Abstract

We used longitudinal information on area deprivation status to explore the relationship between residential-deprivation mobility and Cardiovascular Disease (CVD). Data from 2,418,397 individuals who were: enrolled in any Primary Health Organisation within New Zealand (NZ) during at least 1 of 34 calendar quarters between 1st January 2006 to 30th June 2014; aged between 30 and 84 years (inclusive) at the start of the study period; had no prior history of CVD; and had recorded address information were analysed. Including a novel trajectory analysis, our findings suggest that movers are healthier than stayers. The deprivation characteristics of the move have a larger impact on the relative risk of CVD for younger movers than for older movers. For older movers any kind of move is associated with a decreased risk of CVD.

Keywords

Mobility; Deprivation; Cardiovascular disease; Trajectories; New Zealand

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Introduction

Migration is an inherently selective process. It redistributes populations differentiated by stage in the lifecourse, socioeconomic status and ethnicity, to give a few examples (Boyle et al., 1998; Morrison and Nissen, 2010; Mosca and Wright, 2010; Simpson and Finney, 2009). This selective sorting is one mechanism through which neighbourhood level inequalities in health can emerge or are maintained (Boyle, 2004; Norman et al., 2005). This is a well-established area of investigation, capturing a multitude of geographies, health outcomes and populations. Yet the evidence for persistent social and spatial inequalities in health demonstrates the need to better understand the complexities of the relationship between health and migration.

Age is the strongest and most consistent predictor of migration (Plane, 1993): we are most mobile as young adults. At our most mobile, moves are commonly associated with entering higher education, seeking (graduate) employment, partnering and family formation (Fotheringham et al., 2004). In early childhood, moves may be prompted by changing housing needs while moves in later life are often associated with retirement or seeking (in)formal care. Thus, the factors governing a migration event vary with age, as does the relationship with health (Norman et al., 2005).

Young adult migrants tend to be healthier compared to young adult non-migrants, whereas older migrants tend to be less healthy than older non-migrants (Bentham, 1988; Norman et al., 2005). The apparent age- and health-selectivity of migration is complicated by wider socio-demographic attributes, individual circumstances and experience of particular health outcomes. Movers are not a homogenous group and aggregate summaries of their characteristics (e.g. their better health) are misleading (Larson et al., 2004). For example, Tunstall et al. (2014) found lower rates of poor general health and higher rates of poor mental health in aggregate analysis. But when stratified by age group, movers of all ages had equivalent or higher rates of poor general health and poor mental health relative to stayers.

The evidence for differences in health between movers and stayers varies depending not only on the health outcome in question (Boyle et al., 2002), but also the nature of the migration event. In the context of health, moves need to be defined in terms of frequency and the socio-spatial trajectory of the move. Frequent movers have the greatest risk of poor health outcomes (Geronimus et al., 2014), but highly mobile groups are disproportionately excluded from analysis given the difficulties in tracking them over time (Morris et al., 2018). Therefore, less is known about the experience of highly mobile groups. The relationship between health and migration varies depending on the socio-spatial trajectory of a move, which is important in terms of the role of selective sorting in contributing to health inequalities between areas. The health of those moving from less to more deprived areas tends to be poorer than the health of those moving in the opposite direction (Norman et al., 2005; Exeter et al., 2011).

Although the strength of the association varies depending on the time-frame investigated, the choice of health outcome, and the measure of deprivation. For example, a study in England and Wales covering a twenty-year time period found that selective migration could contribute to widening area level health inequalities for mortality and limiting long-term illness (Norman et al., 2005). In contrast, when looking at first change of address during a 10 year time period in the Netherlands, the influence of selective migration was found to be too small to contribute to neighbourhood inequalities in health and health-related behaviours (Van Lenthe et al., 2007). More recently, a UK-based study concluded that moves towards a more socioeconomically deprived area were associated with poorer general and mental health relative to more favourable socio-spatial trajectories, however this patterning did not hold for deprivation in the physical environment (Tunstall et al., 2014). Similarly, in New Zealand, risk of hospitalisation for a cardiovascular event was found to be higher for people moving to less deprived areas than for those moving in the opposite direction (Exeter et al., 2014).

It is notable that research into the socio-spatial trajectories of a move tends to determine change through combinations of area deprivation at the start and end points of the study period. However, for individuals who move several times over the observed period, this may not be representative of their experiences of deprivation. Furthermore, new residents in an area may not have been settled long enough for aspects of that area to have an influence on their health and health behaviours (Clarke et al., 2013; Curtis et al., 2004). Estimated associations between deprivation and health for those who move near the start or end of the observed period may therefore be biased.

This paper utilises a temporally-rich, morbidity-specific dataset to gain further insights into the complexities of the health-migration relationship. We focus on cardiovascular disease (CVD), an outcome of interest for a number of reasons. Firstly, CVD is the leading cause of death globally. In New Zealand (NZ) CVD is the largest single cause of death, which for many people would be premature or preventable (Ministry of Health, 2015). Secondly, a plethora of international evidence demonstrates a consistent association between neighbourhood-level socioeconomic factors with CVD (Chan et al., 2008; Cubbin et al., 2006; Grey et al., 2010; Pujades-Rodriguez et al., 2014; Ramsay et al., 2015). For example, Chan et al (2008) found that in NZ, people living in more deprived areas were between 1.5 to 2.5 times more likely to have CVD than people living in the least deprived areas, depending upon age. The nature of the local labour market (e.g. unemployment, instability, job-related stress), smoking uptake, healthcare provision are environmental risk factors associated with risk of CVD (Lang et al., 2012) and vary markedly by level of area deprivation. Thus, movement within and between different neighbourhoods will be pertinent to CVD risk: whether through the accumulation of exposure to pathogenic environments (Wannamethee et al., 2002), disrupting access to healthcare (Jelleyman and Spencer, 2008), influencing uptake of risky health-related behaviours, or through the complex interplay between the stress of a migration event (Oishi, 2010) combined with the stressors necessitating this move.

This paper extends existing research into the health-migration relationship in a number of ways. First, we test whether conclusions are enhanced when using a more nuanced measure of socio-spatial trajectories than differences between the first and last recorded experience of deprivation. Second, we contribute to literature examining the mechanisms driving inequalities in CVD in New Zealand, important given the prevalence of CVD-related preventable, premature deaths in the country (Ministry of Health, 2015). We use trajectory analysis to group individual's patterns of movement across deprivation quintiles in order to: i) determine the optimal number of trajectory groupings which captures the variability in movement patterns across the observed time period; and ii) model the association between these trajectories and risk of first CVD event, comparing these results with those participants who either move within the same deprivation quintile, or do not move during the study period.

Trajectory analysis has been used across different disciplines to categorise individuals into groups (Choi et al., 2012; Muthen and Muthen, 2000; Nagin and Land, 1993; Nagin and Odgers, 2010). This approach can reduce potential bias caused by loss to follow-up, and improve the efficiency of the statistical analyses by using all the available data from multiple time points rather than the first and last observations (Kenward and Carpenter, 2007; Little and Rubin, 2002). Trajectory analysis is therefore a useful tool that could offer important insights into whether specific deprivation trajectories increase the risk of CVD. To account for any existing selection effects and establish a cohort of similar risks, excluding those participants in poor health at the start of the study period is common practice (Boyle, 2004; Darlington-Pollock et al., 2016; Exeter et al., 2015; Norman et al., 2005). Following Darlington-Pollock et al.'s (2017) approach to establishing directional effects, we compare the risk of CVD for those who move prior to their first CVD event with risk of CVD for those who do not move prior to their first CVD event.

Data and methods

A cohort of participants was identified using an encrypted unique health identifier assigned to the majority of NZ residents enrolled in any Primary Health Organisation (PHO). These identifiers were used to link patient records in four national routine health databases: Enrolment with a Primary Health Organisation (PHO), hospital discharges, mortality records and pharmaceutical dispensing claims from community pharmacies. The cohort and sample have been described in detail elsewhere (Darlington-Pollock et al., 2016). Figure 1 details the selection of the analytic sample. Participants were eligible for inclusion in this analysis if they were enrolled in any PHO within NZ during at least 1 of 34 calendar quarters between 1st January 2006 to 30th June 2014, were aged between 30 and 84 years (inclusive) at the start of the study period. The cohort was censored such that people who had a CVD event and then moved were counted as stayers up to the event. Participants with a prior history of CVD at 1st January 2006, or prior to joining the cohort thereafter, were also excluded from the analysis. Those who were missing any address information were removed from the sample, leaving an analytic sample of 2,418,397 individuals.

Ethics

Ethical approval for this study was first granted by the Multi-Region Ethics Committee in 2011 (ref: MEC/11/EXP/078) with subsequent approvals from the Health and Disabilities Ethics Committee.

