (4.19)	160	84.86 (9.77)	184	2.07 (2.71)	160	5.87 (8.01)
Q2 (21.6–23.1)	170	24.95 (4.01)	141	85.72 (9.73)	170	1.89 (2.79)	141	5.32 (8.30)
Q3 (23.2–24.3)	174	25.39 (4.71)	151	85.05 (11.25)	174	2.14 (2.97)	151	5.24 (9.31)
Q4 (24.4–26.2)	174	26.43 (4.37)	147	88.00 (12.57)	174	2.12 (3.14)	147	5.34 (10.85)
Q5 (>26.2)	158	28.21 (5.94)	144	91.82 (15.46)	158	2.69 (3.81)	144	7.23 (11.79)
Family socioeconomic status at birth								
1 (unskilled/semiskilled)	203	26.17 (4.84)	184	88.56 (11.82)	203	2.36 (3.24)	184	6.89 (9.90)
2 (technical/trade)	481	26.07 (4.88)	412	87.01 (12.27)	481	2.25 (3.17)	412	6.13 (9.92)
3 (managerial/professional)	186	24.93 (4.57)	157	85.16 (11.99)	186	1.84 (2.81)	157	4.02 (8.97)
Birthweight (kg)								
Q1 (<3.0)	171	26.21 (5.41)	153	87.22 (12.03)	171	2.52 (3.30)	153	6.17 (10.56)
Q2 (3.0–3.3)	174	25.86 (4.47)	153	86.27 (11.09)	174	1.92 (2.94)	153	5.71 (9.03)
Q3 (3.4–3.5)	169	25.49 (4.40)	137	86.76 (11.80)	169	2.12 (3.24)	137	5.70 (9.41)
Q4 (3.6–3.8)	168	25.79 (5.07)	143	87.14 (12.91)	168	2.10 (2.75)	143	5.15 (9.62)
Q5 (>3.8)	176	25.84 (4.68)	155	87.54 (12.79)	176	2.24 (3.21)	155	6.27 (10.05)

Data are: n and mean (standard deviation (SD)). BMI | body mass index. WC | waist circumference. Q1-5 | Quintile 1–5.

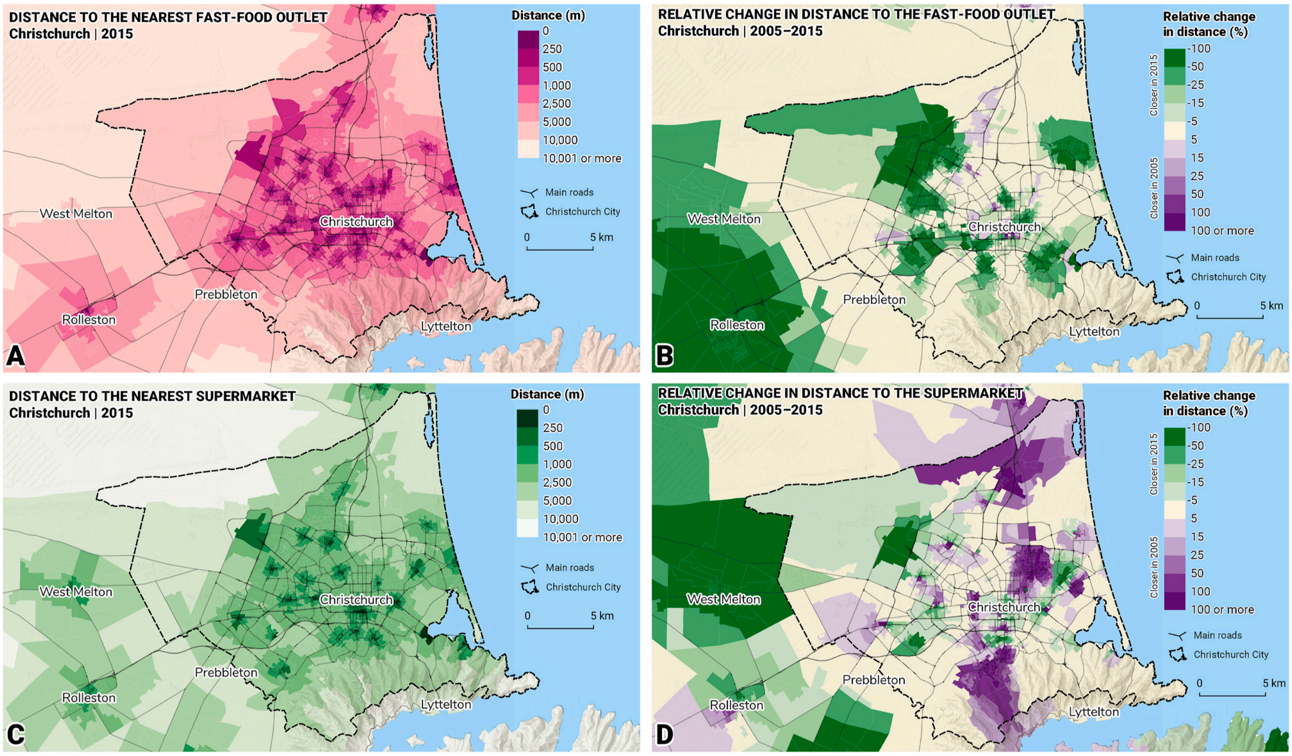

Fig. 1. Distance to the nearest fast food outlet (1A: top left) and nearest supermarket (1C: bottom left) in 2015 and relative percentage change in distance to the nearest fast food outlet (1B: top right) and supermarkets (1D: bottom right) for Christchurch from age 30 to age 40 years (the darker green shades in 1B and 1D represent the greatest proportional change towards shorter distance to food outlets from 2005 to 2015).
Note: The base of plotted data including Meshblock 2018 (X), Functional Urban Area 2018 (Y), Digital Elevation Model (Z) is licensed under CC BY 4.0.
X) Stats NZ. Geographic Data Service - Meshblock 2018 Clipped (generalised). 2017 Dec - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/92198-meshblock-2018-clipped-generalised/
Y) Stats NZ. Geographic Data Service - Functional Urban Area 2018. 2021 Feb - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/105288-functional-urban-area-2018/
Z) Land Information NZ. LINZ Data Service - NZ 8m Digital Elevation Model (2012). 2016 Aug - [cited 2022 Dec 1]. Available from: https://data.linz.govt.nz/layer/51768-nz-8m-digital-elevation-model-2012/.

north of Christchurch had the greatest proportional change in terms of reductions greater distances to supermarkets over time. In contrast, generally, residents throughout the Christchurch area had shorter distance to fast food outlets over time. Changes by the nearest five outlets are shown in Fig. 2, which shows broadly similar patterns although slightly less pronounced in terms of absolute percentages. Fig. 3 displays the food environment for Christchurch region using the E2SFCA model.

Fig. 4 displays the raw change in BMI and WC by relative percentage change in fast food outlets. Change in distance to the nearest fast food outlet (Fig. 4A) and the nearest five fast food outlets (Fig. 4B) is represented by relative percentage change. Quintile 1 (Q1) represents the greatest proportional change towards shorter distance over time from 2005 to 2015. On average all cohort members increased BMI and WC. However, for the nearest one and the nearest five fast food outlets there was some evidence to suggest that cohort members who experienced the greatest proportional change towards shorter distance to fast food outlets displayed slightly larger increases in BMI and WC. In contrast, in Fig. 4C and F, Q5 in the Enhanced Two-Step Floating Catchment Area (E2SFCA) model represents the greatest proportional change towards better access over time. Similarly, there was some evidence which showed that cohort members in Q5 who experienced the greatest proportional change towards better access to fast food outlets over time had slightly larger increases in BMI and WC.

Fig. 5 demonstrates the change in BMI and WC by change in supermarket distance and access over time. For the nearest supermarket and the nearest five supermarkets, Q1 represented the greatest proportional change towards closer distance from 2005 to 2015. There was some evidence to suggest that cohort members who experienced the greatest proportional change (Q1) towards shorter distance to supermarkets from 2005 to 2015 demonstrated smaller increases in BMI and WC. In contrast, in the Enhanced Two-Step Floating Catchment Area (E2SFCA) model, Q5 represents the greatest proportional change towards better access from 2005 to 2015. There was some evidence that cohort members in Q5 who had the greatest proportional change towards better access for supermarkets had smaller increases in BMI and WC. Figs. S1 and S2 (supplementary online materials) present scatter plots of the raw data.

3.3. *Associations between change in the food environment, body mass index and WC over time*

In the fully adjusted model (Table 2), there was some evidence of an association between relative percentage change in distance and access to fast food outlets and changes in BMI and WC. First, relative percentage change in distance to the nearest fast food outlet was associated with change in BMI ($b = -0.005$ [-0.011, -0.0003]) but not change in WC ($b = -0.019$ [-0.044, 0.005]). However, the relative percentage change in distance to the nearest five fast food outlets was associated with small changes in BMI ($b = -0.011$ [-0.022, -0.006]) and changes in WC ($b = -0.05$ [-0.09, -0.02]). Finally, for change in access to fast food outlets as measured by the E2SFCA there was no association with BMI ($b = 2.52$ [-1.23, 6.29]) but there was an association with change in WC ($b = 13.66$ [0.90, 26.41]). In general, remembering that the E2SFCA coefficients are reversed compared to the distance, the associations were