Measures

Cardiovascular Events

First major CVD event was defined by ICD-10-AM codes as a hospitalisation or death from: ischaemic heart disease; ischaemic or haemorrhagic cerebrovascular events, transient ischaemic attacks; peripheral vascular disease, congestive heart failure, other atherosclerotic CVD deaths.(Wells et al., 2015). For ICD-10-AM codes see appendix 1. Of the analytic sample, 6.93% had their first CVD event during the 34 calendar quarters observed.

Demographic measures

Age in years was treated as a continuous variable ranging from 30 to 84 (mean=49.08, SD=13.40). Patient's self-identified ethnicity was prioritised according to national protocols to ensure each individual was assigned to one ethnic group. This study reports results by ethnicity for Māori (8.73%, Pacific (4.98%), Indian (2.49%), Other Asian (5.87%) and New Zealand European and All Other Ethnic groups combined (NZEO 77.93%). We distinguished between Indian and other Asian ethnic groups as Indian participants are known to have a higher risk of CVD (Ministry of Health, 2015).

Geographical measures

We used Meshblock codes from the PHO enrolment database to identify the location of a patient in each calendar quarter. Census Meshblocks are geographical units that consist of an average population of approximately 100 persons. This is the lowest level of geography available with census data in New Zealand. We used the New Zealand Index of Deprivation (NZDep2006) to measure socioeconomic deprivation at the Meshblock level (Atkinson et al., 2014). NZDep2006 combines nine variables representing eight dimensions of deprivation using principal components analysis, and deprivation scores for each Meshblock were categorised into quintiles whereby Quintile 1 (Q1) represents the least deprived 20% of areas in NZ, and Quintile 5 (Q5) the 20% most deprived. Note that the 2011 Census was postponed until 2013 due to devastating earthquakes, and therefore NZDep2013 was not released until the very end of our study period, hence NZDep2006 has been used throughout. Note that quintiles of area deprivation linked to individual records are available for research purposes rather than the original continuous scores.

Mobility

We defined three major residential-deprivation mobility groups: those who moved between deprivation quintiles (‘movers’: n=949,537)), those who moved within the same deprivation quintiles (‘churners’: n=256,179)), and those who did not move (‘stayers’: n=1,212,681). Only moves prior to CVD events were included in the analysis. Movers and churners were those individuals with at least two unique Meshblock values during the 34 calendar quarters (27% of the sample had one move recorded, 12.6% had two moves recorded, 5.6% had three moves recorded and 4.6% had 4 or more moves (up to 20 meshblock values) recorded). Churners were assigned the relevant deprivation quintile: Quintile 1 (n=74,560), Quintile 2 (n=42,635), Quintile 3 (n=36,444), Quintile 4 (n=39,548), Quintile 5 (n=62,992). Stayers were also assigned the deprivation level of the Meshblock they resided in: Quintile 1 (n=289,357), Quintile 2 (n=262,831), Quintile 3(n=241,346), Quintile 4 (n=223,593), Quintile 5 (n=195,554).

Observational time period

We calculated each participant’s observed duration in the study as the number of calendar quarters from first enrolment in a PHO to the calendar quarter of first CVD event, or the entire period of enrolment in any PHO if no CVD event occurred (mean observed time [calendar quarters]=26.24, SD=9.98, min=1, max=34). This measure was created to account for the censoring of the data, acknowledging that a longer observation period, and thus a greater opportunity to observe mobility, would be associated with a lower risk of CVD. Furthermore, a differential number of quarters was observed for participants due to variations in entry time or loss to follow up.

Analysis

Step 1: We used the STATA plug in 'traj' (Jones and Nagin, 2013) to perform trajectory analysis on the movers (Jones and Nagin, 2007; Jones et al., 2001). This procedure groups individuals who follow similar trajectories across deprivation quintiles in the observed time period. Movers were assigned to trajectory groups based on probability of group membership. Following the example of Jones et al. (2001), we used the change in BIC values between models to determine the optimal number of trajectory groups (Jones et al., 2001). In addition to BIC values, we assessed the model's adequacy according to the following criteria, : 1) a close correspondence between the estimated probability of group membership and the proportion assigned to that group based on the probability of group membership; 2) ensuring that the average of the probabilities of group membership for individuals assigned to each group exceeds a minimum threshold of 0.7; and 3) observing reasonably tight confidence intervals around estimated group membership probabilities (Nagin, 2005).

We started with a single group model, and intended to continue to test solutions until there was no longer a change in BIC value. The Centre for E-research at the University of Auckland provided us with additional computing power for a period of time, in which we were able to test cubic solutions (these were not possible with the sample size on our standard work computers). Linear models, quadratic and cubic solutions were tested for each solution. Likelihood ratio tests were used to compare quadratic to linear models and cubic to quadratic models. For the trajectory analysis, missing data were handled using a Maximum Likelihood (ML) algorithm, which does not fill in the missing values, but uses each case's available data to compute the parameter most likely to have resulted in the observed data (Enders and Bandalos, 2001). Simulation studies show that Maximum Likelihood and Multiple Imputation perform equally well under a range of conditions (Newman, 2003). Here we use Maximum Likelihood, as this is the most efficient and robust technique for estimating trajectory membership.

Step 2: We used a Cox proportional hazard model to examine the relationship between mobility and the risk of CVD event (model 1), and between residential-deprivation mobility groups (trajectory groups for movers, deprivation quintiles for churners and stayers) and risk of CVD event (model 2). We present the results as hazard ratios in tables. Stayers in deprivation quintile 1 (least deprived) were the reference category. We adjusted models for age, age squared, sex, ethnicity, number of quarters observed (prior to event), and number of moves. We tested higher order polynomials of age (age squared, and age cubed) to account for a nonlinear relationship between age and CVD, age squared was included in the models. We tested interactions between age (and age squared) and residential-deprivation mobility groups. Following significant interactions, results were presented stratified by age groups.

Comparisons between the trajectory analysis approach and taking the first and last observation are presented in appendix 3.

Results

<u>Trajectory analysis</u>

There were 949,537 movers eligible for trajectory analysis. A six grouping trajectory was chosen as the best fit, based on BIC values (see appendix 2), the statistical stability of the model, and greater adherence to the criteria for optimal groups. Descriptive names were assigned to each trajectory:

- Trajectory 1 (T1): moves out of least deprived areas
- Trajectory 2 (T2): moves into least deprived areas
- Trajectory 3 (T3): moves from mid into less deprived areas
- Trajectory 4 (T4): moves from mid into more deprived areas
- Trajectory 5 (T5): moves out of most deprived areas
- Trajectory 6 (T6): moves into most deprived areas

There were 16 distinct residential-deprivation mobility groups: 6 trajectories for the movers, 5 deprivation quintiles for the churners, and 5 deprivation quintiles for the stayers.

The estimated trajectories are shown in figure 2. All estimated trajectories were monotonic.
An excerpt of the trajectory results are shown in table 1. Individuals are assigned to trajectory groups based on the highest probability of group membership. On average, individuals within trajectory groups had an average probability of >0.94 of being assigned to that trajectory group. For a small number of individuals (0.5%), the probability of being in any trajectory group was <0.5. These individuals had larger amounts of missing data on average (mean number of observed quarters = 9.21). Those movers with no missing information, tended to have more complicated deprivation trajectories such as: highest-, lowest-, highest-, lowest- and mid-levels of deprivation.

As shown in table 1, case 9 represents an example of where taking first and last observation (first=4, last=5) may not provide an accurate summary of experienced deprivation. Further investigation, shown in Appendix 3, demonstrates that taking information from the first and last observation could result in 157,595 (6.5%) individuals being misclassified as remaining within the same deprivation quintile. A further 109,505 (4.5%) could be classified as moving into areas of increased deprivation, when trajectory analysis suggests decreased deprivation, or classified as moving into decreased deprivation when the trajectory analysis suggests increased deprivation.

Cox proportional hazards regression

Table 2 shows the results of the logistic regression modelling the odds of a participant in the sample having their first CVD event. The greater the number of quarters observed (up to event for those who have CVD event), the lower the risk of a CVD event (HR=0.88 (0.88-0.88)). Prior to adjustment for mobility groups (model 1) an increasing number of moves resulted in decreased odds of a CVD event (HR=0.80(0.79-0.80)). However, after adjustment for the differential deprivation profiles of these move events (model 2) there was no association between number of moves and odds of a CVD event (HR=0.99 (0.99-1.00).

The results (model 2) show a lower risk of having a CVD event for all movers compared to stayers in the least deprived areas, with the exception of one trajectory group: Those moving into the most deprived areas (T6: HR=0.99 (0.95-1.02)). Churners in NZDep quintiles 1 through 4 had a lower risk of a CVD event than stayers in the least deprived quintile (Churners Q1: HR=0.59 (0.56-0.62), Q2: HR=0.72 (0.69-0.76) Q3: HR=0.80 (0.76-0.84), Q4: HR=0.92 (0.88-0.96). Churners in NZDep quintile 5 had an increased risk of a CVD event compared to stayers in the least deprived quintile (HR=1.16 (1.12-1.20)), but the risks were much lower than for stayers in the most deprived quintile (HR=1.54 (1.51-1.57)).