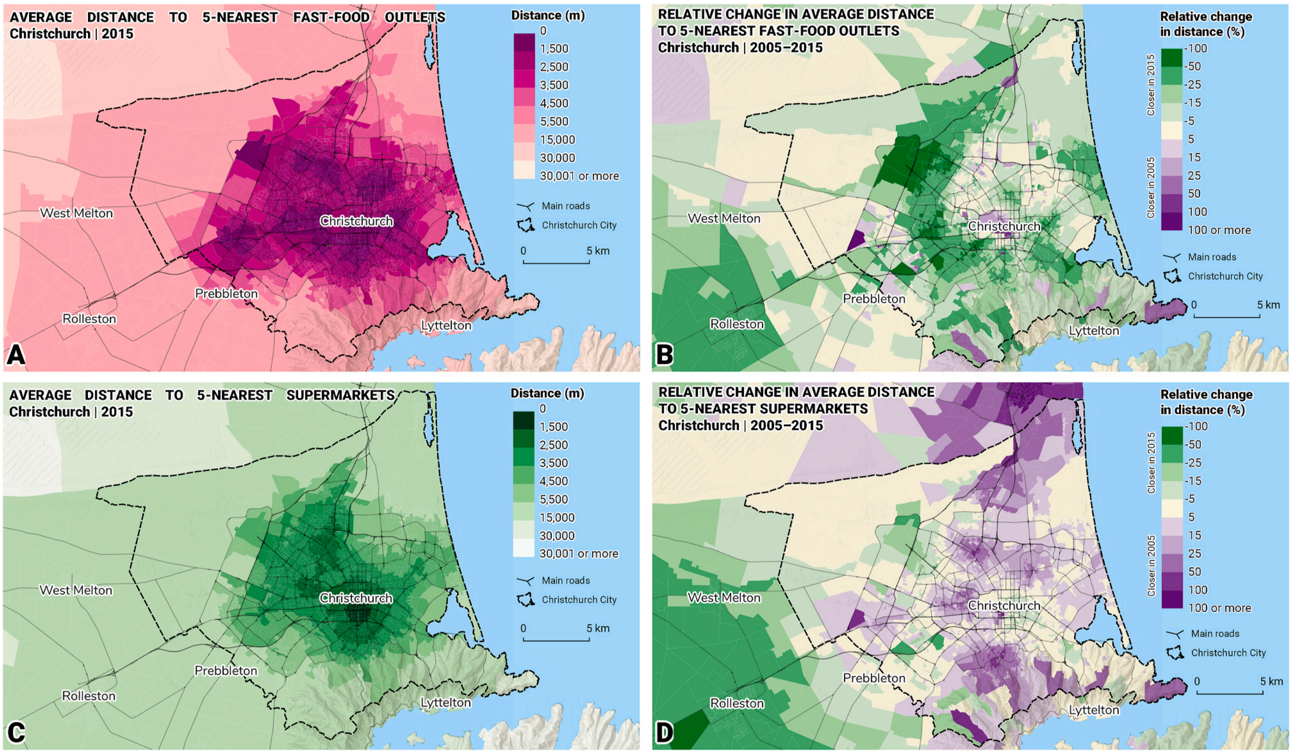

Fig. 2. Distance to the nearest five fast food outlets (2A: top left) and supermarkets (2C: bottom left) in 2015 and relative percentage change in distance to the nearest five fast food outlets (2B: top right) and supermarkets (2D: bottom right) for Christchurch from age 30 to age 40 years (the darker green shades in 2B and 2D represent the greatest proportional change towards shorter distance to food outlets from 2005 to 2015).
Note: The base of plotted data including Meshblock 2018 (X), Functional Urban Area 2018 (Y), Digital Elevation Model (Z) is licensed under CC BY 4.0.
X) Stats NZ. Geographic Data Service - Meshblock 2018 Clipped (generalised). 2017 Dec - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/92198-meshblock-2018-clipped-generalised/
Y) Stats NZ. Geographic Data Service - Functional Urban Area 2018. 2021 Feb - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/105288-functional-urban-area-2018/
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often in the hypothesised direction but not always statistically significant.

In the fully adjusted model (Table 2) there was mixed evidence relating change in distance and access to supermarkets and changes in BMI and WC. For instance, relative percentage change in distance to the nearest supermarket was not related to change in BMI (b = −0.0003 [−0.003, 0.002]) or change in WC (b = −0.001 [−0.009, 0.007]). However, the relative percentage change in distance to the nearest five supermarkets was associated with small but significant changes in BMI (b = 0.007 [0.0006, 0.01]) but not change in WC (b = 0.01 [−0.01, 0.03]). Finally, again remembering that the E2SFCA coefficients are reversed compared to the distance, for change in access to supermarkets, as measured by the E2SFCA model there was a small but significant association with BMI (b = −3.81 [−6.22, −1.40]) and WC (b = −10.11 [−18.18, −2.04]). In general, these associations were again in the hypothesised and expected direction and suggest to some extent that cohort members who experienced the greatest proportional change towards shorter distance and better access to supermarkets had slightly smaller increases in BMI and WC. Full analyses are shown in supplementary online materials (Tables S1–S3). This study was going to examine effect modification by socioeconomic circumstance however when data were stratified by deprivation there were too few observations per cell, limiting confidence in findings.

3.4. *Exploratory analysis of those who moved house and those who stayed at the same address between ages 30 and 40 years*

In this exploratory analysis, we split the sample into those who moved and those who stayed at the same residential address. Our original hypothesis was, if there was an association between the proportional change in distance or access to food outlets and change in BMI or WC in those who stayed at the same residence then it is potentially due to the food environment changing around their place of residence rather than due to selection bias attributable to individuals changing residential address location. This analysis is exploratory in nature as very few participants (11%, n = 90) stayed at the same address between age 30 and 40 with complete food environment data at both waves. Due to the low number of individuals we present descriptive statistics (mean change in BMI and WC) of those who remained and those who moved house rather than mixed effects regression models.

Fig. 6 presents the relative percentage change in distance and access to fast food outlets and change in BMI and WC split by those who changed addresses and those who remained at the same address between age 30 and 40 years. For relative percentage change in the distance to the nearest fast food outlet and nearest five fast food outlets, the larger increases in BMI and WC were seen in those participants with the greatest proportional change towards shorter distance to fast food outlets. However, the effects tended to be larger in Q1, and to some extent Q2, for those who remained at the same address. For change in access, as measured by the E2SFCA model, we noted a similar trend. Those individuals who experienced the greatest proportional change towards