Age interactions

First we tested the interaction of age and residential-deprivation mobility group ($X^2(15)=2761.01$, $p<0.01$), and then the interactions between age ($X^2(15)=48.44$, $p<0.01$), age squared ($X^2(15)=59.66$, $p<0.01$), and residential-deprivation mobility groups. Table 3 presents the model stratified by age groups: 30-39, 40-49, 50-59, 60-69, 70-84.

For the youngest age group (30-39) residential deprivation had a larger impact on the relative risk of CVD event than for older age groups. Moving out of low deprivation (T1: HR=0.78(0.65 – 0.95)) was associated with a lower risk of CVD than staying in low deprivation areas. There was no significant difference in risk between moving out of low dep (T2: HR= 1.09 (0.92-1.29)), or moving in and out of mid deprivation (T3: HR=1.15(0.99-1.32), T4: HR=1.11(0.96-1.28)), and a large increase in risk for those moving into and out of areas of high deprivation (T5: HR=1.69(1.48-1.93), T6: HR=1.69 (1.46-

1.96)). Those staying in the most deprived quintile had over the twice the risk of CVD than those staying in the least deprived quintile (Stayer Q5: HR=2.65 (2.34-2.99)).

By contrast, among the oldest age group (70-84) any form of movement trajectory is associated with a decreased risk of CVD compared to staying in the least deprived quintile (T1: HR=0.55 (0.51-0.59), T2: HR=0.67 (0.62-0.73) T3: HR=0.76 (0.72-0.81) T4: HR=0.76 (0.71-0.80) T5: HR=0.70 (0.66-0.75) T6:HR=0.82 (0.76-0.88)). Similarly, churning within any deprivation quintile showed a similar trend (churning Q1: HR=0.64 (0.59-0.69) Q2: HR=0.75(0.69-0.81) Q3: HR=0.70(0.64-0.76) Q4: HR=0.79(0.73-0.86) Q5: HR=0.89 (0.83-0.96)). Staying in the most deprived quintile (stayer Q5: HR=1.21 (1.1-1.24)) was associated with an increase in CVD risk, but this relative difference is much larger for younger age groups

The risk of CVD is much lower in the younger age groups and so relative differences in CVD risk by residential-deprivation mobility group may not translate into absolute differences. Figure 2 presents a graph from the interaction model for three ages, 30, 50 and 70 demonstrating the predicted probability of having an event across the observation period holding all covariates at their observed values. The deprivation gradients appear much stronger for the older age groups, because the difference in the absolute risk is larger, but the relative differences are larger in the younger age groups.

Discussion

To our knowledge, this is the first use of trajectory analyses to model residential mobility in a health geography context, and the first analysis performed on more than 2 million participants. We found this method produced different classification of individual's deprivation trajectories than taking the first and last observation. We found six mobility groups with distinct patterns of movement between deprivation quintiles. Our main findings were that movers had a lower risk of CVD than stayers. The deprivation characteristics of the move have a larger impact on the relative risk of CVD for younger movers than for older movers. For older movers any move, even to higher deprivation, is associated with a decreased risk of CVD. For movers, churners or stayers there was evidence for a deprivation gradient in CVD risk.

Our findings provide support of the healthy migrant hypothesis: those who move are generally healthier than those who they leave behind (Bentham, 1988; Boyle, 2004; Boyle et al., 1998; Norman et al., 2005). Among older participants any move, even to a more deprived area, was associated with a decreased risk of CVD event. For younger participants the risk of a CVD event was lower for churners and movers in areas of low deprivation than for stayers' in areas of low deprivation. The healthy migrant effect was also apparent among movers in areas of high deprivation, who had lower odds of a CVD event than stayers in areas of high deprivation.

Reasons for moving vary markedly between high and low mobility groups (DeLuca et al., 2011). Highly mobile populations tend to move across shorter distances, be those in poverty, renters, often experiencing 'involuntary' or 'forced' mobility in response to external forces such as increased rent and housing costs, eviction, and poor housing quality (DeLuca et al., 2011). Higher mobility is therefore more commonly associated with people living in lower socioeconomic circumstances, who are also more likely associated with poorer health. Less frequent movers on the other hand comprise a mixture of renters (often young professionals) and home owners who typically move longer distances, and to improve their situation, such as moving closer to work or to a larger house (Böheim and Taylor, 2002; DeLuca et al., 2011; Morrison and Nissen, 2010). The more socioeconomically advantaged circumstances of groups with higher mobility may explain the unadjusted protective effect of mobility against CVD. However, accounting for the deprivation profile of the move fully accounts for the protective effect of mobility.

The relationship between residential mobility and health is complex, with both the move itself and the area deprivation trajectory of the move being important in respect of health. We found deprivation gradients existed for CVD risk for both movers and stayers. These deprivation gradients may be exacerbated through the influence of selective migration: as healthy people leave deprived areas, unhealthy people move in (Norman et al., 2005). This likely interacts with the existing influence of place on individual health (Stafford and Marmot, 2003), whether through shaping uptake of different health behaviours, by access to local services or even features of the social environment such as the existence of support networks (Bécares et al., 2013).

Indeed, a recent analysis of the causal effect of area-level deprivation on health found health differentials were driven by differential mobility patterns by health, rather than neighbourhood deprivation per se (Jokela, 2015). However, these data do not capture reason for the move or record wider experiences of the social environment or socioeconomic attributes. These unrecorded factors may be important in exploring risk of CVD between movers and stayers. More work is needed to examine whether the consequences for health from place-effects and selective migration varies between sub-groups in society, e.g. ethnic groups, depending on aspects such as socioeconomic position and history within a country.

Implications for research/practice

Trajectory modelling resulted in different categorisations of individuals into residential deprivation mobility groups than did taking the first and last observation (appendix 3). However, because of the large sample size, fitting trajectory models was not straightforward. For example, processing time for the chosen quadratic solution with 6 groups was in excess of 3 days. More complex models (higher number of groups, or higher order polynomials) took longer, or did not converge at all. While the trajectory models take advantage of all of the longitudinal deprivation information available, the aim of the analysis is still to provide the simplest model possible to group observations into a smaller number of groups. Trajectory analysis is a flexible approach and can account for nonlinear and non-monotonic changes over time, however our solution suggested six monotonic trajectory groups. Therefore people with complicated deprivation trajectories, or who move frequently, may not be well accounted for. Indeed, we found lower probabilities of assignment to trajectory groups for those with large amounts of missing information, or for those with complex deprivation trajectories. Where people have non-monotonic trajectories, the trajectory model is most likely to select a trajectory group based on the deprivation quintiles in which the individual spent the most amount of quarters. Consider, a person who lives in a most deprived (i.e. highest deprivation quintile) area for the first 10 quarters, and then moves to the an area of average deprivation for the next 20 quarters, and moves again in the last 4 quarters to the highest deprivation quintile. According to these analyses, they would have a very high probability of being in trajectory group 5 (from most deprived to lower deprivation), and a very low probability of being in trajectory group 6 (from lower deprivation to most deprived areas).

Selecting the appropriate trajectory model has been described by some as an “art”(Ram and Grimm, 2009). It is possible in trajectory modelling to end up with a number of groups that is too large to be practically useful, with the BIC value still decreasing. Therefore some authors suggest model testing and selection should be firmly based on previous research and theory, with researchers hypothesising the number of trajectory groups a-priori, and then testing solutions with +/- 1-2 groups from this hypothesised solution (Ram and Grimm, 2009). In this way, trajectory analysis has potential to test and improve upon theories. This hypothesis-driven method would have been an efficient way to conduct the analysis, as the trajectory group’s estimated by the model in this study are similar to those that would have been hypothesised by the authors.

Strengths and limitations

We used a longitudinal set of linked anonymised records covering 94% of NZ's adult population. This provided us with adequate statistical power to assess the relationship between residential mobility and CVD event by residential-deprivation mobility groups. These data also allowed us to take account of the ordering of residential moves and CVD events.

There are several limitations to this research: firstly, we only observe individuals across a given time period, we do not know their prior deprivation, health or migration histories, only that they have never had a CVD event. Secondly, we focus on area level deprivation, but there are many other important predictors of CVD that are not included in this modelling, such as smoking, stress and other lifestyle factors. Thirdly due to data availability, we only use one time point to capture area deprivation though we recognise that areas may change their relative level of deprivation over time (Norman, 2010; Norman and Darlington-Pollock, 2017) in part due to the selective migration of people with particular characteristics. Fourthly, and as already discussed, we do not know the housing tenure or reasons for moving. Given these key mechanisms are likely driving the relationship between mobility and CVD risk, further research is required.

Finally, the meshblock information used to measure residential mobility were obtained from the quarterly Primary Health Organisation (PHO) enrolment data. Unfortunately, information regarding how often a patient is asked about their address is not collected in the national collections by the Ministry of Health. While the last consultation date could be used to determine whether the patient was seen during a particular calendar quarter, there is no information available regarding their move date, or when their address information was updated in the PHO registers (Personal communication, Chris Lewis, Ministry of Health 05/04/2018).

Conclusion

Trajectory analysis provides a novel and useful way to group, and incorporate repeated measures of area level deprivation into analytic models, where the results are potentially more accurate than taking the first and last observation. However, trajectory models are computationally intensive and can be difficult to implement in large data sets. The deprivation characteristics of the move have a larger impact on the relative risk of CVD for younger movers than for older movers.

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Figure 1. Flowchart describing inclusion criteria for the analytic sample

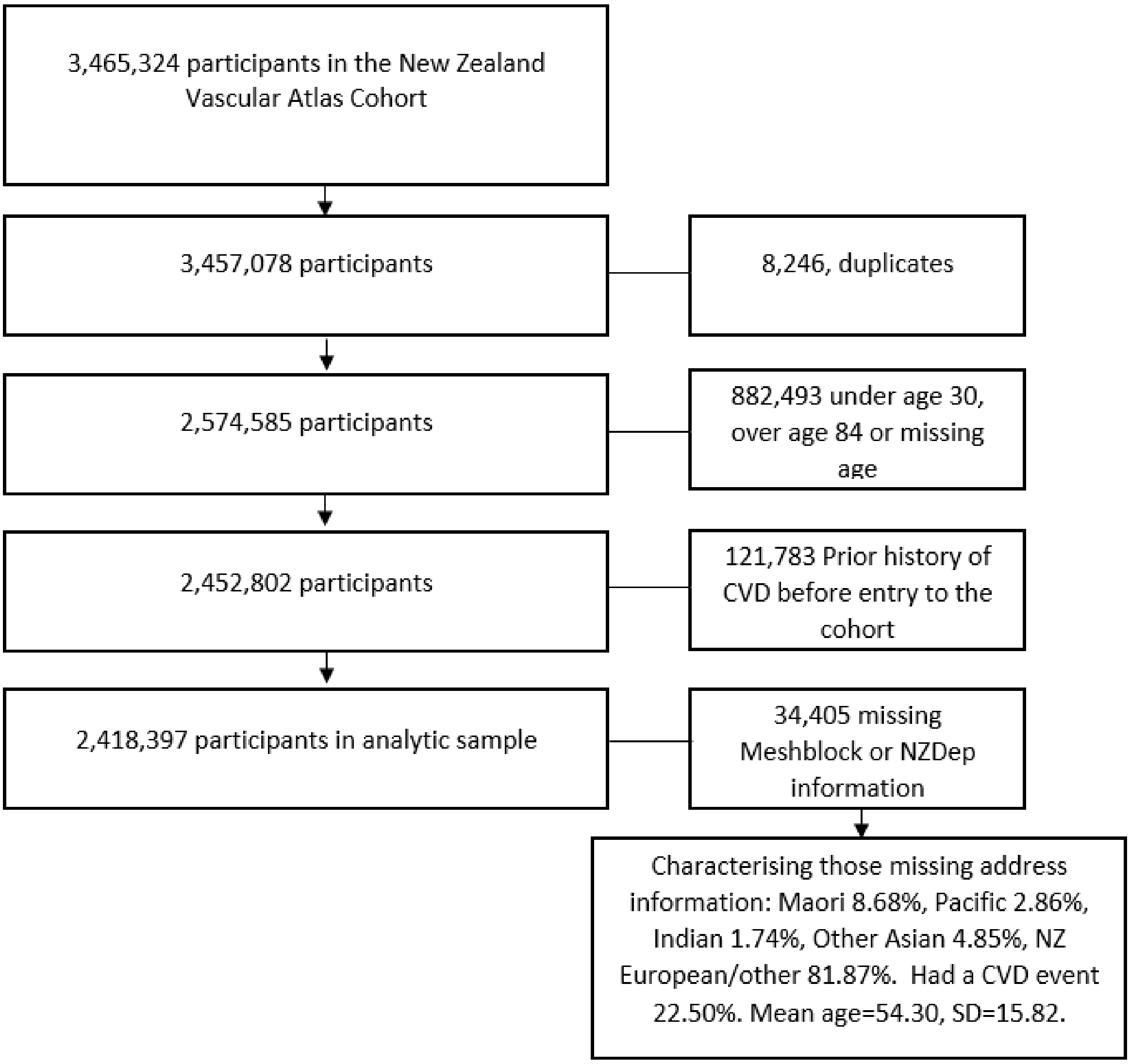
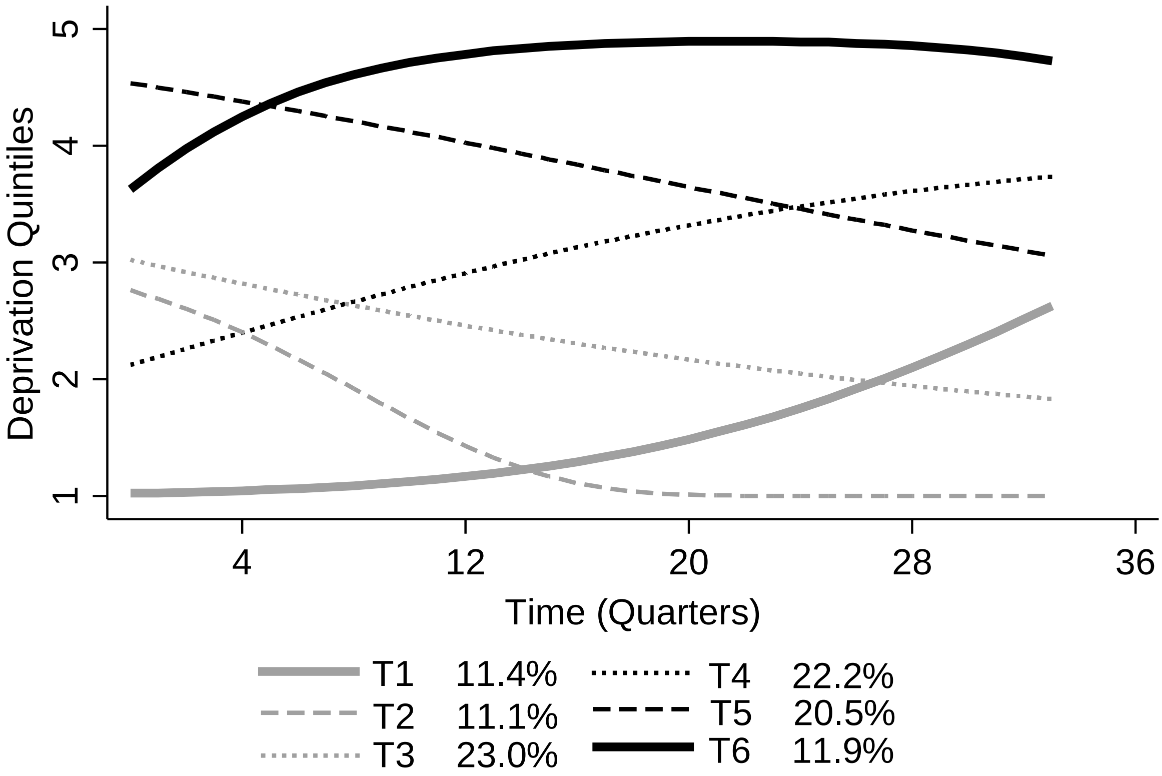


Figure 2. Trajectories of mobility across 34 quarters



T1: move from least deprived quintile to higher deprivation,
T2: move from mid deprivation to least deprived areas,
T3: move from mid deprivation to less deprived area,
T4: move from lower mid deprivation to higher deprivation,
T5: move from most deprived to lower deprivation,
T6: move from lower deprivation into most deprived areas.

Table 1. Example of trajectory analysis output.

	Deprivation quintile across 34 quarters	assigned group	Probability of group assignment T1	T2	T3	T4	T5	T6
1	5555555533333333333333333333333333	5	0.00	0.00	0.00	0.00	1.00	0.00
2	11333333333333333333333333333	4	0.00	0.00	0.00	1.00	0.00	0.00
3	5555555555555555555533333333333333	5	0.00	0.00	0.00	0.00	1.00	0.00
4	3311111111111111111111111111111111	3	0.00	0.00	1.00	0.00	0.00	0.00
5	3333333333...111111114444444444444	4	0.00	0.00	0.00	1.00	0.00	0.00
6	441111111111......................	3	0.15	0.00	0.85	0.00	0.00	0.00
7	333222222222	2	0.07	0.92	0.00	0.00	0.01	0.00
8	2222222222222333312222222222221111	2	0.00	1.00	0.00	0.00	0.00	0.00
9	44444444443333333...233333.......5	5	0.00	0.00	0.00	0.03	0.97	0.00
10	4444444455425555533333333333333333	5	0.00	0.00	0.00	0.00	1.00	0.00

Note: 1= lowest deprivation quintile and 5=lowest deprivation quintile. The "." denotes a missing value for deprivation in that quarter.