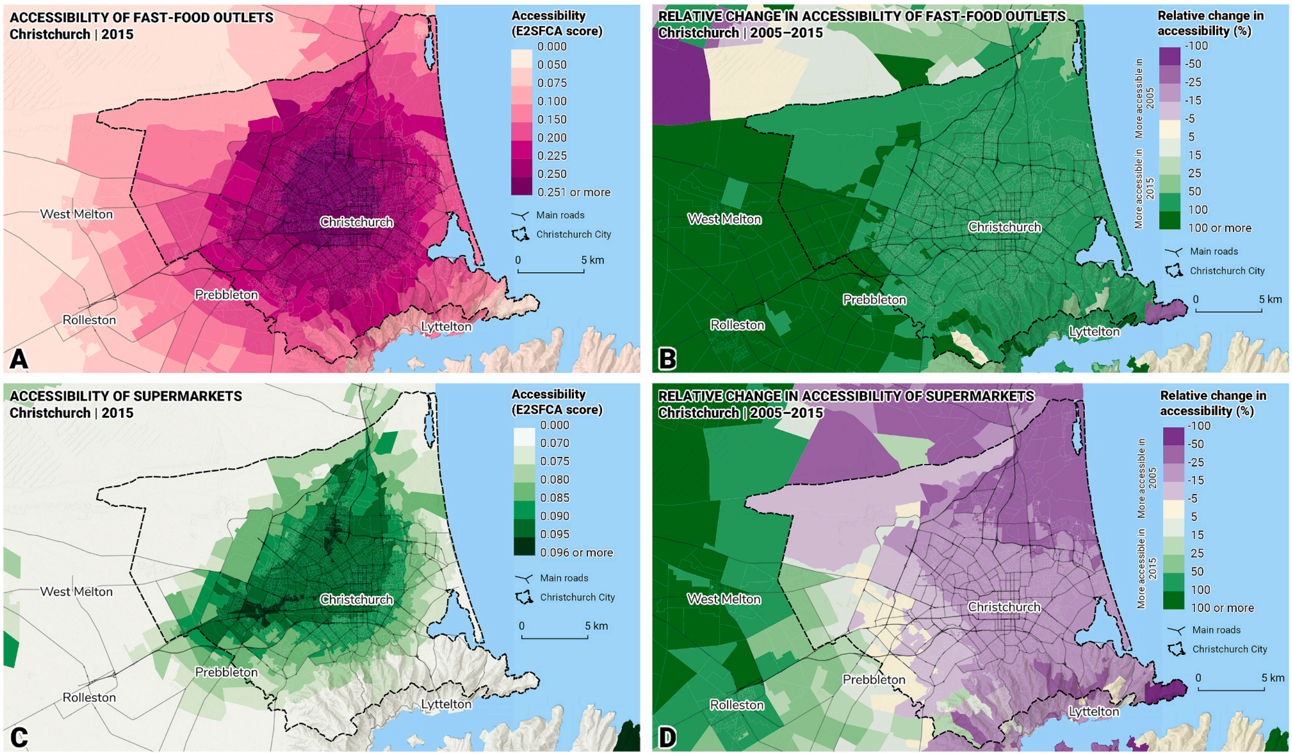

Fig. 3. Enhanced Two-Step Floating Catchment Area (E2SFCA) model for fast food outlets in 2015 (3A: top left) and nearest supermarkets (3C: bottom left) in 2015 and change in E2SFCA for fast food outlets (3B: top right) and supermarkets (3D: bottom right) for Christchurch from age 30 to age 40 years (the darker green shades in 3B and 3D represent the greatest proportional change towards better access to food outlets from 2005 to 2015).

Note: The base of plotted data including Meshblock 2018 (X), Functional Urban Area 2018 (Y), Digital Elevation Model (Z) is licensed under CC BY 4.0.

X) Stats NZ. Geographic Data Service - Meshblock 2018 Clipped (generalised). 2017 Dec - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/92198-meshblock-2018-clipped-generalised/

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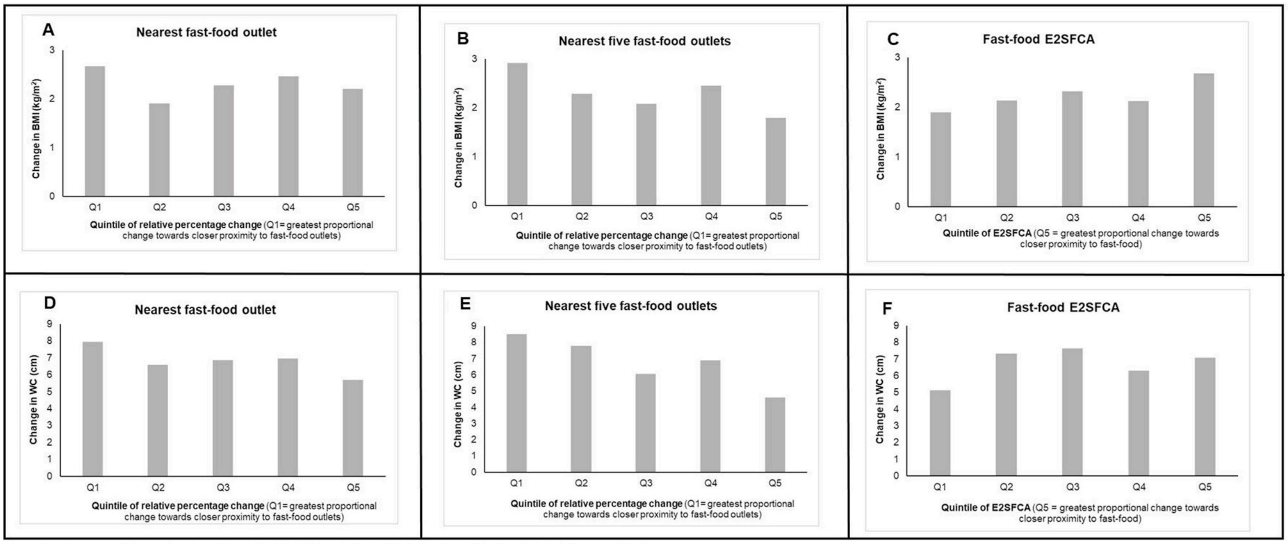
better access to fast food outlets between 2005 and 2015 generally had larger increases in BMI and WC, particularly for those who stayed at the same residential address.

Fig. 7 demonstrates the relative percentage change in access to supermarkets and change in BMI and WC. There was also some evidence that the greatest increases in BMI and WC occurred among those individuals who resided at the same address as opposed to those who moved however, effects were not as consistent as for fast food outlets. Specifically, for relative percentage change in the nearest supermarket and nearest five supermarkets there was mixed evidence as to whether larger gains in BMI and WC were among those who remained at the same address or moved. This is likely due to the small sample used and warrants further investigation.

4. Discussion

This study in Aotearoa New Zealand (NZ) investigated associations between change in the food environment and change in BMI and WC from 30 to 40 years of age, a key period in adulthood for the development of non-communicable diseases. Creating health-promoting environments is a key goal the United Nations and the World Health Organisation Global non-communicable disease action plan 2013–2020 (World Health Organisation, 2013). Our study is also especially relevant as the prevalence of overweight and obesity is very high in mid-adulthood in NZ, and because adverse adiposity outcomes are major public health concerns which lessen life expectancy (Fontaine et al., 2003). There was little evidence relating the relative change in distance to the nearest fast food outlet or nearest supermarket to change in BMI and WC. Slightly more consistent but small significant associations were seen for the relative percentage change in distance to the nearest five food outlets and access in terms of the E2SFCA and change in BMI and WC. For instance, the greatest proportional change reflecting a shorter distance to the nearest five fast food outlets from 30 to 40 years of age was related to adverse changes in both BMI and WC. Effects were mostly small especially when considering that these changes occurred over a 10-year time period however, such small but significant effects should not be dismissed as irrelevant especially when considered at a population level.

This study has several notable strengths and limitations. First, it uses food outlet data spanning 10 years and it uses birth cohort study data over 10 years, which is one of the first studies to combine both to our knowledge outside of the US-centric evidence base. Second, it has multiple metrics of access to the food environment for both fast food outlets and supermarkets in an attempt to capture multiple facets of the environment that individuals are exposed to. We attempted to account for migration affecting the study results through a sub-analysis of adults who moved and attempted to quantify effects of those who stayed in same place although our sample size was small due to Canterbury Earthquake Sequence. Despite this, a significant proportion of the study sample resided overseas or were not included in the age 30 or 40 year data collection wave making it difficult to conduct such analyses. Our data were limited by a tendency for the obtained samples to underrepresent males and those from socially disadvantaged backgrounds. Despite this, when using well-known data-weighting methods to



Note: BMI | Body Mass Index; WC | Waist Circumference; Enhanced Two-Step Floating Catchment Area (E2SFCA).

Fig. 4. Relative percentage change in driving distance from 2005 to 2015 to fast food outlets and change in BMI and WC (4A top left: change in BMI and change in distance to nearest fast food outlet, 4B top middle: nearest five outlets, and 4C top right: E2SFCA, 4D bottom left: change in WC and change in distance to nearest fast food outlet, 4E bottom middle: nearest five outlet and 4F bottom right: E2SFCA)

X) Stats NZ. Geographic Data Service - Meshblock 2018 Clipped (generalised). 2017 Dec - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/92198-meshblock-2018-clipped-generalised/

Y) Stats NZ. Geographic Data Service - Functional Urban Area 2018. 2021 Feb - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/105288-functional-urban-area-2018/

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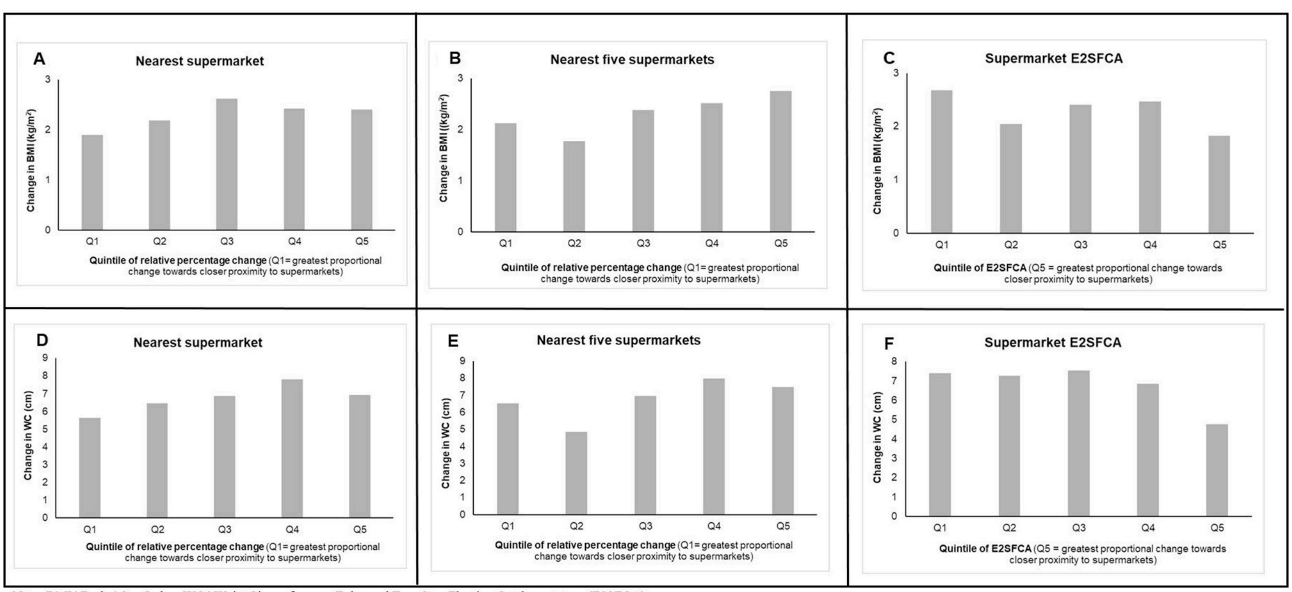

Note: BMI | Body Mass Index; WC | Waist Circumference; Enhanced Two-Step Floating Catchment Area (E2SFCA).

Fig. 5. Relative percentage change from 2005 to 2015 in driving distance to supermarkets and change in BMI and WC (5A top left: change in BMI and change in distance to nearest supermarket, 5B top middle: nearest five supermarkets and 5C top right: E2SFCA, 5D bottom left: change in WC and change in distance to nearest supermarket, 5E bottom middle: nearest five supermarkets and 5F bottom right: E2SFCA).