T1: move from least deprived quintile to higher deprivation,
T2: move from mid deprivation to least deprived areas,
T3: move from mid deprivation to less deprived area,
T4: move from lower mid deprivation to higher deprivation,
T5: move from most deprived to lower deprivation,
T6: move from lower deprivation into most deprived areas.

Table 2. Cox proportional hazards model of the relationship between trajectory mobility groups and risk of CVD event

	Model 1	Model 2
Number of moves	0.80	0.99
	[0.79 -0.80]	[0.98 - 1.00]
quarters observed	0.88	0.88
	[0.88 - 0.88]	[0.88 - 0.88]
Mover T1: *from least deprived quintile to higher deprivation*		0.55
		[0.53 - 0.57]
Mover T2: *from mid deprivation to least deprived areas*		0.75
		[0.72 - 0.78]
Mover T3: *from mid deprivation to less deprived area*		0.77
		[0.75 - 0.80]
Mover T4: *from lower mid deprivation to higher deprivation*		0.78
		[0.76 – 0.80]
Mover T5: f*rom most deprived to lower deprivation*		0.89
		[0.86 – 0.92]
Mover T6: *from lower deprivation into most deprived area*		0.99
		[0.95 - 1.02]
Churner Q1 (least deprived)		0.59
		[0.56 - 0.62]
Churner Q2		0.72
		[0.69 - 0.76]
Churner Q3		0.80
		[0.76 - 0.84]
Churner Q4		0.92
		[0.88 – 0.96]
Churner Q5 (most deprived)		1.16
		[1.12 - 1.20]
Stayer Q1 (least deprived)		ref
Stayer Q2		1.12
		[1.10 - 1.14]
Stayer Q3		1.29
		[1.26 - 1.31]
Stayer Q4		1.47
		[1.44 - 1.50]
Stayer Q5 (most deprived)		1.54
		[1.51 - 1.57]
Log likelihood	-2157076.6	-2153802.9
N	2,400,904	2,400,904

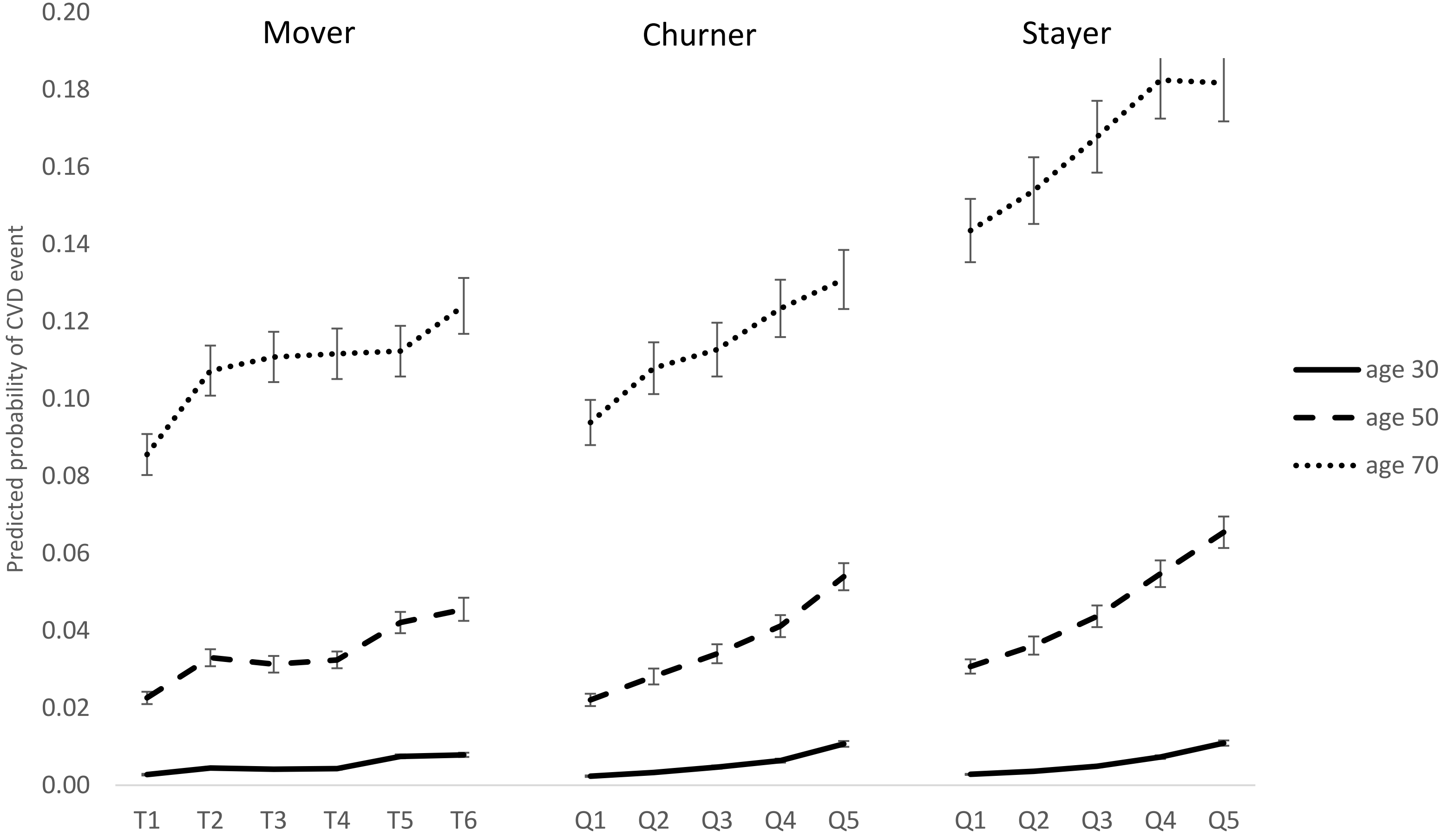
Model 1 considers the relationship between number of moves observed and odds of a CVD event, Model 2 considers mobility groups (trajectory groups, churners, and stayers).
Models also adjusted for age, age squared, gender, and ethnicity.
n=17349 are only observed for one time period and are excluded from the model
Trajectory analysis conducted on Movers (those who move to a different deprivation quintile)

Table 3. Cox proportional hazards model of the relationship between trajectory mobility groups and risk of CVD event stratified by age group.

	30-39	40-49	50-59	60-69	70-84
Number of moves	1.04	1.01	1.00	0.96	0.83
	(1.02 - 1.07)	(0.99 - 1.03)	(0.98 - 1.02)	(0.93 - 0.98)	(0.81 - 0.86)
quarters observed	0.87	0.87	0.88	0.88	0.88
	(0.87 - 0.87)	(0.87 - 0.87)	(0.88 - 0.88)	(0.88 - 0.88)	(0.88 - 0.88)
Mover T1: *from least deprived quintile to higher deprivation*	0.78	0.66	0.66	0.63	0.55
	(0.65 - 0.95)	(0.59 - 0.75)	(0.60 - 0.71)	(0.58 - 0.69)	(0.51 - 0.59)
Mover T2: *from mid deprivation to least deprived areas*	1.09	0.99	0.95	0.89	0.67
	(0.92 - 1.29)	(0.89 - 1.10)	(0.88 - 1.03)	(0.82 - 0.96)	(0.62 - 0.73)
Mover T3: *from mid deprivation to less deprived area*	1.15	1.11	0.90	0.84	0.76
	(0.99 - 1.32)	(1.02 - 1.21)	(0.84 - 0.97)	(0.79 - 0.90)	(0.72 - 0.81)
Mover T4: *from lower mid deprivation to higher deprivation*	1.11	1.07	0.90	0.90	0.76
	(0.96 - 1.28)	(0.99 - 1.16)	(0.84 - 0.96)	(0.85 - 0.96)	(0.71 - 0.80)
Mover T5: f*rom most deprived to lower deprivation*	1.69	1.40	1.13	0.95	0.70
	(1.48 - 1.93)	(1.30 - 1.51)	(1.06 - 1.21)	(0.90 - 1.02)	(0.66 - 0.75)
Mover T6: *from lower deprivation into most deprived area*	1.69	1.41	1.26	1.09	0.82
	(1.46 - 1.96)	(1.29 - 1.54)	(1.17 - 1.36)	(1.01 - 1.17)	(0.76 - 0.88)
Churner Q1 (least deprived)	0.68	0.72	0.67	0.63	0.64
	(0.54 - 0.86)	(0.63 - 0.81)	(0.61 - 0.74)	(0.57 - 0.69)	(0.59 - 0.69)
Churner Q2	1.12	0.92	0.84	0.71	0.75
	(0.90 - 1.40)	(0.80 - 1.05)	(0.75 - 0.94)	(0.64 - 0.80)	(0.69 - 0.81)
Churner Q3	1.06	1.19	1.01	0.92	0.70
	(0.83 - 1.35)	(1.03 - 1.37)	(0.90 - 1.14)	(0.83 - 1.02)	(0.64 - 0.76)
Churner Q4	1.55	1.32	1.16	1.04	0.79
	(1.28 - 1.89)	(1.17 - 1.49)	(1.05 - 1.28)	(0.95 - 1.14)	(0.73 - 0.86)
Churner Q5 (most deprived)	2.13	1.74	1.46	1.13	0.89
	(1.84 - 2.46)	(1.60 - 1.90)	(1.35 - 1.57)	(1.04 - 1.22)	(0.83 - 0.96)
Stayer Q1 (least deprived)	ref	ref	ref	ref	ref
Stayer Q2	1.24	1.14	1.17	1.14	1.06
	(1.08 - 1.41)	(1.07 - 1.22)	(1.12 - 1.22)	(1.10 - 1.18)	(1.04 - 1.09)
Stayer Q3	1.69	1.37	1.36	1.37	1.13
	(1.48 - 1.92)	(1.29 - 1.46)	(1.31 - 1.43)	(1.33 - 1.42)	(1.10 - 1.17)
Stayer Q4	2.15	1.82	1.69	1.55	1.23
	(1.89 - 2.43)	(1.71 - 1.93)	(1.62 - 1.77)	(1.49 - 1.60)	(1.20 - 1.27)
Stayer Q5 (most deprived)	2.65	2.23	1.97	1.58	1.21
	(2.34 - 2.99)	(2.10 - 2.37)	(1.88 - 2.05)	(1.53 - 1.64)	(1.17 - 1.24)
Loglikelihood	-80,663.07	-229,047.52	-379,885.80	-479,790.64	-746,293.78
N	700,724	660,959	501,218	309,674	228,329