X) Stats NZ. Geographic Data Service - Meshblock 2018 Clipped (generalised). 2017 Dec - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/92198-meshblock-2018-clipped-generalised/

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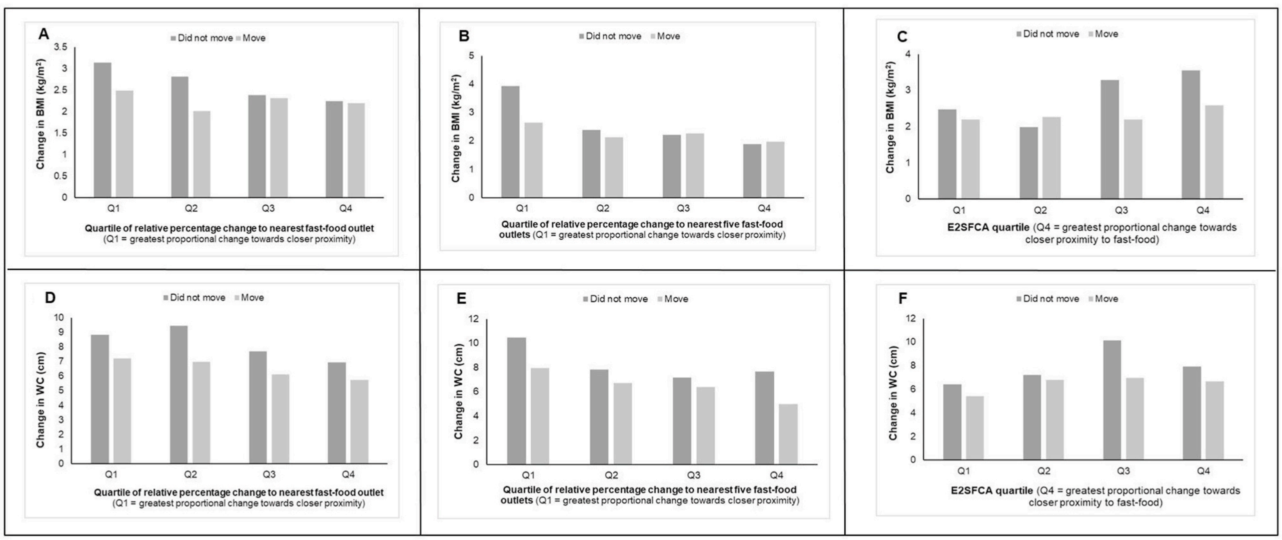
Table 2
Results from several regression models reporting the association between relative percentage change between 2005 and 2015 in distance and access to fast food outlets and supermarkets and change in BMI and WC.

	Distance to the nearest fast food outlet	Distance to the nearest five fast food outlets	E2SFCA fast food	Distance to nearest supermarket	Distance to nearest five supermarkets	ES2FCA supermarkets
Change in BMI	**−0.005 [-0.011, -0.0003]** *	**−0.01 [-0.02, -0.006]** *	2.52 [-1.23, 6.29]	−0.0003 [-0.003, 0.002]	**0.007 [0.0006, 0.01]** *	**−3.81 [-6.22, -1.40]** *
Change in WC	−0.019 [-0.044, 0.005]	**−0.05 [-0.09, -0.02]** *	**13.66 [0.90, 26.41]**	−0.001 [-0.009, 0.007]	0.01 [-0.01, 0.03]	**−10.11 [-18.18, -2.04]** *

Data are (b [95% CI]) and reported to two decimal places unless stated otherwise.
Fully adjusted mixed effects (random intercept) models adjusting for family socioeconomic status at birth, ethnicity, maternal BMI, paternal BMI and birth weight with individuals nested within current geographical areas (meshblock 2018).
Note: BMI | Body Mass Index; WC | Waist Circumference; Enhanced Two-Step Floating Catchment Area (E2SFCA).



Note: BMI | Body Mass Index; WC | Waist Circumference; Enhanced Two-Step Floating Catchment Area (E2SFCA).

Fig. 6. Relative percentage change in distance and access to fast food outlets and change in BMI and WC for those who moved address and those who did not move address between age 30 and 40 years (6A top left: change in BMI and change in distance to nearest fast food, 6B top middle: nearest five fast food and 6C top right: E2SFCA fast food, 6D bottom left: change in WC and change in distance to nearest fast food, 6E bottom middle: nearest five fast food outlets and 6F bottom right: E2SFCA fast food) (Q1 relates to the greatest proportional change towards closer proximity to food outlets).
Note: The base of plotted data including Meshblock 2018 (X), Functional Urban Area 2018 (Y), Digital Elevation Model (Z) is licensed under CC BY 4.0.
X) Stats NZ. Geographic Data Service - Meshblock 2018 Clipped (generalised). 2017 Dec - [cited 2022 Dec 1]. Available from: https://datafinder.stats.govt.nz/layer/92198-meshblock-2018-clipped-generalised/
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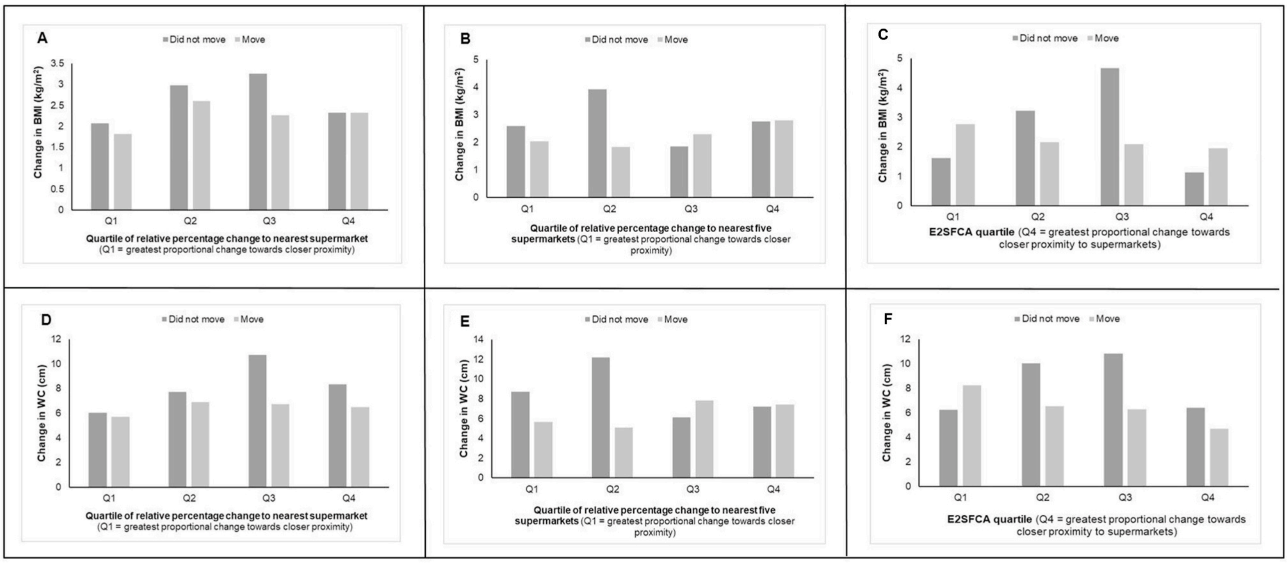
examine possible implications of selection effects arising from the pattern of missing data our analyses produced essentially the same pattern of results as those reported here for associations between change in food environment metrics and change in adiposity. This suggests that the conclusions of this study were unlikely to have been influenced by selection bias.

While this birth cohort study has some major methodological advantages, the use of context-specific methods (e.g. data on actual use of fast food outlets) and analyses (e.g. time-weighted analyses) to more accurately capture an individuals' actual exposure to food environments are needed to help unpick the complexity of associations between the food environment and adiposity (Hobbs and Atlas, 2019; Drewnowski et al., 2016; Jiao et al., 2015). More generally our findings relate to a specific cohort of NZ residents studied at a particular point in the life cycle, as such there is no guarantee that the findings will generalise to other contexts. It should also be noted that we were only able to use current addresses at age 30 and age 40, with no information on residency duration and thus exposure to the food environment between the time points, unless the cohort member had not changed residence. In addition, we were only able to accurately measure change in fast food outlet chains and major supermarket chains over time and could not accurately control for other factors such as physical activity levels or other environmental factors such as walkability. Other types of food outlets i.e. convenience stores/dairies or smaller fast food outlets co-define the healthiness of food environments, but these are harder to define and follow over time especially going back 10 years. We also did not obtain any data on the quality, price or rating of each outlet and as such only capture what is one part of the consumer food environment. In addition, our measure of relative change over time means that a change in access to food outlets from 500m to 250m, 1 km to 500m, and 5 km–2.5 km all have a relative percentage change of −50%, but the final examples are a lot further away in absolute terms. In addition, Christchurch was affected by the 2010-11 Canterbury Earthquake Sequence (CES) and damage to housing, offices and retailers has influenced presence and changes in food retailers; opportunity and necessity to move house and possibly stress-related weight gain (TonkinTaylor, 2021; Begg et al., 2021). Lastly, a small proportion of the sample had self-reported as opposed to objective measurements obtained for the



Note: BMI | Body Mass Index; WC | Waist Circumference; Enhanced Two-Step Floating Catchment Area (E2SFCA).

Fig. 7. Relative percentage change in distance and access to supermarkets and change in BMI and WC for those who moved address and those who did not move address between age 30 and 40 years (7A top left: change in BMI and change in distance to nearest supermarket, 7B top middle: nearest five supermarkets and 7C top right: E2SFCA supermarkets, 7D bottom left: change in WC and change in distance to nearest supermarket, 7E bottom middle: nearest five supermarkets and 7F bottom right: E2SFCA supermarkets) (Q1 relates to the greatest proportional change towards closer proximity to food outlets).

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majority of the cohort members which may induce some systematic bias in the self-reported measurements. Future research could explore in more detail the effects of the CES on the cohort, how the earthquake related to BMI, or for instance how movement in and out of particular areas over time or distance moved relates to changes in physical health outcomes.

Evidential inconsistency relating the food environment to adiposity is often said to exist due to a dominance of a cross-sectional studies (Wilkins et al., 2019). Our study provides evidence using a birth cohort, historical food environment data and controlling for historical factors to examine the extent to which changes in the food environment may explain changes in BMI and WC. In our study, the greatest proportional change towards shorter distance to nearest five fast food outlets from 30 to 40 years of age was related to adverse changes in measured BMI. Small but significant associations were also noted in this study relating relative change in access as measured by the E2SFCA to fast food outlets and measured WC. This is concerning given the adverse health implications of increased WC and visceral fat (Shuster et al., 2012; Jayedi et al., 2020). Mirroring our findings, previous studies have demonstrated similar small environmental effects on adiposity (Wilkins et al., 2019; Wilding et al., 2020; Mackenbach et al., 2014). It is important to interpret the small effects in our study in the light of individual versus population effects. For instance, a 10-year change in fast food outlet access may explain little of an individual's risk to become obese however, it does help explain the shift in population-level average BMI which has gradually shifted upwards and thereby increased burden of disease. It therefore remains important to monitor population level changes in the food environment and population level changes in adiposity (Rose, 1985). One should still be critical about small effect sizes that are statistically significant, but the direction of the associations, consistency among some of the results and the modest birth cohort sample size suggests that the findings should not be dismissed as inconsequential.