Models also adjusted for age, age squared, gender, and ethnicity.

Figure 3. Predicted probability of having a CVD event by age and residential-deprivation mobility group. Error bars represent 95% confidence Intervals.



T1: move from least deprived quintile to higher deprivation, T2: move from mid deprivation to least deprived areas, T3: move from mid deprivation to less deprived area, T4: move from lower mid deprivation to higher deprivation, T5: move from most deprived to lower deprivation, T6: move from lower deprivation into most deprived areas. Q1 = least deprived quintile, and Q5 = most deprived quintile.

Appendix 1: ICD-10-AM codes for defining CVD events

Supplementary table 1 provides the ICD-10-AM codes used to define first major CVD event in this research paper. It relates to a broad definition of CVD events. Prior history of CVD events was defined using the same set of codes with the exception of code I461, referring to sudden cardiac death.

Supplementary table 1. Definition of first CVD event

Clinical Code	Description
I210	Acute transmural myocardial infarction of anterior wall
I211	Acute transmural myocardial infarction of inferior wall
I212	Acute transmural myocardial infarction of other sites
I213	Acute transmural myocardial infarction of unspecified site
I214	Acute subendocardial myocardial infarction
I219	Acute myocardial infarction, unspecified
I220	Subsequent myocardial infarction of anterior wall
I221	Subsequent myocardial infarction of inferior wall
I228	Subsequent myocardial infarction of other sites
I229	Subsequent myocardial infarction of unspecified site
E1050	Insulin-dependent diabetes mellitus with peripheral circulatory complications, not stated as uncontrolled
E1051	Insulin-dependent diabetes mellitus with peripheral circulatory complications, stated as uncontrolled
E1052	
E1059	
E1150	Non-insulin-dependent diabetes mellitus with peripheral circulatory complications, not stated as uncontrolled
E1151	Non-insulin-dependent diabetes mellitus with peripheral circulatory complications, stated as uncontrolled
E1152	
E1159	
E1451	Unspecified diabetes mellitus with peripheral circulatory complications, stated as uncontrolled
E1452	
E1459	
I250	Atherosclerotic cardiovascular disease, so described
I2510	Atherosclerotic heart disease, of unspecified vessel
I2511	Atherosclerotic heart disease, of native coronary artery
I2512	Atherosclerotic heart disease, of autologous bypass graft
I2513	Atherosclerotic heart disease, of nonautologous biological bypass graft
I258	Other forms of chronic ischaemic heart disease
I259	Chronic ischaemic heart disease, unspecified
I469	Cardiac arrest, unspecified
3270000	Carotid bypass using vein
3270001	Carotid-carotid bypass using vein
3270002	Carotid-subclavian bypass using vein
3270003	Carotid-vertebral bypass using vein

3270004	Aorto-subclavian-carotid bypass using vein
3270005	Carotid bypass using synthetic material
3270006	Carotid-carotid bypass using synthetic material
3270007	Carotid-vertebral bypass using synthetic material
3270008	Carotid-subclavian bypass using synthetic material
3270009	Aorto-carotid bypass using synthetic material
3270010	Aorto-carotid-brachial bypass using synthetic material
3270011	Aorto-subclavian-carotid bypass using synthetic material
3270300	Resection of carotid artery with re-anastomosis
3270800	Aorto-femoral bypass using synthetic material
3270801	Aorto-femoro-femoral bypass using synthetic material
3270802	Aorto-iliac bypass using synthetic material
3270803	Aorto-ilio-femoral bypass using synthetic material
3271200	Ilio-femoral bypass using vein
3271201	
3271500	Subclavian-femoral bypass using synthetic material
3271501	Subclavian-femoro-femoral bypass using synthetic material
3271502	Axillo-femoral bypass using synthetic material
3271503	Axillo-femoro-femoral bypass using synthetic material
3271800	Ilio-femoral crossover bypass
3271801	Femoro-femoral crossover bypass
3273000	Mesenteric bypass using vein, single vessel
3273001	Mesenteric bypass using synthetic material, single vessel
3273300	Mesenteric bypass using vein, multiple vessels
3273301	Mesenteric bypass using synthetic material, multiple vessels
3273600	Other procedures on inferior mesenteric artery
3273900	Femoral artery bypass using vein, above knee
3274200	Femoral artery bypass using vein, below knee
3274500	Femoral artery bypass using vein, to tibio-peroneal trunk, tibial or peroneal artery
3274800	Femoral artery bypass using vein, within 5cm of ankle
3275100	Femoral artery bypass using synthetic material, above knee
3275101	Femoral artery bypass using synthetic material, below knee
3275102	Femoral artery bypass using synthetic material, to tibio-peroneal trunk, tibial or peroneal artery
3275103	Femoral artery bypass using synthetic material, within 5 cm of ankle
3275400	Femoro-femoral bypass using composite graft
3275401	Femoro-popliteal bypass using composite graft
3275402	
3275700	Femoral artery sequential bypass using vein
3275701	Femoral artery sequential bypass using synthetic material
3276300	Other arterial bypass using vein
3276301	Other arterial bypass graft using synthetic material
3276302	
3276303	
3276305	
3276306	
3276307	
3276308	
3276309	
3276310	

3276311	
3276312	
3276313	
3276314	
3276316	
3276317	
3276318	
3276319	
3305000	Replacement of popliteal aneurysm using vein
3305500	Replacement of popliteal aneurysm using synthetic graft
3307500	Repair of aneurysm in neck
3308000	Repair of intra-abdominal aneurysm
3310000	Replacement of carotid artery aneurysm with graft
3311200	Replacement of suprarenal abdominal aorta aneurysm with graft
3311500	Replacement of infrarenal abdominal aortic aneurysm with tube graft
3311800	Replacement of infrarenal abdominal aortic aneurysm with bifurcation graft to iliac arteries
3312100	Replacement of infrarenal abdominal aortic aneursym with bifurcation graft to femoral arteries
3312400	Replacement of iliac artery aneurysm with graft, unilateral
3312700	Replacement of iliac artery aneurysm with graft, bilateral
3313000	Excision and repair of visceral artery aneurysm with direct anastomosis
3315100	Replacement of ruptured suprarenal abdominal aortic aneurysm with graft
3315400	Replacement of ruptured infrarenal abdominal aortic aneurysm with tube graft
3315700	Replacement of ruptured infrarenal aortic aneurysm with bifurcation graft to iliac arteries
3316000	Replacement of ruptured infrarenal abdominal aortic aneurysm with bifurcation graft to femoral arteries
3316300	Replacement of ruptured iliac artery aneurysm with graft
3317800	Repair of ruptured aneurysm in neck
3318100	Repair of ruptured intra-abdominal aneurysm
3350000	Carotid endarterectomy
3350600	Innominate endarterectomy
3350601	Subclavian endarterectomy
3350900	Aorta endarterectomy
3351200	Aorto-iliac endarterectomy
3351500	Aorto-femoral endarterectomy
3351501	Ilio-femoral endarterectomy, bilateral
3351800	Iliac endarterectomy
3352100	Ilio-femoral endarterectomy, unilateral
3352400	Renal endarterectomy, unilateral
3352700	Renal endarterectomy, bilateral
3353000	Coeliac endarterectomy
3353001	Superior mesenteric endarterectomy
3353300	Coeliac and superior mesenteric endarterectomy
3353600	Inferior mesenteric endarterectomy
3353900	Endarterectomy of extremities
3354200	Extended endarterectomy of deep femoral artery
3354800	Patch graft of artery using vein
3354801	Patch graft of artery using synthetic material

3354802	Patch graft of vein using vein
3354803	Patch graft of vein using synthetic material
3355100	Procurement of vein from limb for patch graft
3355400	Endarterectomy in conjunction with arterial bypass to prepare site for anastomosis
3530306	
3530307	
3530400	Percutaneous transluminal balloon angioplasty of 1 coronary artery
3530401	Open transluminal balloon angioplasty of 1 coronary artery
3530500	Percutaneous transluminal balloon angioplasty of 2 or more coronary arteries
3530501	Open transluminal balloon angioplasty of 2 or more coronary arteries
3530906	
3530907	
3530908	
3530909	
3531000	Percutaneous insertion of 1 transluminal stent into single coronary artery
3531001	Percutaneous insertion of 2 or more transluminal stents into single coronary artery
3531002	Percutaneous insertion of 2 or more transluminal stents into multiple coronary arteries
3531003	Open insertion of 1 transluminal stent into single coronary artery
3531004	Open insertion of 2 or more transluminal stents into single coronary artery
3531005	Open insertion of 2 or more transluminal stents into multiple coronary arteries
3531200	Percutaneous peripheral artery atherectomy
3531201	Open peripheral artery atherectomy
3531500	Percutaneous peripheral laser angioplasty
3531501	Open peripheral laser angioplasty
3845619	Other intrathoracic procedures on arteries of heart without cardiopulmonary bypass
3849700	Coronary artery bypass, using 1 saphenous vein graft
3849701	Coronary artery bypass, using 2 saphenous vein grafts
3849702	Coronary artery bypass, using 3 saphenous vein grafts
3849703	Coronary artery bypass, using 4 or more saphenous vein grafts
3849704	Coronary artery bypass, using 1 other venous graft
3849705	Coronary artery bypass, using 2 other venous grafts
3849706	Coronary artery bypass, using 3 other venous grafts
3849707	Coronary artery bypass, using 4 or more venous grafts
3850000	Coronary artery bypass, using 1 LIMA graft
3850001	Coronary artery bypass, using 1 RIMA graft
3850002	Coronary artery bypass, using 1 radial artery graft
3850003	Coronary artery bypass, using 1 epigastric artery graft
3850004	Coronary artery bypass, using 1 other arterial graft
3850300	Coronary artery bypass, using 2 LIMA grafts
3850301	Coronary artery bypass, using 2 RIMA grafts
3850302	Coronary artery bypass, using 2 radial artery grafts
3850303	Coronary artery bypass, using 2 epigastric artery grafts
3850304	Coronary artery bypass, using 2 or more other arterial grafts
3850500	Open coronary endarterectomy
3850700	Left ventricular aneurysmectomy
3850800	Left ventricular aneurysmectomy with patch graft
3850900	Repair of ventricular septal rupture
3863700	Re-operation for reconstruction of occluded coronary artery

9020100	Coronary artery bypass, using 1 other material graft, not elsewhere classified
9020101	Coronary artery bypass, using 2 other material grafts, not elsewhere classified
9020102	Coronary artery bypass, using 3 other material grafts, not elsewhere classified
9020103	Coronary artery bypass, using 4 or more other material grafts, not elsewhere classified
9022900	Other endarterectomy
9023000	Embolectomy or thrombectomy of other artery
G450	Vertebro-basilar artery syndrome
G451	Carotid artery syndrome (hemispheric)
G452	Multiple and bilateral precerebral artery syndromes
G453	Amaurosis fugax
G458	Other transient cerebral ischaemic attacks and related syndromes
G459	Transient cerebral ischaemic attack, unspecified
G460	Middle cerebral artery syndrome (I66.0+)
G461	Anterior cerebral artery syndrome (I66.1+)
G462	Posterior cerebral artery syndrome (I66.2+)
G463	Brain stem stroke syndrome (I60-I67+)
G464	Cerebellar stroke syndrome (I60-I67+)
G465	Pure motor lacunar syndrome (I60-I67+)
G466	Pure sensory lacunar syndrome (I60-I67+)
G467	Other lacunar syndromes (I60-I67+)
G468	Other vascular syndromes of brain in cerebrovascular diseases (I60-I67+)
I110	Hypertensive heart disease with heart failure
I130	Hypertensive heart and renal disease with both (congestive) heart failure and renal failure
I132	Hypertensive heart and renal disease with both (congestive) heart failure and renal failure
I200	Unstable angina
I201	Angina pectoris with documented spasm
I208	Other forms of angina pectoris
I209	Angina pectoris, unspecified
I230	Haemopericardium as current complication following acute myocardial infarction
I231	Atrial septal defect as current complication following acute myocardial infarction
I232	Ventricular septal defect as current complication following acute myocardial infarction
I233	Rupture of cardiac wall without haemopericardium as current complication following acute myocardial infarction
I234	Rupture of chordae tendineae as current complication following acute myocardial infarction
I235	Rupture of papillary muscle as current complication following acute myocardial infarction
I236	Thrombosis of atrium, auricular appendage, and ventricle as current complications following acute myocardial infarction
I238	Other current complications following acute myocardial infarction
I240	Coronary thrombosis not resulting in myocardial infarction
I248	Other forms of acute ischaemic heart disease
I249	Acute ischaemic heart disease, unspecified
I252	Old myocardial infarction
I253	Aneurysm of heart
I254	Coronary artery aneurysm

I255	Ischaemic cardiomyopathy
I256	Silent myocardial ischaemia
I460	Cardiac arrest with successful resuscitation
I50	Heart failure
I500	congestive heart failure
I501	Left ventricular failure
I509	Heart failure unspecified
I600	Subarachnoid haemorrhage from carotid siphon and bifurcation
I601	Subarachnoid haemorrhage from middle cerebral artery
I602	Subarachnoid haemorrhage from anterior communicating artery
I603	Subarachnoid haemorrhage from posterior communicating artery
I604	Subarachnoid haemorrhage from basilar artery
I605	Subarachnoid haemorrhage from vertebral artery
I606	Subarachnoid haemorrhage from other intracranial arteries
I607	Subarachnoid haemorrhage from intracranial artery, unspecified
I608	Other subarachnoid haemorrhage
I609	Subarachnoid haemorrhage, unspecified
I610	Intracerebral haemorrhage in hemisphere, subcortical
I611	Intracerebral haemorrhage in hemisphere, cortical
I612	Intracerebral haemorrhage in hemisphere, unspecified
I613	Intracerebral haemorrhage in brain stem
I614	Intracerebral haemorrhage in cerebellum
I615	Intracerebral haemorrhage, intraventricular
I616	Intracerebral haemorrhage, multiple localized
I618	Other intracerebral haemorrhage
I619	Intracerebral haemorrhage, unspecified
I630	Cerebral infarction due to thrombosis of precerebral arteries
I631	Cerebral infarction due to embolism of precerebral arteries
I632	Cerebral infarction due to unspecified occlusion or stenosis of precerebral arteries
I633	Cerebral infarction due to thrombosis of cerebral arteries
I634	Cerebral infarction due to embolism of cerebral arteries
I635	Cerebral infarction due to unspecified occlusion or stenosis of cerebral arteries
I636	Cerebral infarction due to cerebral venous thrombosis, nonpyogenic
I638	Other cerebral infarction
I639	Cerebral infarction, unspecified
I64	Stroke, not specified as haemorrhage or infarction
I650	Occlusion and stenosis of vertebral artery
I651	Occlusion and stenosis of basilar artery
I652	Occlusion and stenosis of carotid artery
I653	Occlusion and stenosis of multiple and bilateral precerebral arteries
I658	Occlusion and stenosis of other precerebral artery
I659	Occlusion and stenosis of unspecified precerebral artery
I660	Occlusion and stenosis of middle cerebral artery
I661	Occlusion and stenosis of anterior cerebral artery
I662	Occlusion and stenosis of posterior cerebral artery
I663	Occlusion and stenosis of cerebellar arteries
I664	Occlusion and stenosis of multiple and bilateral cerebral arteries
I668	Occlusion and stenosis of other cerebral artery
I669	Occlusion and stenosis of unspecified cerebral artery
I670	Dissection of cerebral arteries, nonruptured