This study also demonstrated that the greatest proportional change towards shorter distance to supermarkets from 30 to 40 years of age was sometimes associated with more favourable changes in BMI and WC in this study sample. It could be argued that as access to supermarkets improves over time this may be beneficial for their BMI or WC. This may be due to the healthy foods available within supermarkets, although the role of supermarkets remains heavily disputed (Hobbs et al., 2021). With some exceptions (Morland et al., 2006; Jilcott et al., 2011; Morland and Evenson, 2009; Hattori et al., 2013), our findings are largely in contrast to previous inconsistent cross-sectional (Wilkins et al., 2019; Drewnowski et al., 2012; Cobb et al., 2015) and some longitudinal evidence (Gibson, 2011; Block et al., 2011; Hobbs et al., 2019b). For instance, a longitudinal study over 15 years of adults aged 18–30 years showed little association between supermarket access, diet quality and fruit and vegetable intake (Boone-Heinonen et al., 2011). Further, a recent natural experiment showed no relationship between a new neighbourhood grocery store and dietary behaviours respectively (Cummins et al., 2014). However, a recent randomised control trial saw the results of their obesity intervention modified by the number of supermarkets within an individual's neighbourhood. For the individuals participating in the randomised control trial, each 1-mile shorter distance to a supermarket was related to intervention participants increasing their fruit and vegetable intake by 0.29 servings/day and decreased their BMI z-score by −0.04 units relative to controls (Fiechtner et al., 2016). Supermarkets provide access to both fresh healthy produce and ultra-processed foods, and thus the role of the supermarket requires further exploration particularly within the NZ context. More broadly, it is also worth noting that in many prior longitudinal studies have short term follow-up periods.

In our study, the vast majority of participants moved house over the 10-year study period, limiting our ability to distinguish between selection effects of change in access to the food environment. The high number of movers in this sample was perhaps expected due to the Canterbury Earthquake Sequence, which commenced in 2010 and forced many to relocate during this time-period in this area (Tonkin-Taylor, 2021; Teng et al., 2017; Fergusson et al., 2014b; King et al., 2014; Bannister and Gledhill, 2012). For this analysis, we disregarded tests for statistical significance due to lower sample power however, the descriptive statistics provided some indications that associations between greatest proportional change towards shorter distance to fast food outlets and an increase in BMI and WC was somewhat stronger for those who stayed at the same address. This may suggest that the observed overall associations are mostly likely due to a causal effect of changing food environments on changing adiposity, rather than due to selective migration. However, this requires further research as the sample size of those who stayed was small and this uncertainty does not allow for strong conclusions to be drawn. We were unable to account for duration of any exposure in this study, which would contribute to more confidence in these sensitivity analyses. It needs to be noted though that historical and accurate food outlet data in NZ is sparse, limiting the opportunities to do so and this still remains an important step forward in the quality of evidence available for policy to intervene.

Recent policy efforts have focused on improving population level diet by creating healthy environments, in particular healthy food environments, for instance by restricting the proliferation of fast food outlets in areas where there is already a high concentration of fast food outlets (World Health Organisation, 2021b; Keeble et al., 2019). This is particularly important as diet-related non-communicable diseases are the leading contributors to poor health worldwide (Swinburn et al., 2013). Moreover, as little as 5 kg weight gain in middle adulthood has shown to be associated with significantly elevated incidence of a composite measure of major chronic diseases, consisting of type 2 diabetes, cardiovascular disease, cancer, and non-traumatic death (Zheng et al., 2017). This study adds to literature around the global (Vandevijvere et al., 2015), national (Ministry of Health, 2018b; Swinburn et al., 2013; Eyles et al., 2018) and local initiatives (Hond et al., 2019; Egli et al., 2016) carried out by policymakers including in public health and town planning as well who are focusing on the environmental determinants of health. One potential national-level lever is through the promotion of healthy food outlets or the restriction or regulation of unhealthy food outlets such as fast food outlets if, for instance, obesity levels are beyond a certain threshold within an area or if the density or proximity of fast food outlets exceeds an acceptable threshold. Recent UK documentation shows that 50.5% of local government areas ($n = 325$) had a policy specifically regulating proliferation of fast food outlets through urban planning using such means. It remains plausible that restricting or regulating unhealthy nutrient-poor, energy-dense foods is a potential policy-level intervention for the early prevention for adiposity among adults in New Zealand (Swinburn et al., 2011, 2013; Shill et al., 2012; Gortmaker et al., 2011) and such restrictions are already in place for alcohol outlets due to the social harm they may cause (Hobbs et al., 2020; Day et al., 2012). While evidence is not always consistent (Wilkins et al., 2019; Egli et al., 2020; Hobbs et al., 2019c), notable studies have related actual exposure such as time-weighted analyses for fast food outlets to consumption of fast food, which is in turn related to adverse outcomes such as BMI in both cross-sectional (Liu et al., 2020; Burgoine et al., 2016, 2018) and longitudinal research (Boone-Heinonen et al., 2011). This is important as exposure and consumption of fast food are the proposed mechanisms by which fast food outlets relate to adverse adiposity outcomes.

5. Conclusion

We provide evidence in a birth cohort study for statistically significant associations between several metrics of change in access to food outlets and change in measured adiposity as represented by measured BMI and waist circumference in New Zealand adults. Our findings may begin to help to explain the changes and increase in BMI and WC at a population level. Our findings may offer some support for the hypothesis that changes in modern food environments may have contributed to the obesity epidemic at a population level. It could therefore be argued that leverage points for halting the increases in population level BMI and WC should be sought in upstream interventions in terms of restricting access to unhealthy foods and fast foods outlets.

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Declaration of competing interest

The authors declare they have nothing to disclose.

Data availability

Details noted on cover page

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2023.103078.

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