I672	Cerebral atherosclerosis
I690	Sequelae of subarachnoid haemorrhage
I691	Sequelae of intracerebral haemorrhage
I693	Sequelae of cerebral infarction
I694	Sequelae of stroke, not specified as haemorrhage or infarction
I698	Sequelae of other and unspecified cerebrovascular diseases
I700	Atherosclerosis of aorta
I701	Atherosclerosis of renal artery
I7020	Atherosclerosis of arteries of extremities, unspecified
I7021	Atherosclerosis of arteries of extremities with intermittent claudication
I7022	Atherosclerosis of arteries of extremities with rest pain
I7023	Atherosclerosis of arteries of extremities with ulceration
I7024	Atherosclerosis of arteries of extremities with gangrene
I708	Atherosclerosis of other arteries
I709	Generalized and unspecified atherosclerosis
I7100	Dissection of aorta, unspecified site
I7101	Dissection of thoracic aorta
I7102	Dissection of abdominal aorta
I7103	Dissection of thoracoabdominal aorta
I711	Thoracic aortic aneurysm, ruptured
I713	Abdominal aortic aneurysm, ruptured
I714	Abdominal aortic aneurysm, without mention of rupture
I715	Thoracoabdominal aortic aneurysm, ruptured
I718	Aortic aneurysm of unspecified site, ruptured
I739	Peripheral vascular disease, unspecified
I740	Embolism and thrombosis of abdominal aorta
I741	Embolism and thrombosis of other and unspecified parts of aorta
I742	Embolism and thrombosis of arteries of upper extremities
I743	Embolism and thrombosis of arteries of lower extremities
I744	Embolism and thrombosis of arteries of extremities, unspecified
I745	Embolism and thrombosis of iliac artery
I748	Embolism and thrombosis of other arteries
I749	Embolism and thrombosis of unspecified artery
Z951	Presence of aortocoronary bypass graft
Z955	Presence of coronary angioplasty implant and graft
Z958	Presence of other cardiac and vascular implants and grafts
Z959	Presence of cardiac and vascular implant and graft, unspecified
I461	Sudden cardiac death, so described

Appendix 2: Model fit for trajectory analysis.

Supplementary table 2. Model fit for group trajectories

Number of groups	BIC	ΔBIC
2	-40224001	
3	-37524013	-2699988
4	-36049005	-1475008
5	-34975401	-1073605
6	-33880744	-1094657
7 [a]	-33362004	-518740

[a] variance matrix is nonsymmetric or highly singular suggesting insufficient portioning of the variance between groups.

Appendix 3: Comparison of first and last observation and trajectory analysis

Supplementary table 3 shows the deprivation quintiles of the first and last observations. By using this information in addition to whether they recorded a move over the period we classified individuals with varying levels of detail into movers and stayers and compared this with the results of trajectory analysis.

Supplementary table 3: First and last observed deprivation quintile.

		Last observed deprivation quintile					
First observed deprivation quintile		1	2	3	4	5	Total
	1	396,659	57,709	41,031	28,514	13,764	537,677
	2	67,536	336,148	48,068	36,809	20,488	509,049
	3	50,969	51,827	307,597	45,372	28,881	484,646
	4	36,928	41,169	48,073	295,194	45,609	466,973
	5	19,602	25,369	33,348	50,876	290,857	420,052
Total		571,694	512,222	478,117	456,765	399,599	2,418,397

The simplest classification was: stays in Quintile 1, stays in Quintile 2, stays in Quintile 3, stays in Quintile 4, stays in Quintile 5, increasing dep, and decreasing dep. The most detailed version would be to use an indicator of whether they moved. The most detailed classification included information on whether they moved during the period and classified individuals into 16 groups: Stayers Q1-Q5 (5 groups), churners Q1-Q5 (5 groups), increasing deprivation by 1 quintile, increasing deprivation by 2 quintiles, increasing deprivation by 3/4 quintiles, decreasing deprivation by 1 quintile, decreasing deprivation by 2 quintiles, decreasing deprivation by 3/4 quintiles.

A comparison of the simplest classification with the mobility trajectory groups used in the paper is shown in supplementary table 4. In total 157,595 would be classified as staying in Q1-Q5 when they actually changed deprivation quintiles over the course of the observation period. A further 109,505 would be classified as moving into areas of increased deprivation, when the trajectory analysis suggests decreased deprivation, or classified as moving into decreased deprivation when the trajectory analysis suggests increased deprivation.   If we didn't account for churning, A total of 256,179 people would be classified as staying in Q1-Q5 when they actually churned in Q1-Q5. Taking account of the churners is important as they differ from the stayers in terms of their relative risks for health outcomes. This is fairly easy to account for if we look at the minimum and maximum deprivation score observed across the period and count people as churners where they move, and the deprivation quintile does not change.

A comparison of the detailed classification with the mobility trajectory groups used in the paper is shown in supplementary table 5. In this more detailed classification 157,595 are incorrectly classified as churners based on first and last observation of deprivation. These people change deprivation score over the course of the observation period, but the first and last observed deprivation quintiles are the same. The magnitude of the change in deprivation based on first and last quintile is captured. There is a substantial amount of disagreement between first and last observation classifications of deprivation-mobility and trajectory groupings of deprivation-mobility.

Supplementary table 4. Comparison of mobility groups based on trajectory analysis and simple classification of first and last observation

Trajectory groupings	Simplest first and last observation classification							
	Stayer Q1	Stayer Q2	Stayer Q3	Stayer Q4	Stayer Q5	Increasing deprivation	Decreasing deprivation	Total
(T1): moves out of least deprived areas	12,879	2,687	753	277	48	87,293	4,096	108,033
(T2): moves into least deprived areas	12,599	197	51	4	4	145	92,256	105,256
(T3): moves from mid into less deprived areas	5,169	21,758	7,902	2,753	492	37,141	142,349	217,564
(T4): moves from mid into more deprived areas	1,753	4,811	16,193	7,064	1,402	158,668	21,221	211,112
(T5): moves out of most deprived areas	254	932	4,056	18,387	9,300	21,346	140,219	194,494
moves into most deprived areas	88	297	852	3,568	21,065	61,652	25,556	113,078
Churner Q1	74,560	0	0	0	0	0	0	74,560
Churner Q2	0	42,635	0	0	0	0	0	42,635
Churner Q3	0	0	36,444	0	0	0	0	36,444
Churner Q4	0	0	0	39,548	0	0	0	39,548
Churner Q5	0	0	0	0	62,992	0	0	62,992
Stayer Q1	289,357	0	0	0	0	0	0	289,357
Stayer Q2	0	262,831	0	0	0	0	0	262,831
Stayer Q3	0	0	241,346	0	0	0	0	241,346
Stayer Q4	0	0	0	223,593	0	0	0	223,593
Stayer Q5	0	0	0	0	195,554	0	0	195,554
Total	396,659	336,148	307,597	295,194	290,857	366,245	425,697	2,418,397

Supplementary table 5. Comparison of mobility groups based on trajectory analysis and detailed classification of first and last observation

Trajectory groupings	Most detailed classification from first and last observation										
	Churner					Mover					
	Q1	Q2	Q3	Q4	Q5	Increase +1	Increase +2	Increase +3	Decrease -1	Decrease -2	Decrease -3
(T1): moves out of least deprived areas	12,879	2,687	753	277	48	45,512	24,263	17,518	2,659	1,035	402
(T2): moves into least deprived areas	12,599	197	51	4	4	125	19	1	40,399	26,745	25,112
(T3): moves from mid into less deprived areas	5,169	21,758	7,902	2,753	492	28,429	6,922	1,790	72,865	47,244	22,240
(T4): moves from mid into more deprived areas	1,753	4,811	16,193	7,064	1,402	72,276	56,102	30,290	16,549	4,183	489
(T5): moves out of most deprived areas	254	932	4,056	18,387	9,300	17,189	3,258	899	70,877	40,331	29,011
(T6): moves into most deprived areas	88	297	852	3,568	21,065	33,227	16,157	12,268	14,963	5,948	4,645
Churner Q1	74,560	0	0	0	0	0	0	0	0	0	0
Churner Q2	0	42,635	0	0	0	0	0	0	0	0	0
Churner Q3	0	0	36,444	0	0	0	0	0	0	0	0
Churner Q4	0	0	0	39,548	0	0	0	0	0	0	0
Churner Q5	0	0	0	0	62,992	0	0	0	0	0	0
Total	107,302	73,317	66,251	71,601	95,303	196,758	106,721	62,766	218,312	125,486	81,899

Note stayers are not included in this table, this would be a duplication of the information shown in supplementary table 4. For the first and last observations moves are broken down into increasing or decreasing deprivation based on changing by 1,2 or 3+ deprivation quintiles. Increase +1 for example refers to an increase in deprivation quintile, from say Quintile 1 to Quintile 2. Whereas increase +2 refers to a change in deprivation of two quintiles, from say Quintile 1 to Quintile 3.